USAID Economic Analysis and Planning for Global Climate Mitigation – April 28-May 2, 2014

This course will address the economic and financial analysis of climate change mitigation projects. Mitigation projects in climate change include clean energy, energy efficiency and sustainable landscape actions that reduce greenhouse gas emissions over a projected "Business-as-Usual" (BAU) situation. Economic and financial assessment of mitigation projects involves cost-benefit and cost-effectiveness analysis, marginal abatement cost curve (MACC) analysis, valuation of extra-market co-benefits (such as environmental quality or health improvements), and multiple-objective decision criteria. The course will also discuss the Long-range Energy Alternatives Model (LEAP) and computerized general equilibrium (CGE) modeling for Low Emission Development Strategies (LEDS).

Location: Nairobi computer room and Cairo and Port au Prince break out rooms

Day 1: April 28

9:00-9:10 AM Welcome and Introductions: Eric Hyman (USAID/E3/EP)

9:10 AM-5:30 PM: Jerrod Mason (USAID/E3/EP)

- Excel Tutorial
- Energy Sector Overview
- Levelized Cost of Energy
- Table of Inputs
- Counterfactual, Cash Flows and Discounting
- Indices and Production Table
- Financial Analysis and Net Present Value (NPV)
- Economic Analysis and C/E Ratios
- Decision Criteria

Includes an exercise on cost-effectiveness analysis of diesel generation, landfill gas, hydroelectric development, and wind turbines

Day 2: April 29

9:00-9:15 AM Welcome and Course Objectives: Juan Belt (USAID/E3/EP)

9:15-10:15 AM USAID Climate Change Mitigation Activities for Low-Emission Development Strategies (LEDS): Matthew Ogonowski (USAID/E3/GCC)

10:30 AM-12:30 PM Economic and Policy Analysis of Sustainable Landscape Programs to Support LEDS: Evan Notman and Matthew Ogonowski (USAID/E3/GCC)

12:30-1:30 PM Lunch (on own)

1:30-3:15 PM Valuing Environment and Natural Resource Co-Benefits: Eric Hyman (USAID/E3/EP)

3:30-4:30 PM USAID AILEG Project Research on Valuing Environmental Benefits from Fragile Ecosystems in Colombia: Marcia Gowen Trump (Abt Associates)

4:30-5:30 MCC Green Prosperity Project Research on Economic Valuation of Alternative Rural Land Uses for Clean Development in Indonesia: Marcia Gowen Trump (Abt Associates)

Day 3: April 30

9:00 -10:00 AM: Valuing Health Co-Benefits From Climate Change Mitigation: Allyala Nandakumar (USAID/GH)

10:00-10:45 AM Benefit Transfer Approach: Greater Dhaka Rapid Transit Health Benefits: Eric Hyman (USAID/E3/EP)

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11:30 AM-12:45 PM Building Marginal Abatement Cost Curves (MACCs) for LEDS Programming: Bill Ward (USAID/E3/EP)

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1:00-4:30 Stockholm Energy Institute Long-Range Energy Alternatives Planning (LEAP) Model: Charlie Heaps (SEI)

4:30-5:30 Exercise on the LEAP Model: Charlie Heaps (SEI)

Day 5: May 2

9:00-11:00 AM Computable General Equilibrium (CGE) Models and Other Macroeconomic Models: Erika Jorgensen (World Bank)

11:15 AM-12:15 PM Demos of CGE Models and Other Macroeconomic Models: Erika Jorgensen (World Bank)

12:15-1:15 PM Lunch (on your own)

1:15-1:45 Economics of Intermittent Renewable Source of Electricity: Allen Eisendrath (USAID/E3/E&I)

1:45 2:30 PM Uses and Applications of Macroeconomic Analysis and Models for Climate Policy: Matthew Ogonowski (USAID/E3/GCC)

2:30-2:45 PM Break

2:45- 4:15 PM Discount Rate, Intergenerational Equity, and Long-Term Environmental Benefits and Costs: Bill Ward (USAID/E3/EP)

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Economic Analysis of Climate Change Mitigation Course

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SPEAKER BIOS

Juan Belt
jbelt@usaid.gov
Juan Belt has held senior economist and manager positions at USAID, the Inter-American Development Bank, and the World Bank. He received USAID's highest award, the Administrator's Distinguished Career Service Award. He played a key role in the liberalization and privatization of the power and telecommunications of several countries in Central America, including co-drafting the telecommunications privatization law of El Salvador. He directed a program to make the Central American countries ready for a free trade agreement with the US. At the IDB, he designed the first integrated Information and Communications Technology project. At USAID, he reintroduced cost-benefit analysis to the agency and promoted alliances with private firms to expand connectivity to rural areas under the "Last Mile Initiative". He has designed over 30 agricultural, forestry, fishery, education and transport projects, mostly for the World Bank and IDB, and taught cost-benefit analysis at universities in the US and Latin America.

Allen Eisendrath
eisendrath@usaid.gov
Dr. Eisendrath is the Energy Division Chief in USAID's.Office of Energy & Infrastructure. His work focuses on water and power sector reform, corporatization and restructuring of utilities, regulation of infrastructure and use of innovative contracts for infrastructure. He has worked with the reform of electricity utilities in Afghanistan, Bangladesh, India, Indonesia, Iraq, Jordan, Kazakhstan, Kyrgyz Republic, Liberia, Marshall Islands, Nepal, Nigeria, Pakistan, the Philippines, and Sri Lanka, and with water and sanitation utilities in Afghanistan, Armenia, Colombia, Egypt, India, Jordan, Montenegro, Nigeria, the Philippines, and Uganda. Since 2004, he has assisted the development of a regional electricity market in Central Asia, and commercialization of power utilities in Afghanistan, Iraq and Haiti. Dr. Eisendrath supported Central Asian electricity exports to Afghanistan via the Northeast Power System. Dr. Eisendrath is currently leading efforts to develop new programming approaches to building smart power grids and integration of intermittent renewables in Asia, and is supporting activities related to the privatization of Nigeria's power sector.

Prior to joining USAID in 2004, Dr. Eisendrath worked for Deloitte Emerging Markets in the Washington, D.C. Utilities & Infrastructure Division.

Charlie Heaps
charlie.heaps@sei-us.org
Dr. Charles Heaps is the Director of the U.S. Center of the Stockholm Environment Institute and a senior researcher in its climate and energy research programme. Dr. Heaps is the author and lead developer of SEI's Long-range Energy Alternatives Planning System (LEAP), a scenario-based modeling system for integrated energy planning and climate change mitigation assessment, which is widely used by Government agencies, academic researchers, NGOs, utilities and consulting organizations in over 190 countries. Dr. Heaps has been developing LEAP for over 20 years over which time it has been adopted as the tool of choice by many countries for developing Low Emission Development Strategies (LEDS) and Nationally Appropriate Mitigation Actions (NAMAs) as well for developing their mitigation reporting as part of National Communications to the UNFCCC.

Aside from developing LEAP, Dr. Heaps work is also focused on building capacity in the developing world to support climate mitigation assessments. To this end, he founded and manages COMMEND, an online initiative designed to foster a community among energy planners and climate mitigation practitioners, which now has over 21,000 members worldwide.

Dr. Heaps has also led numerous climate mitigation studies. In 2009, he was the lead author for the study: "Europe's Share of the Climate Challenge", which examined how Europe can show leadership in keeping global climate change within safe limits: by undertaking domestic actions to rapidly reduce emissions of greenhouse gases. In 2010 he was involved in a study that supported the Commonwealth of Massachusetts in developing plans for reducing State-wide GHG emissions by 80% in 2050. More recently, Dr. Heaps has been providing technical support to a number of international efforts aimed at helping developing countries build capacity for climate change mitigation assessment. These include the UNDP's Low Emission Capacity Building (LECB) Program, US-AID's Low Emission Asia Development (LEAD) and Analysis and Investment for Low-Emission Growth (AILEG) programs, UNEP's Facilitating Implementation and Readiness for Mitigation (FIRM) program, and the Southern-led Mitigation Action Plans and Scenarios (MAPS) program.

Dr. Heaps has worked in more than 40 countries and has consulted widely with numerous national and international agencies including EPA, AID, DOE, UNDP, UNEP, UNFCCC, UNIDO, the IAEA, OLADE (the Latin American Energy Agency), the Asian Development Bank, APEC and the World Bank.

Eric Hyman
ehyman@usaid.gov
Eric Hyman is an Enterprise Development Advisor in E3/Economic Policy/Capacity Building supporting procurement reform with local organizations and the private sector. He was Co-Activity Manager for the USAID Analysis of Low-Emissions Growth (AILEG) Project and will be Co-Activity Manager for the upcoming Climate Economic Analysis, Development, Investment, and Resilience (CEADIR). Dr. Hyman has over thirty-three years of experience in monitoring and evaluation, project appraisal, policy analysis, cost-benefit analysis, and environmental and social impact assessment. His areas of specialization include small- and micro-enterprise development; agricultural production and processing, renewable energy, community forestry, and natural resource management. He previously served as the International Economist/Environment Officer for the US African Development Foundation, Chief of Program Evaluation at /EnterpriseWorks Worldwide (Appropriate Technology International), and Congressional Fellow at the US Congress Office of Technology Assessment. Dr. Hyman is the lead author of a book on environmental impact assessment and co-edited books on environment/natural resources issues in cost-benefit analysis and macro-policies for appropriate technology in the Philippines. He has published over 75 journal articles or book chapters. He received a Ph.D. and M.R.P. in Environmental Planning from the University of North Carolina/Chapel Hill and a B.A. in Economics and Environmental Science from the University of Virginia.

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Erika Jorgensen
ejorgensen@worldbank.org
Ms. Erika Jorgensen holds a PhD in Economics from Harvard University as well as degrees from Oxford University and Williams College. Mr. Jorgensen is an Economic Adviser in the macroeconomics department of the World Bank's Europe and Central Asia Region, where she also serves as the focal point for the economics of climate change and green growth. She recently completed a low-carbon growth country study for Poland and is leading a major program of analytic work and technical assistance on green growth for FYR Macedonia. Over the past twenty years, she has worked as a macroeconomist in Europe and Central Asia, East Asia and the Pacific, and Latin America and the Caribbean, focusing on a broad range of economic topics including financial markets, competitiveness and growth, migration, poverty, pension policy, labor markets, governance and corruption, and now climate change and green growth.

Jerrod Mason
jemason@usaid.gov
Jerrod Mason is an economist in the office of Economic Policy at the US Agency for International Development (USAID), located within the Economics, Education and Environment (E3) Bureau. Jerrod has been at USAID since 2011, and has been an integral part of the Agency's efforts to reintroduce cost-benefit analysis (CBA) as part of the project life-cycle. In his work at USAID, Jerrod has led teams conducting CBA of agricultural projects in Ethiopia and Kenya, and has worked with other office economists to author course materials which have been used to introduce CBA concepts to more than 200 agency staff. Before joining USAID, Jerrod studied public policy at the University of California at Berkeley's Goldman School of Public Policy.

Allyala Krishna Nandakumar
anandakumar@usaid.gov
Dr. Nandakumar is the Chief Economist for Global Health at USAID. Dr. Nandakumar is also a Professor of the Practice at Brandeis University where he directs the PhD Program at the Heller School of Social Policy and is the Director of the Institute for Global Health and Development. Dr. Nandakumar is an internationally recognized health economist, known specifically for his work in resource tracking, health financing, and healthcare policy and research. His recent research has focused on the fungibility of donor assistance, factors affecting technology adoption in low and middle-income countries, the linkages between health expenditures and maternal and infant mortality, the relationship between growth in a country's income and its healthcare spending and the effect of governance on health outcomes. He has studied the impact of economic transition and its implications for increasing investments in health. A former Indian Administrative Services Officer, his thinking is framed by the importance of governance, driven by the need for greater accountability, arising from limited resources and a growing demand to demonstrate results. After leaving the Indian Administrative Service, Dr. Nandakumar was an Assistant Professor at the Harvard School of Public Health, a Principal Associate with Abt Associates, a Senior Program Officer at the Bill and Melinda Gates foundation and a Director with Deloitte Consulting. Dr. Nandakumar has a Master of Science Degree in Mathematics from Bangalore University where he specialized in the General and Special Theory of Relativity and a PhD in Economics from Boston University. Dr. Nandakumar has published extensively in peer reviewed journals and has worked on health financing issues in various countries including Bangladesh, Egypt, India, Jordan, Kenya, Lebanon, Mongolia, Rwanda, Tonga, Western Samoa, United States, Sudan, Yemen and Zambia.

Evan Notman
enotman@usaid.gov
Evan Notman is a Forest and Climate specialist for USAID in the Washington, DC office where he manages USAIDs Washington based sustainable landscapes programs and provides guidance for USAID's overall work on Sustainable Landscapes. Prior to joining USAID, Evan was a program officer for the Gordon and Betty Moore Foundation where he coordinated the foundation's program on REDD. Evan also has experience managing cooperative research grants and programs with Latin American countries as a program manager for the National Science Foundation's Office of International Science and Engineering. Previously he served as an AAAS Fellow in the USDA Forest Service's Office of Research and Development, and as a Congressional Fellow on the U.S. Senate Committee on Agriculture, Nutrition, and Forestry. He has further research and teaching experience working with the Organization for Tropical Studies. Evan received a Master's degree in Tropical Ecology from University Missouri – St. Louis and a PhD in Botany from Miami University. He has done research in Peru, Colombia, Costa Rica and Panama focused on understanding the role animals play on tropical forest regeneration and how hunting and land use impacts regeneration.

Matthew Ogonowski
mogonowski@usaid.gov
Matthew Ogonowski is a Global Climate Change Specialist in USAID's GCC Office working on GHG emissions mitigation (sustainable landscapes and clean energy), EC-LEDS, GHG inventories and economic analysis of climate change policy. He has 15 years' experience in multi-sector energy emissions mitigation, REDD+/forestry and international climate policy. From 2004-2011, Matthew worked at the Center for Clean Air Policy (CCAP) in Washington, D.C. He managed CCAP's *Developing Countries Project* to mitigate GHG emissions in the electric power, industry and transportation sectors in China, India, Indonesia and other countries, and the *Forestry and Climate Change Program* to design REDD+ policies in tropical forest countries. His accomplishments include one of the first studies to quantify emission reductions from energy efficiency efforts undertaken by China and other countries, and a study with the first estimates of opportunity costs of REDD+ in Cambodia. Matthew has also worked for ICF Consulting, the Netherlands Development Organisation (SNV), EPA's Greenhouse Gas Inventory and the World Bank. He has an M.S in International Environmental Policy from Georgetown University's School of Foreign Service.

Marcia Gowen Trump
marcia_trump@abtassoc.com
Dr. Marcia Trump is a resource economist with 30 years of experience managing technical projects in climate change economics, mitigation and adaptation, clean energy development, environmental valuation, and carbon market financing. She has served from 2011-2013 as the Project Director for AILEG, a USD5 Million USAID climate economic and investment technical assistance project. ALIEG helped expand USAID's low-emission development analytical, policy, and data strengthening services to 7 EC-LEDS countries and provided technical leadership on climate change economics/investments. Under AILEG, she led the first USAID University Cost-Benefit Analysis (CBA) for Global Climate Change Mitigation course. She has directed interdisciplinary teams on climate change mitigation and adaptation economics, clean energy feasibility analyses for LEDS, environmental valuations of forestry and agricultural studies, gender analyses of farm/off-farm

income, and investment into clean energy and sustainable landscapes projects around the world. She has developed financial and economic cost-benefit analyses for low-emission projects around the world. Her work for major carbon funds and investors resulted in over 2 million tons/CO_2-e/yr. being sold and verified by the Clean Development Mechanism, Verified Carbon Standard, and other trading registries. Climate change clients include USAID, ADB, World Bank, USEPA, International Finance Corporation, private energy companies and project developers, trade associations, and developing country governments. She has worked with activities in Argentina, Bangladesh, Brazil, Canada, China, Chile, Colombia, Costa Rica, Guatemala, India, Indonesia, Kazakhstan, Latvia, Liberia, Mexico, Netherlands, Pacific Islands, Philippines, Poland, Thailand, Ukraine, United Kingdom, United States, and Vietnam. Dr. Trump holds a Ph.D. and M.S. in Agricultural Economics from the Ohio State University, a B.A. in biology from Smith College.

Bill Ward
wward@usaid.gov
Bill Ward became a Senior Economic Advisor in USAID E3/EP in 2013 following 23 years as Professor of Economics at Clemson University. He served for seven years at the World Bank and ten years as president of a consulting firm. He wrote course notes that became the economic analysis section of Gittinger (1982). He co-wrote cost-benefit analysis guidelines for Ireland, the Philippines, Portugal, South Korea, and Yugoslavia and was the author of *The Economics of Project Analysis: A Practitioners' Guide*. Dr. Ward developed the net-CBA and cost-effectiveness methods for greenhouse gas mitigation studies in China, Colombia, and Mexico. He is currently developing cost-benefit methods for climate change adaptation projects and new approaches to market failure in development project identification and appraisal.

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Location: Nairobi computer room and Cairo and Port au Prince break out rooms

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9:10 AM-5:30 PM: Jerrod Mason (USAID/E3/EP)

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- Energy Sector Overview
- Levelized Cost of Energy
- Table of Inputs
- Counterfactual, Cash Flows and Discounting
- Indices and Production Table
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- Decision Criteria

Includes an exercise on cost-effectiveness analysis of diesel generation, landfill gas, hydroelectric development, and wind turbines

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10:30 AM-12:30 PM Economic and Policy Analysis of Sustainable Landscape Programs to Support LEDS: Evan Notman and Matthew Ogonowski (USAID/E3/GCC)

12:30-1:30 PM Lunch (on own)

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Day 5: May 2

9:00-11:00 AM Computable General Equilibrium (CGE) Models and Other Macroeconomic Models: Erika Jorgensen (World Bank)

11:15 AM-12:15 PM Demos of CGE Models and Other Macroeconomic Models: Erika Jorgensen (World Bank)

12:15-1:15 PM Lunch (on your own)

1:15-1:45 Economics of Intermittent Renewable Source of Electricity: Allen Eisendrath (USAID/E3/E&I)

1:45 2:30 PM Uses and Applications of Macroeconomic Analysis and Models for Climate Policy: Matthew Ogonowski (USAID/E3/GCC)

2:30-2:45 PM Break

2:45- 4:15 PM Discount Rate, Intergenerational Equity, and Long-Term Environmental Benefits and Costs: Bill Ward (USAID/E3/EP)

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2:15-3:15 PM Exercise on Developing MACCs: Bill Ward and Jerrod Mason (USAID/E3/EP)

3:30-4:30 PM Uses and Applications of MACCs for Climate Policy: Matthew Ogonowski (USAID/E3/GCC)

4:30- 5:30 PM Lessons from the World Bank MACCs for Mexico and Colombia and the ADB's North Asia Studies: Bill Ward (USAID/E3/EP)

Day 4: May 1

9:00-10:15 AM USAID AILEG Project on Marginal Abatement Cost Curves (MACCs) for Rice and Livestock Production in Vietnam: Marcia Gowen Trump (Abt Associates)

10:30 AM-12:00 PM USAID AILEG Project on Marginal Abatement Cost Curves (MACCs) for Energy Efficiency in Colombia and the Philippines: Marcia Gowen Trump (Abt Associates)

12:00-1:00 PM Lunch (on your own)

1:00-4:30 Stockholm Energy Institute Long-Range Energy Alternatives Planning (LEAP) Model: Charlie Heaps (SEI)

4:30-5:30 Exercise on the LEAP Model: Charlie Heaps (SEI)

Day 5: May 2

9:00-11:00 AM Computable General Equilibrium (CGE) Models and Other Macroeconomic Models: Erika Jorgensen (World Bank)

11:15 AM-12:15 PM Demos of CGE Models and Other Macroeconomic Models: Erika Jorgensen (World Bank)

12:15-1:15 PM Lunch (on your own)

1:15-1:45 Economics of Intermittent Renewable Source of Electricity: Allen Eisendrath (USAID/E3/E&I)

1:45 2:30 PM Uses and Applications of Macroeconomic Analysis and Models for Climate Policy: Matthew Ogonowski (USAID/E3/GCC)

2:30-2:45 PM Break

2:45- 4:15 PM Discount Rate, Intergenerational Equity, and Long-Term Environmental Benefits and Costs: Bill Ward (USAID/E3/EP)

4:30-5:30 PM Panel Discussion on Cost-Effectiveness Analysis and Economic Valuation of Co-Benefits Juan Belt (USAID/E3/EP) and selected participants

Introduction to Cost-Effectiveness for GCC Mitigation Projects

Jerrod Mason

April 26, 2014

Intro to Case Study & Excel Tutorial

Day Overview

- Intro to case study – clean energy
- Excel tutorial
- Energy sector overview
- Table of inputs
- Counterfactuals, cashflows and discounting
- Financial analysis and NPV
- Economic analysis and C/E ratios
- Decision criteria

Intro to Case Study

- A realistic-but-fictional clean energy project in Vietnam
- Replacing high-cost, high-GHG electricity production (via diesel) with low-emission alternative
- Objective: choosing the technology that reduces GHGs as efficiently as possible—that is, has the lowest cost-effectiveness ratio, USD/tCO2e mitigated
- Important parameters

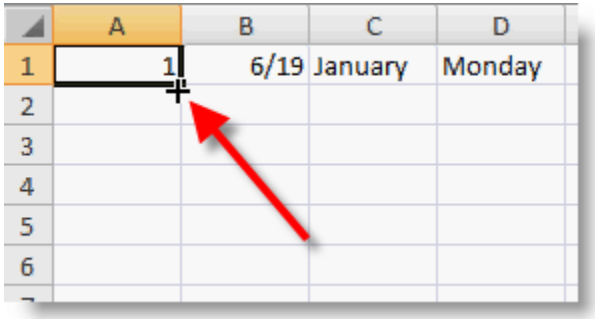
Investment costs	Rated capacity
Asset life	Capacity factor
Recurring maintenance costs	Capacity decline per year
	Feed-in tariff
O&M costs	Tax credits, subsidies, etc.
tCO2e per kWh	Externalities

How many of the following tasks do you know how to do in Excel?

- Enter a formula or a function into a cell
- Use cell references in a formula or function
- Fill the value/formula from one cell into others in the same row/column
- Fix a reference so that the reference doesn’t change when you fill or copy the formula to another location
- Fix only the row/column so that part of a cell reference changes while the other part doesn’t
- Use financial functions in Excel like NPV, IRR, PV and PMT

Excel Tutorial

- The “=“ key tells Excel to perform a calculation
- The “F4” key <u>fixes</u> the reference of a cell
- The “fill” function (lower right-hand corner of the cell, makes a cross-shape) copies and pastes the cell’s formula into adjacent cells



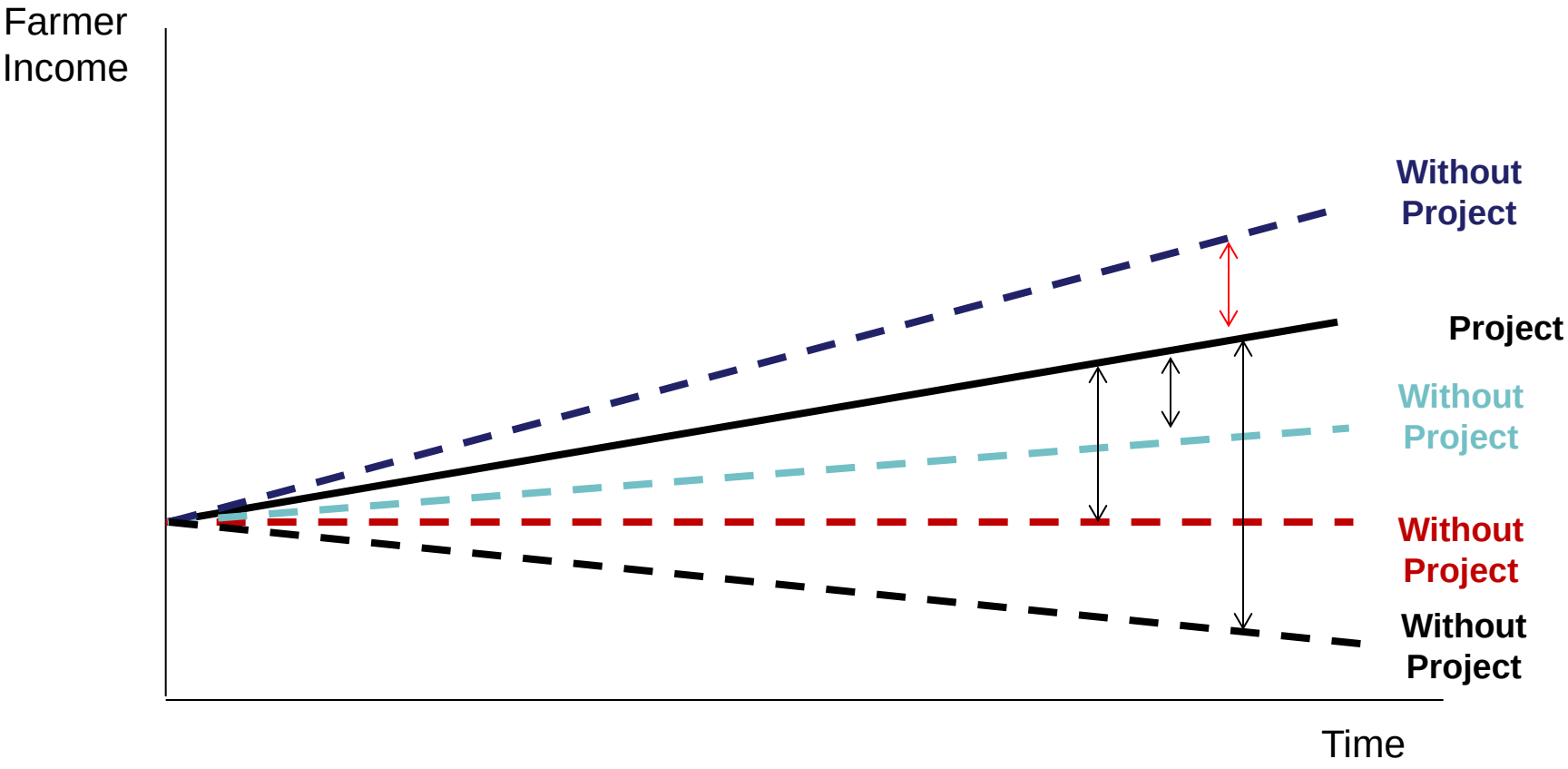
Counterfactuals, Cash Flows and Discounting

Establishing a Counterfactual

- In order to evaluate the impact of our project, we first need to understand what would happen in the absence of the project.
- This is called the "**without-project**" or "**baseline**" scenario, or the "**counterfactual**".
- The difference between this "without-project" scenario and the "with-project" scenario is the net (or incremental) impact of the project.

CBA Basics: Counterfactual

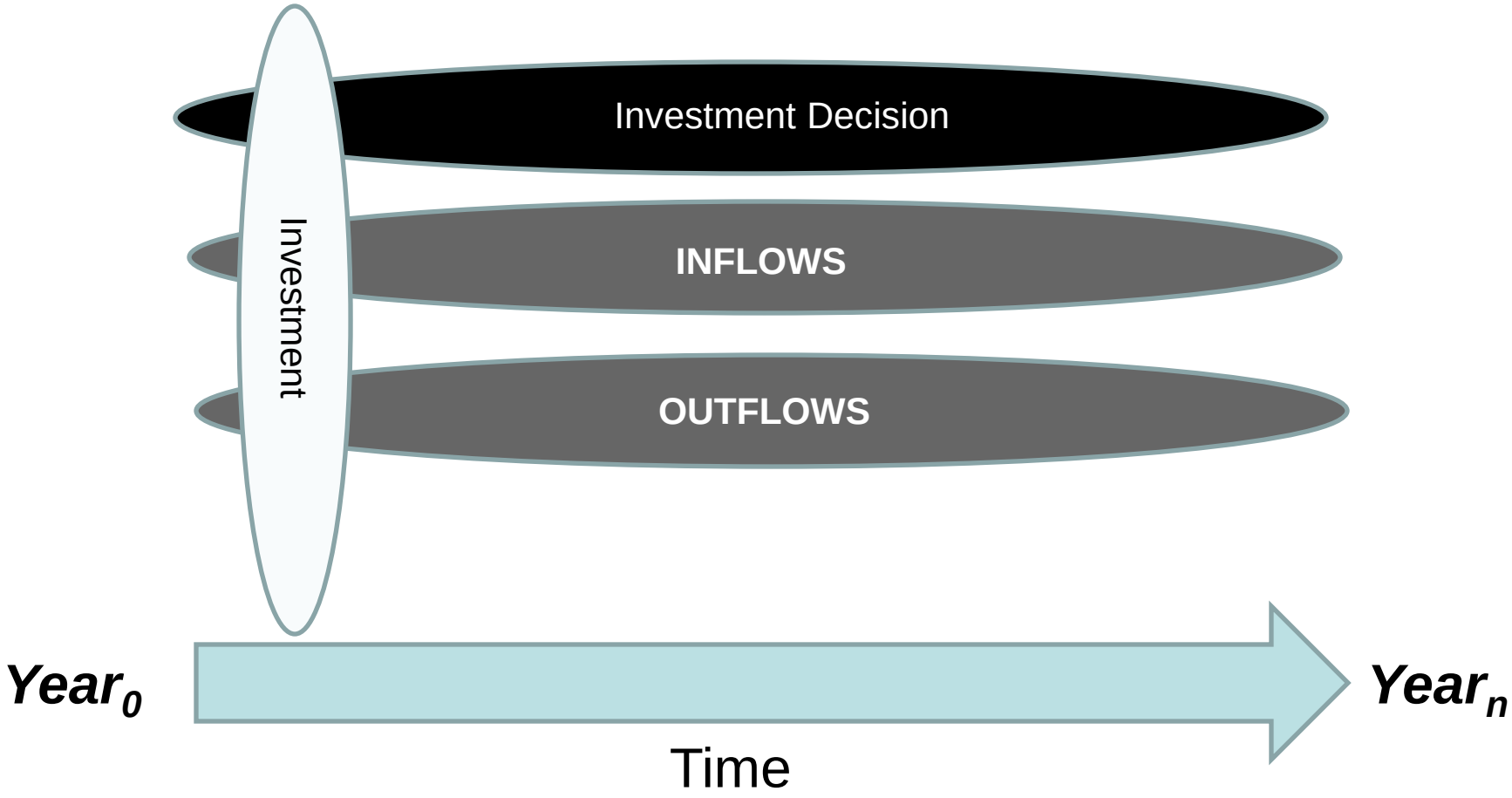
USAID Project Impact on Farm Income



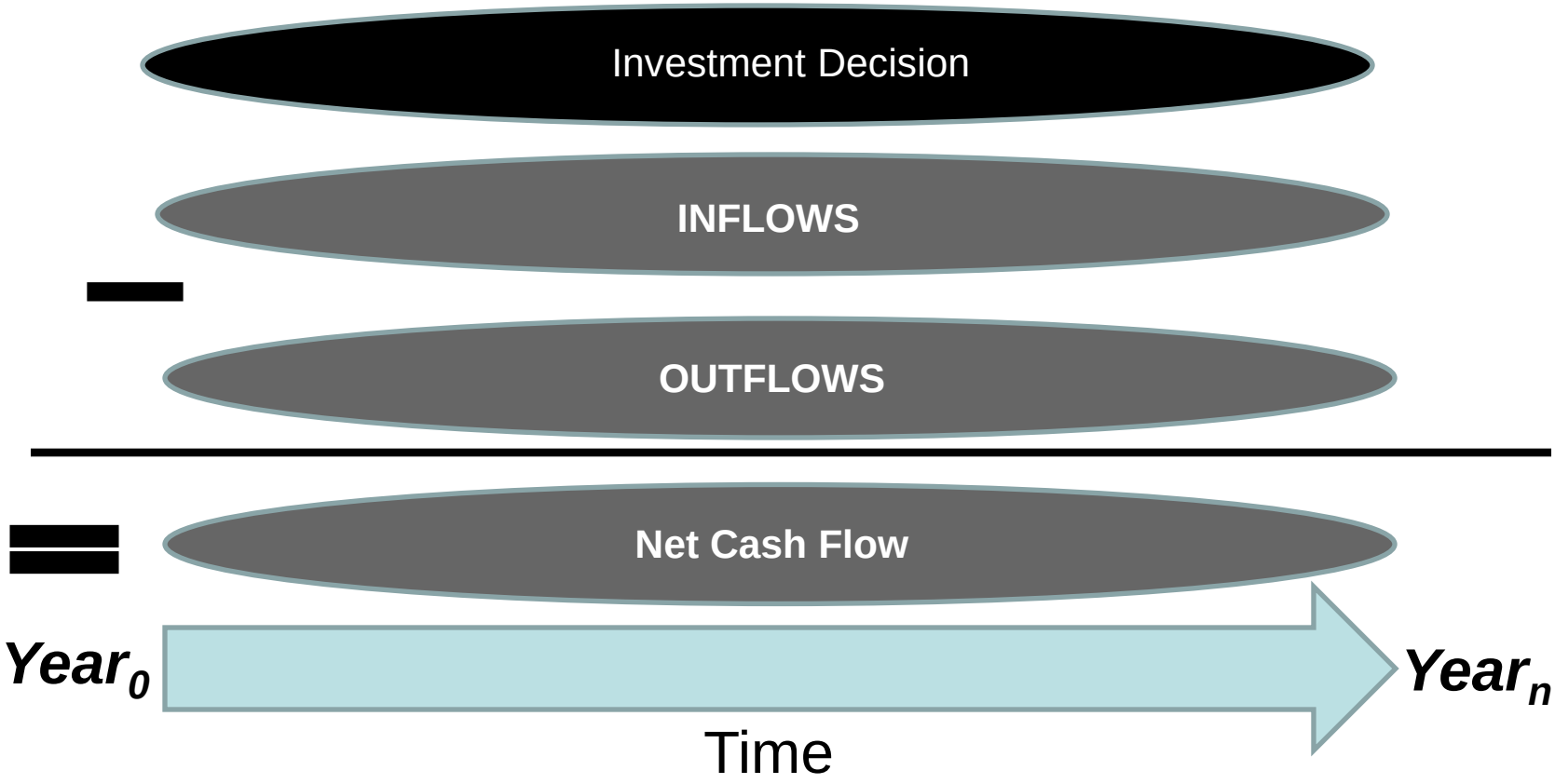
Financial Analysis

- Why do financial analysis for a public project?
  - Ensuring the availability of funds
  - Identify financial shortfalls
  - Do private sector participants have an incentive to get involved?
  - Assessing distributional impacts (who wins and who loses?)

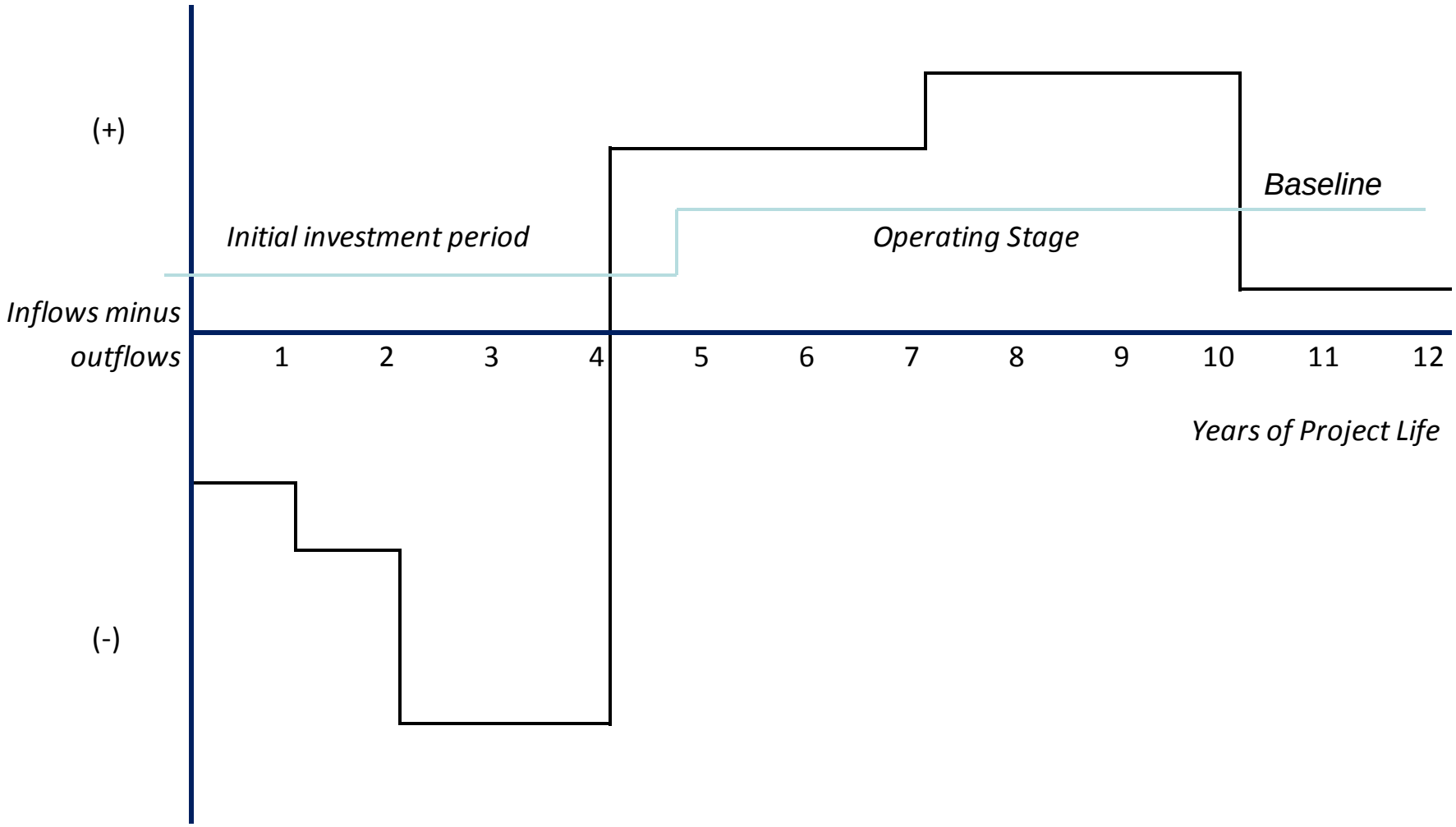
Time Horizon of Investment Decision



Time Horizon of Investment Decision



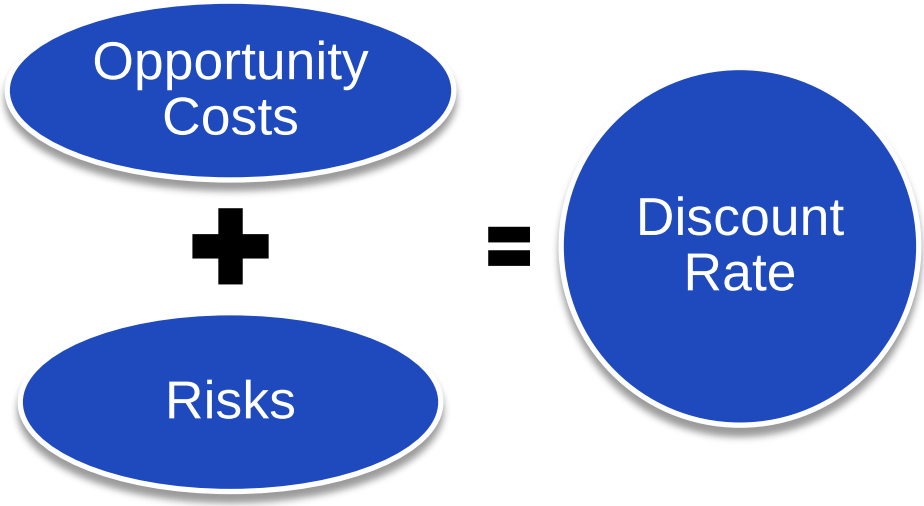
Net Cash Flow Profile of a Project



Time Preference

Almost all projects have up-front, periodic and future costs and benefits that accrue over time.

- How can we compare these costs?
- We solve this timing problem with **discounting** – that is, converting future payments into their present-day terms.



CBA Basics: Time Preferences and Discounting

And now, for some math:

Discounting can be described informally (*intuitively*) with words or *formally* with mathematics.

Intuitively: *Risks* to future resources and the *opportunity cost* of other uses of those resources cause us to **discount** the value of resource received in the future. We reduce the value of benefits and costs that occur in the future.

CBA Basics: Time Preferences and Discounting

Formally:

$$\boldsymbol{PV(1+r) = FV}$$

Where:

PV : **value today** (this present period) – present value

FV : **value in one year** (future period) – future value

r : the **discount rate**, a measure of how much *more* you would need to receive *tomorrow* in order to give up some amount of money *today*

CBA Basics: Time Preferences and Discounting

For discounting multiple time periods:

$$\boldsymbol{PV(1+r)^n = FV}$$

Where:

PV : **value today** (this present period) – present value

FV : **value in one year** (future period) – future value

r : the **discount rate**, a measure of how much *more* you would need to receive *tomorrow* in order to give up some amount of money *today*

n : the number of **time periods** to be discounted

CBA Basics: Time Preferences and Discounting

Since we want to know the value of the future payment (*FV*) in terms of present money (*PV*) we must rearrange our equation, starting with

$$PV(1+r) = FV$$

we divide both sides by $(1+r)$, and get:

$$\boldsymbol{PV = FV\left(\frac{1}{1+r}\right)^{n}}$$

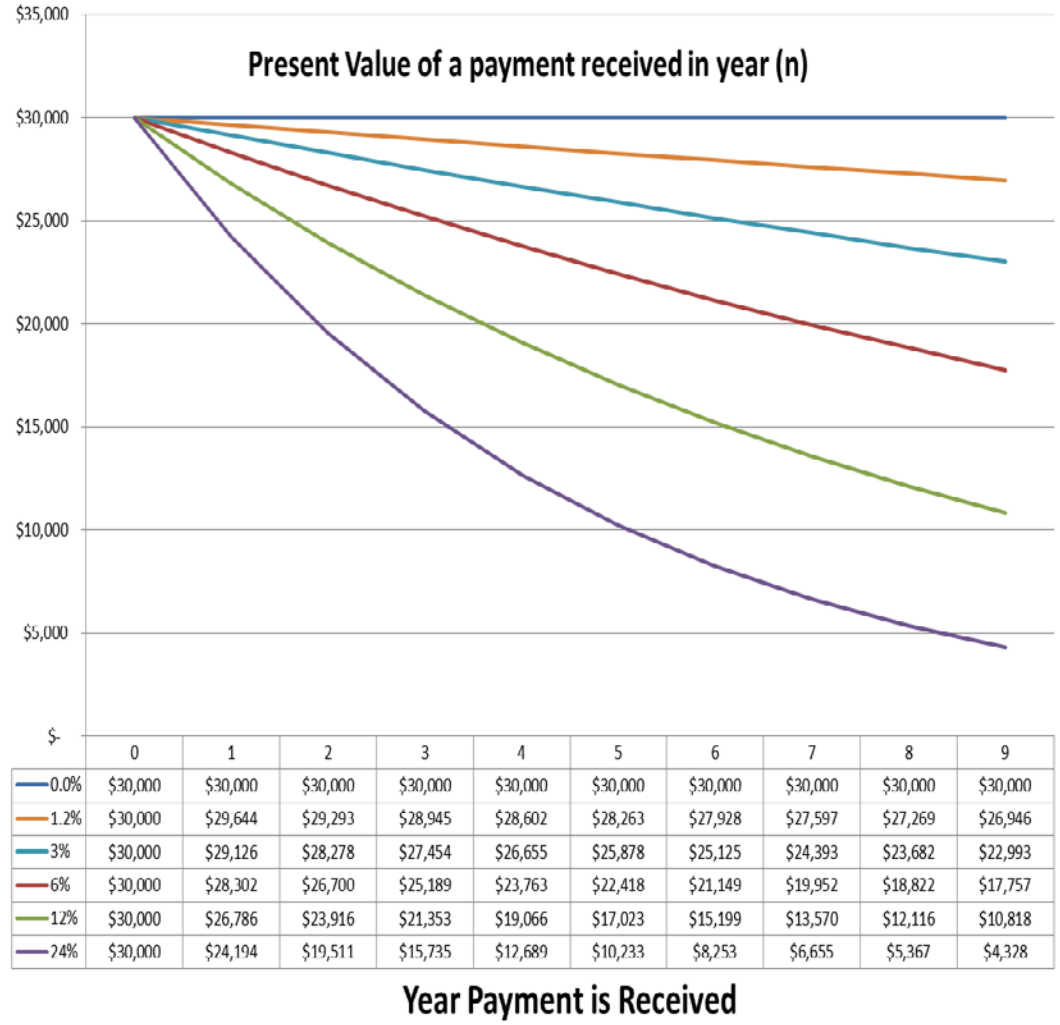
The ***r*** in the denominator is the **discount rate**

This equation describes how we **discount** future payments (FV) relative to present ones (PV)

Effects of discount rate

Example:

1. **$300,000 paid out in 10 equal payments over 10 years.**
2. **Receive $30,000/year**
3. **What is the present value of that payment?**
4. **What is the effect of the different discount rates?**



	0	1	2	3	4	5	6	7	8	9
0.0%	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000
1.2%	$30,000	$29,644	$29,293	$28,945	$28,602	$28,263	$27,928	$27,597	$27,269	$26,946
3%	$30,000	$29,126	$28,278	$27,454	$26,655	$25,878	$25,125	$24,393	$23,682	$22,993
6%	$30,000	$28,302	$26,700	$25,189	$23,763	$22,418	$21,149	$19,952	$18,822	$17,757
12%	$30,000	$26,786	$23,916	$21,353	$19,066	$17,023	$15,199	$13,570	$12,116	$10,818
24%	$30,000	$24,194	$19,511	$15,735	$12,689	$10,233	$8,253	$6,655	$5,367	$4,328

Financial Analysis and Net Present Value

Net Present Value

Now, let's consider an example:

We have the opportunity to invest in a project. It requires an up-front investment of $350 today, and will pay out $100 at the end of each year for the next four years, after which the project is finished.

Should we make the investment?

How do we make this decision?

Net Present Value

Visualizing the Project's Impacts

Benefits		$100	$100	$100	$100	
Costs	$350					
	Year 0 (today)	Year 1	Year 2	Year 3	Year 4	…

We will choose an annual discount rate of **10%**.

Net Present Value

Benefits		$100	$100	$100	$100	
Costs	$350					…
PV of Benefits		$91	$82.81	$75.13	$68.30	
PV of Costs	$350					
	Year 0 (today)	Year 1	Year 2	Year 3	Year 4	…

Net Present Value

Now that all of our payments are valued in terms of the same time period, we can add up the project's costs and benefits and decide whether the project is worth the investment:

Costs	Benefits
350	
	91
	82.81
	75.13
	68.30
32.76	

Now we can answer the question: **should we undertake this project?**

Net Present Value

No, because, the costs of the program outweigh its benefits. Specifically:

317.24 – 350 = -$32.76

This calculation is known as the ***Net Present Value*** **(NPV)** of a project, which is the total value of the project, expressed in terms of the present time, after accounting for all costs and benefits.

Decision Rule: **If a project's NPV is negative, it should not be pursued (on economic grounds).**

Economic Analysis and Cost-effectiveness

Why do we do economic analysis in addition to financial analysis?

What is a distortion?

Financial price ≠ Economic price

- *Something that causes the market to reach a financial price for an item that is substantially <u>different</u> from the economic price*

- Financial price = price as seen in the market

- Economic price = price if the economy is operating in perfect competition and there are no externalities

Types of distortions

- Taxes & subsidies
- Other transfers
- Financing
- Price/quantity constraints
- Externalities
- Market power (monopolies, oligopolies, etc.)
- Foreign exchange premium (FEP)

Other Non-traded Distortions

Negative Externality

Positive Externality

Positive Financial NPV

+ Fin NPV - Econ NPV → *Should NOT fund except for non quantifiable benefits*	+ Fin NPV + Econ NPV → *USAID could fund*
- Fin NPV - Econ NPV → *Should NOT fund, except for non quantifiable benefits*	- Fin NPV + Econ NPV → *USAID could fund but need to ensure sustainability*

Negative Economic NPV

Positive Economic NPV

Negative Financial NPV

CEA for GCC Projects

- Cost-Benefit Analysis requires us to monetize all important costs and benefits of a project
  - What is the price of a ton of CO2 equivalents emitted?
- Instead of answering this question, we assume that reducing GHGs is good, and try to determine the most effective way to do so
  - Incremental Cost-Effectiveness Ratio: how much will it cost to get more of the outcome I want?
- For GCC, use tCO2e
- Constrained vs. unconstrained optimization

CEA for GCC Projects

- C/E ratio for GCC projects defined as:

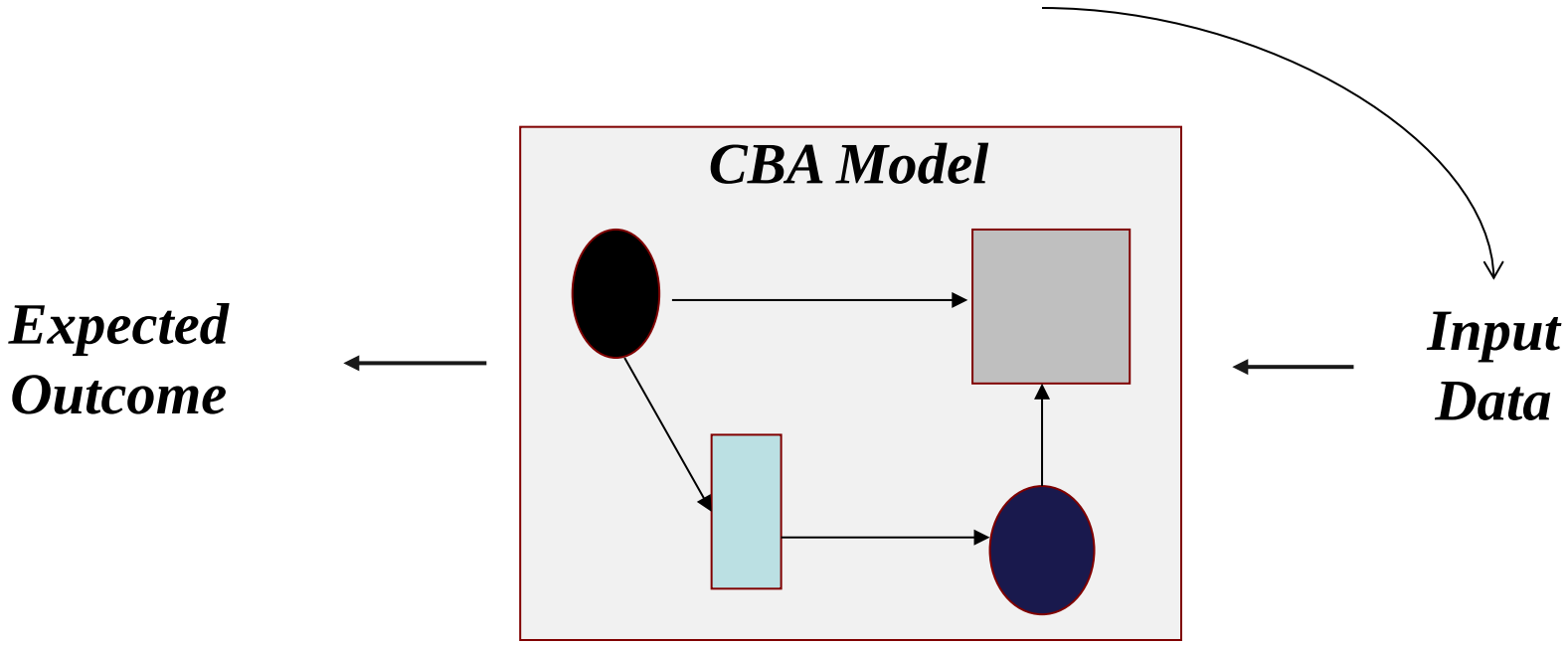
$$\frac{USD}{tCO2e\ mitigated} = \frac{Incremental\ NPV}{Incremental\ tCO2e}$$

- Important to normalize both NPV and tCO2e mitigated for the level of production—that is, discounted MWh
- Goal is to pick the alternative with the lowest cost per tCO2e mitigated

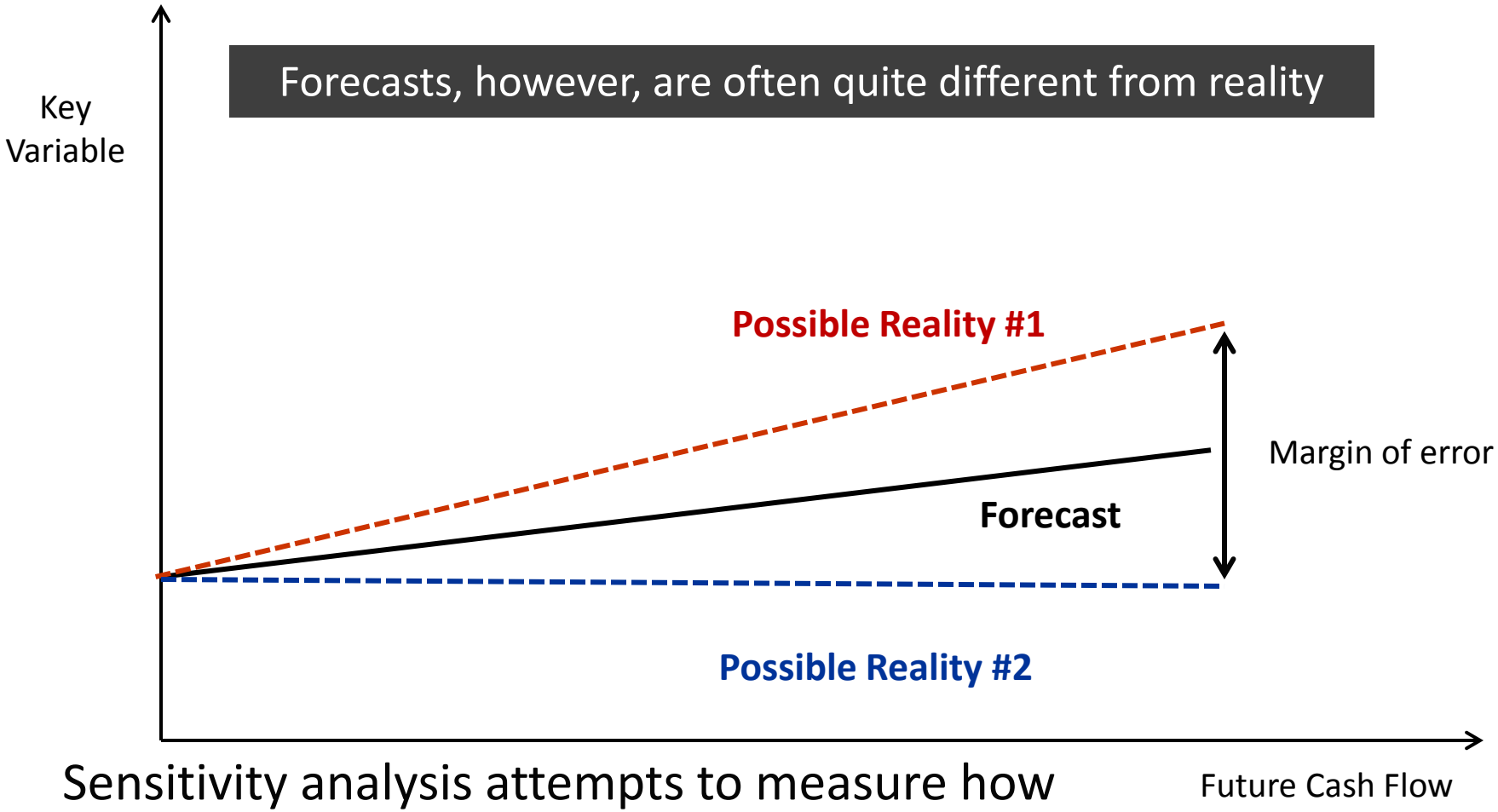
Sensitivity Analysis

Why do we need sensitivity analysis?

Assumptions expressed as estimated, quantifiable variables



Sensitivity Analysis



Sensitivity analysis attempts to measure how movements in variables impact the project

On what variables should we perform sensitivity analysis?

- Variables that may affect decision-making from a viewpoint of interest
- Variables that are expected to vary significantly over time
- Variables that are based on limited data

The above types of variables can vary by country, sector, and project.

This is where good modeling is vital to CBA model analysis!

Remember the good tips for modeling:

- *Only hard code in the table of parameters*
- All formulas should be links to cell parameters
- Only list each parameter once
- Logically group your tables
- Don’t put too many functions into one cell

CELL REFERENCE

Key Parameters	Quantity	Units
Exchange Rate	43	HTG/$

Cell Reference

Item	Haiti Gourde (HTG)	Amount of Input	Total Cost (HTG)
Fertilizer	516	7	
Seeds	559	3	
Power Tiller	21500	1	
Pesticide	860	10	
Cost<<<<		1	2

Item	Haiti Gourde (HTG)
Fertilizer	516
Seeds	559
Power Tiller	21500
Pesticide	860

Unit	Total Cost($)	Unit
HTG		$
HTG		$
HTG		$
HTG		$
3	4	5

Table of Parameters

	Units	Option 1: Diesel Generation Plant
Cost Components		
Fixed Costs		
Investment cost, y1	1000 VND	105,000,000
Investment cost, y2	1000 VND	-
Investment cost, y3	1000 VND	-
Life of fixed asset	years	40
Fixed asset residual value	1000 VND	21,000,000
Land rental price	1000 VND/ha	2,000
Land area required	ha	15
Recurring costs	USD	10,000
Recurring cost period	years	5
Recurring cost growth	% per year	0.0%
Variable Costs		
Operations and maintenance	1000 VND per kWh	0.294
Fuel	USD per kWh	0.056
Taxes	% of revenues less O&M	10.0%
O&M cost growth	% per year	0.0%
Fuel cost growth	% per year	0.0%
First year of operation		1
Benefit Components		
Wholesale price of electricity	1000 VND per kWh	
Production tax credit (subsidy)	1000 VND per kWh	0
Income tax credit	% of tax liability	0
Annual environmental externality	1000 VND	-1575000
Carbon credit payments	USD per ton of CO2 avoided	2
Technical Components		
Greenhouse gas emissions	tons of CO2 equivalent per kWh	0.000424
Capacity factor	% of annual capacity	85.0%
Availability factor	% of annual capacity	90.0%
Rated capacity	MW	5
Capacity decline	% decline per year	1.0%
Power type		Base
Economic Components		
Financial discount rate	%	15.0%

Economic discount rate	%	12.0%
Exchange rate	1000 VND per USD	21
Real exchange rate adjustment	%	0.0%
Foreign exchange premium	%	8.5%
Unit Conversions		
kWh per MWh		1000
Days per year		365
Hours per day		24
Pounds per ton		2000

Option 1: Diesel Generation Plant

Preliminary Tables

Table A: Indices	Year	0
Recurring cost growth		1.0
O&M cost growth		1.0
Fuel cost growth		1.0
Exchange rate		21.0

Table B: Production	Year	0
Rated capacity less capacity decline		-
After capacity factor		-
After availability factor		-
Total annual production (MWh)		-
GHG production (tCO2e)		-

Financial Cash Flows, 1000 VND

Table 1: Financial Analysis, firm perspective	Year	0
Revenues		
Value of production		-
Production tax credit		-
Income tax credit		-
Carbon credit payments		-
Total revenues		-
Costs		
Investment cost		105,000,000
Land rental		30,000
Recurring costs		-
Fixed costs subtotal		105,030,000
Operations and maintenance		-
Fuel		-

Taxes		-
Variable costs subtotal		-
Total costs		105,030,000
Net cash flows (1000 VND)		(105,030,000)
Total costs (USD)		5,001,429
Net cash flows (USD)		(5,001,429)
		1000 VND
NPV		#############
IRR		#NUM!
Discounted MWh		198,953.19
tCO2 generated		258,699
Financial LCOE (cost per kWh)		1.85

Economic Resource Flows

Table 2: Economic Analysis, economy perspective	Conversion factor	Year	0
Benefits			
Value of production	1.40		-
Production tax credit	0.00		-
Income tax credit	0.00		-
Carbon credit payments	0.00		-
Environmental externality	1.00		-
Total benefits			-
Costs			
Investment cost	0.91		95,319,000
Land rental	1.00		30,000
Recurring costs	0.91		-
Fixed costs subtotal			95,349,000
Operations and maintenance	1.02		-
Fuel	1.61		-
Taxes	0.00		-
Variable costs subtotal			-
Total costs			95,349,000
Net cash flows			(95,349,000)
Total costs (USD)			4,540,429
Net cash flows (USD)			(4,540,429)
			1000 VND
NPV			#############

IRR	#NUM!
Discounted MWh	235,892
tCO2 generated	258,699
Economic LCOE (cost per kWh)	2.60

Option 2: Landfill Gas Plant

Preliminary Tables

Table A: Indices	Year	0
Recurring cost growth		1.0
O&M cost growth		1.0
Fuel cost growth		1.0
Exchange rate		21.0

Table B: Production	Year	0
Rated capacity less capacity decline		-
After capacity factor		-
After availability factor		-
Total annual production (MWh)		-
GHG production (tCO2e)		-

Financial Cash Flows

Table 1: Financial Analysis, firm perspective	Year	0
Revenues		
Value of production		-
Production tax credit		-
Income tax credit		-
Carbon credit payments		-
Total revenues		-
Costs		
Investment cost		-
Land rental		32,500
Recurring costs		-
Fixed costs subtotal		32,500
Operations and maintenance		-
Fuel		-
Taxes		-
Variable costs subtotal		-
Total costs		32,500
Net cash flows		(32,500)

Total costs (USD)			1,548
Net cash flows (USD)			(1,548)
			1000 VND
NPV			2,107,134.60
IRR			31.8%
Discounted MWh			-
tCO2 generated			-
Financial LCOE (cost per kWh)			#DIV/0!

Economic Resource Flows

Table 2: Economic Analysis, economy perspective	Conversion factor	Year	0
Benefits			
Value of production	1.40		-
Production tax credit	0.00		-
Income tax credit	0.00		-
Carbon credit payments	0.00		-
Environmental externality	1.00		-
Total benefits			-
Costs			
Investment cost	1.07		-
Land rental	1.00		32,500
Recurring costs	0.91		-
Fixed costs subtotal			32,500
Operations and maintenance	1.02		-
Fuel	1.61		-
Taxes	0.00		-
Variable costs subtotal			-
Total costs			32,500
Net cash flows			(32,500)
Total costs (USD)			1,548
Net cash flows (USD)			(1,548)
			1000 VND
NPV			4,084,190
IRR			32.3%
Discounted MWh			-
tCO2 generated			-
Economic LCOE (cost per kWh)			#DIV/0!

Option 3: Hydro-dam

Preliminary Tables

Table A: Indices	Year	0
Recurring cost growth		1.0
O&M cost growth		1.0
Fuel cost growth		1.0
Exchange rate		21.0

Table B: Production	Year	0
Rated capacity less capacity decline		-
After capacity factor		-
After availability factor		-
Total annual production (MWh)		-
GHG production (tCO2e)		-

Financial Cash Flows

Table 1: Financial Analysis, firm perspective	Year	0
Revenues		
Value of production		-
Production tax credit		-
Income tax credit		-
Carbon credit payments		-
Total revenues		-
Costs		
Investment cost		100,800,000
Land rental		10,000
Recurring costs		-
Fixed costs subtotal		100,810,000
Operations and maintenance		-
Fuel		-
Taxes		-
Variable costs subtotal		-
Total costs		100,810,000
Net cash flows		(100,810,000)
Total costs (USD)		4,800,476
Net cash flows (USD)		(4,800,476)
		1000 VND

NPV			#############
IRR			#NUM!
Discounted MWh			174,939.55
tCO2 generated			-
Financial LCOE (cost per kWh)			2.60

Economic Resource Flows

Table 2: Economic Analysis, economy perspective	Conversion factor	Year	0
Benefits			
Value of production	1.40		-
Production tax credit	0.00		-
Income tax credit	0.00		-
Carbon credit payments	0.00		-
Environmental externality	1.00		-
Total benefits			-
Costs			
Investment cost	1.07		107,654,400
Land rental	1.00		10,000
Recurring costs	0.91		-
Fixed costs subtotal			107,664,400
Operations and maintenance	1.02		-
Fuel	1.61		-
Taxes	0.00		-
Variable costs subtotal			-
Total costs			107,664,400
Net cash flows			(107,664,400)
Total costs (USD)			5,126,876
Net cash flows (USD)			(5,126,876)
			1000 VND
NPV			(557,278,958)
IRR			#NUM!
Discounted MWh			217,593
tCO2 generated			-
Economic LCOE (cost per kWh)			2.56

Option 4: Wind Turbines

Preliminary Tables

Table A: Indices		Year	0

Recurring cost growth	1.0
O&M cost growth	1.0
Fuel cost growth	1.0
Exchange rate	21.0

Table B: Production	Year	0
Rated capacity less capacity decline		-
After capacity factor		-
After availability factor		-
Total annual production (MWh)		-
GHG production (tCO2e)		-

Financial Cash Flows

Table 1: Financial Analysis, firm perspective	Year	0
Revenues		
Value of production		-
Production tax credit		-
Income tax credit		-
Carbon credit payments		-
Total revenues		-
Costs		
Investment cost		504,000,000
Land rental		25,000
Recurring costs		-
Fixed costs subtotal		504,025,000
Operations and maintenance		-
Fuel		-
Taxes		-
Variable costs subtotal		-
Total costs		504,025,000
Net cash flows		(504,025,000)
Total costs (USD)		24,001,190
Net cash flows (USD)		(24,001,190)
		1000 VND
NPV		#############
IRR		#NUM!
Discounted MWh		188,368.29
tCO2 generated		-
Financial LCOE (cost per kWh)		3.40

Economic Resource Flows

Table 2: Economic Analysis, economy perspective	Conversion factor	Year	0
Benefits			
Value of production	1.40		-
Production tax credit	0.00		-
Income tax credit	0.00		-
Carbon credit payments	0.00		-
Environmental externality	1.00		-
Total benefits			-
Costs			
Investment cost	1.07		538,272,000
Land rental	1.00		25,000
Recurring costs	0.91		-
Fixed costs subtotal			538,297,000
Operations and maintenance	1.02		-
Fuel	1.61		-
Taxes	0.00		-
Variable costs subtotal			-
Total costs			538,297,000
Net cash flows			(538,297,000)
Total costs (USD)			25,633,190
Net cash flows (USD)			(25,633,190)
			1000 VND
NPV			(718,683,202)
IRR			#NUM!
Discounted MWh			224,056
tCO2 generated			-
Economic LCOE (cost per kWh)			3.21

	Financi
	Option 1: Diesel Generation Plant
FNPV (USD)	(17,500,574)
IRR	#NUM!
Financial LCOE (USD per kWh)	0.09
Discounted MWh generated	198,953

tCO2 generated	258,699
tCO2 mitgated (relative to Option 1)	-
Incremental FNPV (USD)	
USD/tCO2 mitigated	

	Econon
	Option 1: Diesel Generation Plant
ENPV (USD)	(29,741,383)
EIRR	#NUM!
Economic LCOE (USD per kWh)	0.12
Discounted MWh generated	235,892
tCO2 generated	258,699
tCO2 mitgated	-
Incremental ENPV (USD)	
USD/tCO2 mitigated	

Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
	100,800,000	504,000,000
	100,800,000	-
-	100,800,000	-
	40	20
44,100,000	60,480,000	126,000,000
500	2,000	1,000
65	5	25
	20,000	20,000
5	7	5
0.0%	0.0%	0.0%
	1.23	0.84
0	0	0
10.0%	10.0%	10.0%
0.0%	0.0%	0.0%
0.0%	0.0%	0.0%
2	3	1
0	0	0
	0	0
0.1	0.1	0.1
	0	0
2	2	2
	0	0
	65.0%	30.0%
98.0%	85.0%	98.0%
	8	12
4.0%	0.5%	0.5%
Base	Intermittent	Intermittent

1	2	3	4	5	6
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

1	2	3	4	5	6
5.00	4.95	4.90	4.85	4.80	4.75
4.25	4.21	4.17	4.12	4.08	4.04
3.83	3.79	3.75	3.71	3.67	3.64
33,507	33,172	32,840	32,512	32,187	31,865
14,206.97	14,065	13,924	13,785	13,647	13,511

1	2	3	4	5	6
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
30,000	30,000	30,000	30,000	30,000	30,000
-	-	-	-	210,000	-
30,000	30,000	30,000	30,000	240,000	30,000
9,851,058	9,752,547	9,655,022	9,558,472	9,462,887	9,368,258
39,404,232	39,010,190	38,620,088	38,233,887	37,851,548	37,473,033

(4,925,529)	(4,876,274)	(4,827,511)	(4,779,236)	(4,731,444)	(4,684,129)
44,329,761	43,886,463	43,447,599	43,013,123	42,582,992	42,157,162
44,359,761	43,916,463	43,477,599	43,043,123	42,822,992	42,187,162
(44,359,761)	(43,916,463)	(43,477,599)	(43,043,123)	(42,822,992)	(42,187,162)
2,112,370	2,091,260	2,070,362	2,049,673	2,039,190	2,008,912
(2,112,370)	(2,091,260)	(2,070,362)	(2,049,673)	(2,039,190)	(2,008,912)
USD					
$ (17,500,574)					
0.088					

1	2	3	4	5	6
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)
(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)
-	-	-	-	-	-
30,000	30,000	30,000	30,000	30,000	30,000
-	-	-	-	190,638	-
30,000	30,000	30,000	30,000	220,638	30,000
10,060,393	9,959,789	9,860,191	9,761,589	9,663,973	9,567,334
63,627,984	62,991,704	62,361,787	61,738,169	61,120,787	60,509,579
-	-	-	-	-	-
73,688,377	72,951,493	72,221,978	71,499,758	70,784,761	70,076,913
73,718,377	72,981,493	72,251,978	71,529,758	71,005,399	70,106,913
(75,293,377)	(74,556,493)	(73,826,978)	(73,104,758)	(72,580,399)	(71,681,913)
3,510,399	3,475,309	3,440,570	3,406,179	3,381,209	3,338,424
(3,585,399)	(3,550,309)	(3,515,570)	(3,481,179)	(3,456,209)	(3,413,424)
USD					
$ (29,741,383)					

0.12					

1	2	3	4	5	6
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

1	2	3	4	5	6
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-

1	2	3	4	5	6
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
(32,500)	(32,500)	(32,500)	(32,500)	(32,500)	(32,500)

	1,548	1,548	1,548	1,548	1,548	1,548
	(1,548)	(1,548)	(1,548)	(1,548)	(1,548)	(1,548)
USD						
$	100,340					
	#DIV/0!					

	1	2	3	4	5	6
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	32,500	32,500	32,500	32,500	32,500	32,500
	-	-	-	-	-	-
	32,500	32,500	32,500	32,500	32,500	32,500
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	32,500	32,500	32,500	32,500	32,500	32,500
	(32,500)	(32,500)	(32,500)	(32,500)	(32,500)	(32,500)
	1,548	1,548	1,548	1,548	1,548	1,548
	(1,548)	(1,548)	(1,548)	(1,548)	(1,548)	(1,548)
USD						
$	194,485					
	#DIV/0!					

1	2	3	4	5	6
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

1	2	3	4	5	6
-	-	8.00	7.96	7.92	7.88
-	-	5.20	5.17	5.15	5.12
-	-	4.42	4.40	4.38	4.35
-	-	38,719	38,526	38,333	38,141
-	-	-	-	-	-

1	2	3	4	5	6
-	-	-	-	-	-
-	-	-	-	-	-
-	-	(476,246)	(473,865)	(471,496)	(469,138)
-	-	689,512	686,064	682,634	679,220
-	-	213,265	212,199	211,138	210,082
100,800,000	100,800,000	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
-	-	-	-	-	-
100,810,000	100,810,000	10,000	10,000	10,000	10,000
-	-	47,624,616	47,386,493	47,149,560	46,913,813
-	-	-	-	-	-
-	-	(4,762,462)	(4,738,649)	(4,714,956)	(4,691,381)
-	-	42,862,154	42,647,844	42,434,604	42,222,431
100,810,000	100,810,000	42,872,154	42,657,844	42,444,604	42,232,431
(100,810,000)	(100,810,000)	(42,658,889)	(42,445,645)	(42,233,466)	(42,022,349)
4,800,476	4,800,476	2,041,531	2,031,326	2,021,172	2,011,068
(4,800,476)	(4,800,476)	(2,031,376)	(2,021,221)	(2,011,117)	(2,001,064)
USD					

$	(21,640,118)
	0.124

1	2	3	4	5	6
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
107,654,400	107,654,400	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
-	-	-	-	-	-
107,664,400	107,664,400	10,000	10,000	10,000	10,000
-	-	48,636,639	48,393,456	48,151,489	47,910,731
-	-	-	-	-	-
-	-	-	-	-	-
-	-	48,636,639	48,393,456	48,151,489	47,910,731
107,664,400	107,664,400	48,646,639	48,403,456	48,161,489	47,920,731
(107,664,400)	(107,664,400)	(48,646,639)	(48,403,456)	(48,161,489)	(47,920,731)
5,126,876	5,126,876	2,316,507	2,304,926	2,293,404	2,281,940
(5,126,876)	(5,126,876)	(2,316,507)	(2,304,926)	(2,293,404)	(2,281,940)

USD	
$	(26,537,093)
	0.12

1	2	3	4	5	6

1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

1	2	3	4	5	6
12.00	11.94	11.88	11.82	11.76	11.70
3.60	3.58	3.56	3.55	3.53	3.51
3.53	3.51	3.49	3.48	3.46	3.44
30,905	30,751	30,597	30,444	30,292	30,140
-	-	-	-	-	-

1	2	3	4	5	6
-	-	-	-	-	-
-	-	-	-	-	-
(259,604)	(258,306)	(257,015)	(255,730)	(254,451)	(253,179)
550,361	547,609	544,871	542,147	539,436	536,739
290,757	289,303	287,857	286,417	284,985	283,560
-	-	-	-	-	-
25,000	25,000	25,000	25,000	25,000	25,000
-	-	-	-	420,000	-
25,000	25,000	25,000	25,000	445,000	25,000
25,960,435	25,830,633	25,701,480	25,572,972	25,445,108	25,317,882
-	-	-	-	-	-
(2,596,044)	(2,583,063)	(2,570,148)	(2,557,297)	(2,544,511)	(2,531,788)
23,364,392	23,247,570	23,131,332	23,015,675	22,900,597	22,786,094
23,389,392	23,272,570	23,156,332	23,040,675	23,345,597	22,811,094
(23,098,635)	(22,983,267)	(22,868,475)	(22,754,258)	(23,060,612)	(22,527,534)
1,113,781	1,108,218	1,102,682	1,097,175	1,111,695	1,086,243
(1,099,935)	(1,094,441)	(1,088,975)	(1,083,536)	(1,098,124)	(1,072,740)
USD					
$ (30,405,295)					
0.162					

	1	2	3	4	5	6
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	25,000	25,000	25,000	25,000	25,000	25,000
	-	-	-	-	381,276	-
	25,000	25,000	25,000	25,000	406,276	25,000
	26,512,094	26,379,534	26,247,636	26,116,398	25,985,816	25,855,887
	-	-	-	-	-	-
	-	-	-	-	-	-
	26,512,094	26,379,534	26,247,636	26,116,398	25,985,816	25,855,887
	26,537,094	26,404,534	26,272,636	26,141,398	26,392,092	25,880,887
	(26,537,094)	(26,404,534)	(26,272,636)	(26,141,398)	(26,392,092)	(25,880,887)
	1,263,671	1,257,359	1,251,078	1,244,828	1,256,766	1,232,423
	(1,263,671)	(1,257,359)	(1,251,078)	(1,244,828)	(1,256,766)	(1,232,423)
USD						
$	(34,223,010)					
	0.15					

ial Summary Tables

	Option 2: Landfill Gas Plant		Option 3: Hydro-dam		Option 4: Wind Turbines
	100,340		(21,640,118)		(30,405,295)
	31.8%		#NUM!		#NUM!
	#DIV/0!		0.12		0.16
	-		174,940		188,368

	-	-	-
	#DIV/0!	258,699	258,699
	#DIV/0!	(7,110,044)	(14,613,272)
	#DIV/0!	27.48	56.49

nic Summary Tables

	Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
	194,485	(26,537,093)	(34,223,010)
	32.3%	#NUM!	#NUM!
	#DIV/0!	0.12	0.15
	-	217,593	224,056
	-	-	-
	#DIV/0!	258,699	258,699
	#DIV/0!	972,588	(6,289,425.99)
	#DIV/0!	(3.76)	24.31

7	8	9	10	11	12
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

7	8	9	10	11	12
4.71	4.66	4.61	4.57	4.52	4.48
4.00	3.96	3.92	3.88	3.84	3.81
3.60	3.57	3.53	3.49	3.46	3.42
31,546	31,231	30,918	30,609	30,303	30,000
13,376	13,242	13,109	12,978	12,849	12,720

7	8	9	10	11	12
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
30,000	30,000	30,000	30,000	30,000	30,000
-	-	-	210,000	-	-
30,000	30,000	30,000	240,000	30,000	30,000
9,274,576	9,181,830	9,090,012	8,999,111	8,909,120	8,820,029
37,098,302	36,727,319	36,360,046	35,996,446	35,636,481	35,280,116

(4,637,288)	(4,590,915)	(4,545,006)	(4,499,556)	(4,454,560)	(4,410,015)
41,735,590	41,318,234	40,905,052	40,496,001	40,091,041	39,690,131
41,765,590	41,348,234	40,935,052	40,736,001	40,121,041	39,720,131
(41,765,590)	(41,348,234)	(40,935,052)	(40,736,001)	(40,121,041)	(39,720,131)
1,988,838	1,968,964	1,949,288	1,939,810	1,910,526	1,891,435
(1,988,838)	(1,968,964)	(1,949,288)	(1,939,810)	(1,910,526)	(1,891,435)

7	8	9	10	11	12
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)
(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)
-	-	-	-	-	-
30,000	30,000	30,000	30,000	30,000	30,000
-	-	-	190,638	-	-
30,000	30,000	30,000	220,638	30,000	30,000
9,471,660	9,376,944	9,283,174	9,190,343	9,098,439	9,007,455
59,904,484	59,305,439	58,712,384	58,125,260	57,544,008	56,968,568
-	-	-	-	-	-
69,376,144	68,682,382	67,995,559	67,315,603	66,642,447	65,976,022
69,406,144	68,712,382	68,025,559	67,536,241	66,672,447	66,006,022
(70,981,144)	(70,287,382)	(69,600,559)	(69,111,241)	(68,247,447)	(67,581,022)
3,305,054	3,272,018	3,239,312	3,216,011	3,174,878	3,143,144
(3,380,054)	(3,347,018)	(3,314,312)	(3,291,011)	(3,249,878)	(3,218,144)

7	8	9	10	11	12
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

7	8	9	10	11	12
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-

7	8	9	10	11	12
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
(32,500)	(32,500)	(32,500)	(32,500)	(32,500)	(32,500)

1,548	1,548	1,548	1,548	1,548	1,548
(1,548)	(1,548)	(1,548)	(1,548)	(1,548)	(1,548)

7	8	9	10	11	12
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
(32,500)	(32,500)	(32,500)	(32,500)	(32,500)	(32,500)
1,548	1,548	1,548	1,548	1,548	1,548
(1,548)	(1,548)	(1,548)	(1,548)	(1,548)	(1,548)

7	8	9	10	11	12
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

7	8	9	10	11	12
7.84	7.80	7.76	7.72	7.69	7.65
5.10	5.07	5.05	5.02	5.00	4.97
4.33	4.31	4.29	4.27	4.25	4.23
37,951	37,761	37,572	37,384	37,197	37,011
-	-	-	-	-	-

7	8	9	10	11	12
-	-	-	-	-	-
-	-	-	-	-	-
(466,792)	(464,458)	(462,136)	(459,826)	(457,526)	(455,239)
675,824	672,445	669,083	665,738	662,409	659,097
209,032	207,987	206,947	205,912	204,883	203,858
-	-	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
420,000	-	-	-	-	-
430,000	10,000	10,000	10,000	10,000	10,000
46,679,244	46,445,847	46,213,618	45,982,550	45,752,637	45,523,874
-	-	-	-	-	-
(4,667,924)	(4,644,585)	(4,621,362)	(4,598,255)	(4,575,264)	(4,552,387)
42,011,319	41,801,263	41,592,256	41,384,295	41,177,374	40,971,487
42,441,319	41,811,263	41,602,256	41,394,295	41,187,374	40,981,487
(42,232,287)	(41,603,276)	(41,395,309)	(41,188,383)	(40,982,491)	(40,777,629)
2,021,015	1,991,013	1,981,060	1,971,157	1,961,304	1,951,499
(2,011,061)	(1,981,108)	(1,971,205)	(1,961,352)	(1,951,547)	(1,941,792)

7	8	9	10	11	12
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
381,276	-	-	-	-	-
391,276	10,000	10,000	10,000	10,000	10,000
47,671,178	47,432,822	47,195,658	46,959,679	46,724,881	46,491,256
-	-	-	-	-	-
-	-	-	-	-	-
47,671,178	47,432,822	47,195,658	46,959,679	46,724,881	46,491,256
48,062,454	47,442,822	47,205,658	46,969,679	46,734,881	46,501,256
(48,062,454)	(47,442,822)	(47,205,658)	(46,969,679)	(46,734,881)	(46,501,256)
2,288,688	2,259,182	2,247,888	2,236,651	2,225,471	2,214,346
(2,288,688)	(2,259,182)	(2,247,888)	(2,236,651)	(2,225,471)	(2,214,346)

7 8 9 10 11 12

1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

7	8	9	10	11	12
11.64	11.59	11.53	11.47	11.41	11.36
3.49	3.48	3.46	3.44	3.42	3.41
3.42	3.41	3.39	3.37	3.36	3.34
29,990	29,840	29,690	29,542	29,394	29,247
-	-	-	-	-	-

7	8	9	10	11	12
-	-	-	-	-	-
-	-	-	-	-	-
(251,913)	(250,653)	(249,400)	(248,153)	(246,912)	(245,678)
534,055	531,385	528,728	526,085	523,454	520,837
282,142	280,732	279,328	277,931	276,542	275,159
-	-	-	-	-	-
25,000	25,000	25,000	25,000	25,000	25,000
-	-	-	420,000	-	-
25,000	25,000	25,000	445,000	25,000	25,000
25,191,293	25,065,336	24,940,010	24,815,309	24,691,233	24,567,777
-	-	-	-	-	-
(2,519,129)	(2,506,534)	(2,494,001)	(2,481,531)	(2,469,123)	(2,456,778)
22,672,163	22,558,803	22,446,009	22,333,779	22,222,110	22,110,999
22,697,163	22,583,803	22,471,009	22,778,779	22,247,110	22,135,999
(22,415,021)	(22,303,071)	(22,191,680)	(22,500,847)	(21,970,568)	(21,860,840)
1,080,817	1,075,419	1,070,048	1,084,704	1,059,386	1,054,095
(1,067,382)	(1,062,051)	(1,056,747)	(1,071,469)	(1,046,218)	(1,040,992)

7	8	9	10	11	12
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
25,000	25,000	25,000	25,000	25,000	25,000
-	-	-	381,276	-	-
25,000	25,000	25,000	406,276	25,000	25,000
25,726,608	25,597,975	25,469,985	25,342,635	25,215,922	25,089,842
-	-	-	-	-	-
-	-	-	-	-	-
25,726,608	25,597,975	25,469,985	25,342,635	25,215,922	25,089,842
25,751,608	25,622,975	25,494,985	25,748,911	25,240,922	25,114,842
(25,751,608)	(25,622,975)	(25,494,985)	(25,748,911)	(25,240,922)	(25,114,842)
1,226,267	1,220,142	1,214,047	1,226,139	1,201,949	1,195,945
(1,226,267)	(1,220,142)	(1,214,047)	(1,226,139)	(1,201,949)	(1,195,945)

13	14	15	16	17	18
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

13	14	15	16	17	18
4.43	4.39	4.34	4.30	4.26	4.21
3.77	3.73	3.69	3.66	3.62	3.58
3.39	3.36	3.32	3.29	3.26	3.22
29,700	29,403	29,109	28,818	28,530	28,244
12,593	12,467	12,342	12,219	12,097	11,976

13	14	15	16	17	18
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
30,000	30,000	30,000	30,000	30,000	30,000
-	-	210,000	-	-	-
30,000	30,000	240,000	30,000	30,000	30,000
8,731,829	8,644,510	8,558,065	8,472,485	8,387,760	8,303,882
34,927,315	34,578,042	34,232,262	33,889,939	33,551,040	33,215,529

(4,365,914)	(4,322,255)	(4,279,033)	(4,236,242)	(4,193,880)	(4,151,941)
39,293,230	38,900,297	38,511,294	38,126,181	37,744,919	37,367,470
39,323,230	38,930,297	38,751,294	38,156,181	37,774,919	37,397,470
(39,323,230)	(38,930,297)	(38,751,294)	(38,156,181)	(37,774,919)	(37,397,470)
1,872,535	1,853,824	1,845,300	1,816,961	1,798,806	1,780,832
(1,872,535)	(1,853,824)	(1,845,300)	(1,816,961)	(1,798,806)	(1,780,832)

13	14	15	16	17	18
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)
(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)	(1,575,000)
-	-	-	-	-	-
30,000	30,000	30,000	30,000	30,000	30,000
-	-	190,638	-	-	-
30,000	30,000	220,638	30,000	30,000	30,000
8,917,380	8,828,206	8,739,924	8,652,525	8,566,000	8,480,340
56,398,882	55,834,893	55,276,544	54,723,779	54,176,541	53,634,776
-	-	-	-	-	-
65,316,262	64,663,100	64,016,469	63,376,304	62,742,541	62,115,115
65,346,262	64,693,100	64,237,107	63,406,304	62,772,541	62,145,115
(66,921,262)	(66,268,100)	(65,812,107)	(64,981,304)	(64,347,541)	(63,720,115)
3,111,727	3,080,624	3,058,910	3,019,348	2,989,169	2,959,291
(3,186,727)	(3,155,624)	(3,133,910)	(3,094,348)	(3,064,169)	(3,034,291)

13	14	15	16	17	18
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

13	14	15	16	17	18
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-

13	14	15	16	17	18
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
(32,500)	(32,500)	(32,500)	(32,500)	(32,500)	(32,500)

1,548	1,548	1,548	1,548	1,548	1,548
(1,548)	(1,548)	(1,548)	(1,548)	(1,548)	(1,548)

13	14	15	16	17	18
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
(32,500)	(32,500)	(32,500)	(32,500)	(32,500)	(32,500)
1,548	1,548	1,548	1,548	1,548	1,548
(1,548)	(1,548)	(1,548)	(1,548)	(1,548)	(1,548)

13	14	15	16	17	18
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

13	14	15	16	17	18
7.61	7.57	7.53	7.50	7.46	7.42
4.95	4.92	4.90	4.87	4.85	4.82
4.20	4.18	4.16	4.14	4.12	4.10
36,826	36,642	36,459	36,277	36,095	35,915
-	-	-	-	-	-

13	14	15	16	17	18
-	-	-	-	-	-
-	-	-	-	-	-
(452,963)	(450,698)	(448,444)	(446,202)	(443,971)	(441,751)
655,801	652,522	649,260	646,013	642,783	639,569
202,839	201,825	200,816	199,811	198,812	197,818
-	-	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
-	420,000	-	-	-	-
10,000	430,000	10,000	10,000	10,000	10,000
45,296,255	45,069,773	44,844,425	44,620,202	44,397,101	44,175,116
-	-	-	-	-	-
(4,529,625)	(4,506,977)	(4,484,442)	(4,462,020)	(4,439,710)	(4,417,512)
40,766,629	40,562,796	40,359,982	40,158,182	39,957,391	39,757,604
40,776,629	40,992,796	40,369,982	40,168,182	39,967,391	39,767,604
(40,573,790)	(40,790,971)	(40,169,167)	(39,968,371)	(39,768,579)	(39,569,786)
1,941,744	1,952,038	1,922,380	1,912,771	1,903,209	1,893,695
(1,932,085)	(1,942,427)	(1,912,817)	(1,903,256)	(1,893,742)	(1,884,276)

13	14	15	16	17	18
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
-	381,276	-	-	-	-
10,000	391,276	10,000	10,000	10,000	10,000
46,258,800	46,027,506	45,797,369	45,568,382	45,340,540	45,113,837
-	-	-	-	-	-
-	-	-	-	-	-
46,258,800	46,027,506	45,797,369	45,568,382	45,340,540	45,113,837
46,268,800	46,418,782	45,807,369	45,578,382	45,350,540	45,123,837
(46,268,800)	(46,418,782)	(45,807,369)	(45,578,382)	(45,350,540)	(45,123,837)
2,203,276	2,210,418	2,181,303	2,170,399	2,159,550	2,148,754
(2,203,276)	(2,210,418)	(2,181,303)	(2,170,399)	(2,159,550)	(2,148,754)

13 14 15 16 17 18

1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

13	14	15	16	17	18
11.30	11.24	11.19	11.13	11.08	11.02
3.39	3.37	3.36	3.34	3.32	3.31
3.32	3.31	3.29	3.27	3.26	3.24
29,101	28,956	28,811	28,667	28,523	28,381
-	-	-	-	-	-

13	14	15	16	17	18
-	-	-	-	-	-
-	-	-	-	-	-
(244,449)	(243,227)	(242,011)	(240,801)	(239,597)	(238,399)
518,233	515,642	513,063	510,498	507,946	505,406
273,783	272,414	271,052	269,697	268,349	267,007
-	-	-	-	-	-
25,000	25,000	25,000	25,000	25,000	25,000
-	-	420,000	-	-	-
25,000	25,000	445,000	25,000	25,000	25,000
24,444,938	24,322,713	24,201,100	24,080,094	23,959,694	23,839,895
-	-	-	-	-	-
(2,444,494)	(2,432,271)	(2,420,110)	(2,408,009)	(2,395,969)	(2,383,990)
22,000,444	21,890,442	21,780,990	21,672,085	21,563,724	21,455,906
22,025,444	21,915,442	22,225,990	21,697,085	21,588,724	21,480,906
(21,751,661)	(21,643,027)	(21,954,937)	(21,427,388)	(21,320,376)	(21,213,899)
1,048,831	1,043,592	1,058,380	1,033,195	1,028,034	1,022,900
(1,035,793)	(1,030,620)	(1,045,473)	(1,020,352)	(1,015,256)	(1,010,186)

13	14	15	16	17	18
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
25,000	25,000	25,000	25,000	25,000	25,000
-	-	381,276	-	-	-
25,000	25,000	406,276	25,000	25,000	25,000
24,964,393	24,839,571	24,715,373	24,591,796	24,468,837	24,346,493
-	-	-	-	-	-
-	-	-	-	-	-
24,964,393	24,839,571	24,715,373	24,591,796	24,468,837	24,346,493
24,989,393	24,864,571	25,121,649	24,616,796	24,493,837	24,371,493
(24,989,393)	(24,864,571)	(25,121,649)	(24,616,796)	(24,493,837)	(24,371,493)
1,189,971	1,184,027	1,196,269	1,172,228	1,166,373	1,160,547
(1,189,971)	(1,184,027)	(1,196,269)	(1,172,228)	(1,166,373)	(1,160,547)

19	20	21
1.0	1.0	1.0
1.0	1.0	1.0
1.0	1.0	1.0
21.0	21.0	21.0

19	20	21
4.17	4.13	-
3.55	3.51	-
3.19	3.16	-
27,962	27,682	-
11,856	11,737	-

19	20	21
-	-	-
-	-	-
-	-	-
-	-	-
-	-	-
-	-	(21,000,000)
30,000	30,000	-
-	210,000	-
30,000	240,000	(21,000,000)
8,220,843	8,138,635	-
32,883,374	32,554,540	-

(4,110,422)	(4,069,318)	-
36,993,796	36,623,858	-
37,023,796	36,863,858	(21,000,000)
(37,023,796)	(36,863,858)	21,000,000
1,763,038	1,755,422	(1,000,000)
(1,763,038)	(1,755,422)	1,000,000

19	20	21
-	-	-
-	-	-
-	-	-
-	-	-
(1,575,000)	(1,575,000)	-
(1,575,000)	(1,575,000)	-
-	-	(19,063,800)
30,000	30,000	-
-	190,638	-
30,000	220,638	(19,063,800)
8,395,536	8,311,581	-
53,098,428	52,567,444	-
-	-	-
61,493,964	60,879,025	-
61,523,964	61,099,663	(19,063,800)
(63,098,964)	(62,674,663)	19,063,800
2,929,713	2,909,508	(907,800)
(3,004,713)	(2,984,508)	907,800

19	20	21
1.0	1.0	1.0
1.0	1.0	1.0
1.0	1.0	1.0
21.0	21.0	21.0

19	20	21
-	-	-
-	-	-
-	-	-
-	-	-
-	-	-

19	20	21
-	-	-
-	-	-
-	-	-
-	-	-
-	-	-
-	-	(44,100,000)
32,500	32,500	-
-	-	-
32,500	32,500	(44,100,000)
-	-	-
-	-	-
-	-	-
-	-	-
32,500	32,500	(44,100,000)
(32,500)	(32,500)	44,100,000

1,548	1,548	(2,100,000)
(1,548)	(1,548)	2,100,000

19	20	21
-	-	-
-	-	-
-	-	-
-	-	-
-	-	-
-	-	-
-	-	(47,098,800)
32,500	32,500	-
-	-	-
32,500	32,500	(47,098,800)
-	-	-
-	-	-
-	-	-
-	-	-
32,500	32,500	(47,098,800)
(32,500)	(32,500)	47,098,800
1,548	1,548	(2,242,800)
(1,548)	(1,548)	2,242,800

19	20	21
1.0	1.0	1.0
1.0	1.0	1.0
1.0	1.0	1.0
21.0	21.0	21.0

19	20	21
7.38	7.35	-
4.80	4.78	-
4.08	4.06	-
35,735	35,556	-
-	-	-

19	20	21
-	-	-
-	-	-
(439,542)	(437,345)	-
636,372	633,190	-
196,829	195,845	-
-	-	(60,480,000)
10,000	10,000	-
-	-	-
10,000	10,000	(60,480,000)
43,954,240	43,734,469	-
-	-	-
(4,395,424)	(4,373,447)	-
39,558,816	39,361,022	-
39,568,816	39,371,022	(60,480,000)
(39,371,987)	(39,175,177)	60,480,000
1,884,229	1,874,811	(2,880,000)
(1,874,857)	(1,865,485)	2,880,000

19	20	21
-	-	-
-	-	-
-	-	-
-	-	-
-	-	-
-	-	-
-	-	(64,592,640)
10,000	10,000	-
-	-	-
10,000	10,000	(64,592,640)
44,888,268	44,663,827	-
-	-	-
-	-	-
44,888,268	44,663,827	-
44,898,268	44,673,827	(64,592,640)
(44,898,268)	(44,673,827)	64,592,640
2,138,013	2,127,325	(3,075,840)
(2,138,013)	(2,127,325)	3,075,840

19	20	21

1.0	1.0	1.0
1.0	1.0	1.0
1.0	1.0	1.0
21.0	21.0	21.0

19	20	21
10.96	10.91	-
3.29	3.27	-
3.22	3.21	-
28,239	28,098	-
-	-	-

19	20	21
-	-	-
-	-	-
(237,207)	(236,021)	-
502,879	500,364	-
265,672	264,343	-
-	-	(126,000,000)
25,000	25,000	-
-	420,000	-
25,000	445,000	(126,000,000)
23,720,696	23,602,092	-
-	-	-
(2,372,070)	(2,360,209)	-
21,348,626	21,241,883	-
21,373,626	21,686,883	(126,000,000)
(21,107,954)	(21,422,540)	126,000,000
1,017,792	1,032,709	(6,000,000)
(1,005,141)	(1,020,121)	6,000,000

19	20	21
-	-	-
-	-	-
-	-	-
-	-	-
-	-	-
-	-	-
-	-	(134,568,000)
25,000	25,000	-
-	381,276	-
25,000	406,276	(134,568,000)
24,224,760	24,103,637	-
-	-	-
-	-	-
24,224,760	24,103,637	-
24,249,760	24,509,913	(134,568,000)
(24,249,760)	(24,509,913)	134,568,000
1,154,750	1,167,139	(6,408,000)
(1,154,750)	(1,167,139)	6,408,000

Table of Parameters

	Units	Option 1: Diesel Generation Plant
Cost Components		
Fixed Costs		
Investment cost, y1	1000 VND	105,000,000
Investment cost, y2	1000 VND	-
Investment cost, y3	1000 VND	-
Life of fixed asset	years	40
Fixed asset residual value	1000 VND	21,000,000
Land rental price	1000 VND/ha	2,000
Land area required	ha	15
Recurring costs	USD	10,000
Recurring cost period	years	5
Recurring cost growth	% per year	0.0%
Variable Costs		
Operations and maintenance	1000 VND per kWh	0.294
Fuel	USD per kWh	0.056
Taxes	% of revenues less O&M	10.0%
O&M cost growth	% per year	0.0%
Fuel cost growth	% per year	0.0%
First year of operation		1
Benefit Components		
Wholesale price of electricity	1000 VND per kWh	2.31
Production tax credit (subsidy)	1000 VND per kWh	0
Income tax credit	% of tax liability	0
Annual environmental externality	1000 VND	-1575000
Carbon credit payments	USD per ton of CO2 avoided	2
Technical Components		
Greenhouse gas emissions	tons of CO2 equivalent per kWh	0.000424
Capacity factor	% of annual capacity	85.0%
Availability factor	% of annual capacity	90.0%
Rated capacity	MW	5
Capacity decline	% decline per year	1.0%
Power type		Base
Economic Components		
Financial discount rate	%	15.0%

Economic discount rate	%		12.0%
Exchange rate	1000 VND per USD		21
Real exchange rate adjustment	%		0.0%
Foreign exchange premium	%		8.5%
Unit Conversions			
kWh per MWh			1000
Days per year			365
Hours per day			24
Pounds per ton			2000

Option 2: Landfill Gas Plant

Preliminary Tables

Table A: Indices		Year	0
Recurring cost growth			1.0
O&M cost growth			
Fuel cost growth			1.0
Exchange rate			21.0

Table B: Production		Year	0
Rated capacity less capacity decline			-
After capacity factor			-
After availability factor			-
Total annual production (MWh)			-
GHG production (tCO2e)			-

Financial Cash Flows

Table 1: Financial Analysis, firm perspective		Year	0
Revenues			
Value of production			-
Production tax credit			-
Income tax credit			-
Carbon credit payments			-
Total revenues			-
Costs			
Investment cost			73,500,000
Land rental			32,500
Recurring costs			-
Fixed costs subtotal			73,532,500
Operations and maintenance			-
Fuel			-

Taxes		-
Variable costs subtotal		-
Total costs		73,532,500
Net cash flows		(73,532,500)
Total costs (USD)		3,501,548
Net cash flows (USD)		(3,501,548)
		1000 VND
NPV		#############
IRR		-5.8%
Discounted MWh		-
tCO2 generated		-
Financial LCOE (cost per kWh)		#DIV/0!

Economic Resource Flows

Table 2: Economic Analysis, economy perspective	Conversion factor	Year	0
Benefits			
Value of production	1.40		-
Production tax credit	0.00		-
Income tax credit	0.00		-
Carbon credit payments	0.00		-
Environmental externality	1.00		-
Total benefits			-
Costs			
Investment cost	1.07		78,498,000
Land rental	1.00		32,500
Recurring costs	0.91		-
Fixed costs subtotal			78,530,500
Operations and maintenance	1.02		-
Fuel	1.61		-
Taxes	0.00		-
Variable costs subtotal			-
Total costs			78,530,500
Net cash flows			(78,530,500)
Total costs (USD)			3,739,548
Net cash flows (USD)			(3,739,548)
			1000 VND
NPV			(150,253,748)

IRR		-6.7%
Discounted MWh		-
tCO2 generated		-
Economic LCOE (cost per kWh)		#DIV/0!

Option 3: Hydro-dam

Preliminary Tables

Table A: Indices	Year	0
Recurring cost growth		1.0
O&M cost growth		1.0
Fuel cost growth		1.0
Exchange rate		21.0

Table B: Production	Year	0
Rated capacity less capacity decline		-
After capacity factor		-
After availability factor		-
Total annual production (MWh)		-
GHG production (tCO2e)		-

Financial Cash Flows

Table 1: Financial Analysis, firm perspective	Year	0
Revenues		
Value of production		-
Production tax credit		-
Income tax credit		-
Carbon credit payments		-
Total revenues		-
Costs		
Investment cost		100,800,000
Land rental		10,000
Recurring costs		-
Fixed costs subtotal		100,810,000
Operations and maintenance		-
Fuel		-
Taxes		-
Variable costs subtotal		-
Total costs		100,810,000
Net cash flows		(100,810,000)

Total costs (USD)			4,800,476
Net cash flows (USD)			(4,800,476)
			1000 VND
NPV			(49,964,743.05)
IRR			11.9%
Discounted MWh			174,939.55
tCO2 generated			-
Financial LCOE (cost per kWh)			2.83

Economic Resource Flows

Table 2: Economic Analysis, economy perspective	Conversion factor	Year	0
Benefits			
Value of production	1.40		-
Production tax credit	0.00		-
Income tax credit	0.00		-
Carbon credit payments	0.00		-
Environmental externality	1.00		-
Total benefits			-
Costs			
Investment cost	1.07		107,654,400
Land rental	1.00		10,000
Recurring costs	0.91		-
Fixed costs subtotal			107,664,400
Operations and maintenance	1.02		-
Fuel	1.61		-
Taxes	0.00		-
Variable costs subtotal			-
Total costs			107,664,400
Net cash flows			(107,664,400)
Total costs (USD)			5,126,876
Net cash flows (USD)			(5,126,876)
			1000 VND
NPV			140,892,191
IRR			18.3%
Discounted MWh			217,593
tCO2 generated			-
Economic LCOE (cost per kWh)			2.56

Option 4: Wind Turbines

Preliminary Tables

Table A: Indices	Year	0
Recurring cost growth		1.0
O&M cost growth		1.0
Fuel cost growth		1.0
Exchange rate		21.0

Table B: Production	Year	0
Rated capacity less capacity decline		-
After capacity factor		-
After availability factor		-
Total annual production (MWh)		-
GHG production (tCO2e)		-

Financial Cash Flows

Table 1: Financial Analysis, firm perspective	Year	0
Revenues		
Value of production		-
Production tax credit		-
Income tax credit		-
Carbon credit payments		-
Total revenues		-
Costs		
Investment cost		504,000,000
Land rental		25,000
Recurring costs		-
Fixed costs subtotal		504,025,000
Operations and maintenance		-
Fuel		-
Taxes		-
Variable costs subtotal		-
Total costs		504,025,000
Net cash flows		(504,025,000)
Total costs (USD)		24,001,190
Net cash flows (USD)		(24,001,190)
		1000 VND
NPV		#############

IRR			7.5%
Discounted MWh			188,368.29
tCO2 generated			-
Financial LCOE (cost per kWh)			3.63

Economic Resource Flows

Table 2: Economic Analysis, economy perspective	Conversion factor	Year	0
Benefits			
Value of production	1.40		-
Production tax credit	0.00		-
Income tax credit	0.00		-
Carbon credit payments	0.00		-
Environmental externality	1.00		-
Total benefits			-
Costs			
Investment cost	1.07		538,272,000
Land rental	1.00		25,000
Recurring costs	0.91		-
Fixed costs subtotal			538,297,000
Operations and maintenance	1.02		-
Fuel	1.61		-
Taxes	0.00		-
Variable costs subtotal			-
Total costs			538,297,000
Net cash flows			(538,297,000)
Total costs (USD)			25,633,190
Net cash flows (USD)			(25,633,190)
			1000 VND
NPV			390,691
IRR			12.0%
Discounted MWh			224,056
tCO2 generated			-
Economic LCOE (cost per kWh)			3.21

Financi

	Option 1: Diesel Generation Plant
FNPV (USD)	2,195,791
IRR	22.8%
Financial LCOE (USD per kWh)	0.10
Discounted MWh generated	198,953
tCO2 generated	258,699
tCO2 mitgated (relative to Option 1)	-
Incremental FNPV (USD)	
USD/tCO2 mitigated	

	Econon
	Option 1: Diesel Generation Plant
ENPV (USD)	6,585,973
EIRR	33.5%
Economic LCOE (USD per kWh)	0.12
Discounted MWh generated	235,892
tCO2 generated	258,699
tCO2 mitgated	-
Incremental ENPV (USD)	
USD/tCO2 mitigated	

SEI

Option 1: Diesel Generation Plant

Total Investment cost
105,000,000
115,500,000
138,600,000
180,180,000
252,252,000
378,378,000

Recurring costs
210,000
262,500
315,000
420,000
630,000
840,000

Recurring cost growth
-
10%
20%
40%
50%

Operations and maintenance
0.21
0.24
0.26
0.29
0.32
0.37
0.44

Fuel cost

0.039
0.045
0.050
0.056
0.062
0.067
0.073

O&M cost growth
-
1%
2%
3%
4%
5%

Fuel cost growth
-
1%
2%
3%
4%
5%

First year of operation
1
2
3
4
5
6

Wholesale price of electricity
1.85
2.08
2.31
2.54
2.77
3.00

Carbon credit payments
1.50
1.75
2.00
2.50
3.00
4.00

Capacity factor
55%
65%
75%
85%
90%
95%

Availability factor
60%
70%
80%
90%
95%
98%

Capacity decline
1.0%
1.5%
2.0%
2.5%
3.0%
3.5%

Financial discount rate
10.0%
12.0%
14.0%

15.0%
18.0%
20.0%

Economic discount rate
6.0%
8.0%
10.0%
12.0%
14.0%
15.0%

Real exchange rate depreciation
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%

Option 2: Landfill Gas Plant

Total Investment cost
147,000,000
161,700,000
176,400,000
191,100,000
205,800,000
220,500,000

Recurring costs (USD)
14,000
15,400
16,800
18,200
19,600
21,000

Recurring cost growth
-
10%
20%
40%
50%

Operations and maintenance
1.37
1.57
1.61
1.79
1.96
2.14
2.32

Fuel cost
-
-
-
-
-
-
-

O&M cost growth
0.0%
1%
2%
3%
4%
5%

Fuel cost growth
0.0%
1%
2%
3%
4%

5%

First year of operation
2
3
4
5
6
7

Wholesale price of electricity
1.85
2.08
2.31
2.54
2.77
3.00

Carbon credit payments
1.50
1.75
2.00
2.50
3.00
4.00

Capacity factor
55%
65%
75%
85%
90%
95%

Availability factor
75%
85%

90%
95%
98%
99%

Capacity decline
2.0%
3.0%
4.0%
4.5%
5.0%
6.0%

Financial discount rate
10.0%
12.0%
14.0%
15.0%
18.0%
20.0%

Economic discount rate
6.0%
8.0%
10.0%
12.0%
14.0%
15.0%

Real exchange rate depreciation
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%

Option 3: Hydro-dam

Total Investment cost
302,400,000
332,640,000
362,880,000
393,120,000
423,360,000
453,600,000

Recurring costs (USD)
20,000
22,000
24,000
26,000
28,000
30,000

Recurring cost growth
-
10%
20%
40%
50%

Operations and maintenance
0.97
1.11
1.13
1.26
1.39
1.51
1.64

Fuel cost
-
-
-
-
-

-
-

O&M cost growth
0.0%
1%
2%
3%
4%
5%

Fuel cost growth
0.0%
1%
2%
3%
4%
5%

First year of operation
3
4
5
6
7
8

Wholesale price of electricity
1.85
2.08
2.31
2.54
2.77
3.00

Carbon credit payments
1.50

1.75
2.00
2.50
3.00
4.00

Capacity factor
50%
55%
60%
65%
70%
75%

Availability factor
65%
70%
75%
80%
85%
90%

Capacity decline
0.0%
0.25%
0.5%
1.0%
2.0%
3.0%

Financial discount rate
10.0%
12.0%
14.0%
15.0%
18.0%
20.0%

Economic discount rate
6.0%
8.0%
10.0%
12.0%
14.0%
15.0%

Real exchange rate depreciation
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%

Option 4: Wind Turbines

Total Investment cost
504,000,000
554,400,000
604,800,000
655,200,000
705,600,000
756,000,000

Recurring costs (USD)
20,000
22,000
24,000
26,000
28,000
30,000

Recurring cost growth
-
10%
20%
40%

50%

Operations and maintenance
0.65
0.74
0.76
0.84
0.92
1.01
1.09

Fuel cost
-
-
-
-
-
-
-

O&M cost growth
0.0%
1%
2%
3%
4%
5%

Fuel cost growth
0.0%
1%
2%
3%
4%
5%

First year of operation

1
2
3
4
5
6

Wholesale price of electricity
1.85
2.08
2.31
2.54
2.77
3.00

Carbon credit payments
1.50
1.75
2.00
2.50
3.00
4.00

Capacity factor
20%
25%
30%
35%
40%
50%

Availability factor
80%
85%
90%
95%
98%
99%

Capacity decline
0.0%
0.25%
0.5%
1.0%
2.0%
3.0%

Financial discount rate
10.0%
12.0%
14.0%
15.0%
18.0%
20.0%

Economic discount rate
6.0%
8.0%
10.0%
12.0%
14.0%
15.0%

Real exchange rate depreciation
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%

Incremental Sensitivity Analysis

Recurring cost growth	Base Case
	0%
	1%
	2%
	3%
	4%
	5%

Fuel	Base Case
	0.043
	0.049
	0.050
	0.056
	0.062
	0.067
	0.073

O&M cost growth	Base Case
	0%
	1%
	2%
	3%
	4%
	5%

Fuel cost growth	Base Case
	0%
	1%
	2%
	3%
	4%
	5%

Wholesale price of electricity	Base Case
	1.78
	2.03
	2.08
	2.31
	2.54
	2.77
	3.00

Production tax credit (subsidy)	Base Case
	0.21
	0.25
	0.29
	0.34
	0.38
	0.42

Carbon credit payments	Base Case
	2.00
	2.25
	2.50
	3.00
	4.00
	5.00

Greenhouse gas emissions	Base Case

0.00036
0.00037
0.00038
0.00042
0.00047
0.00051
0.00055

Financial discount rate	Base Case
	10%
	12%
	15%
	18%
	20%

Economic discount rate	Base Case
	8%
	10%
	12%
	14%
	15%

Real exchange rate depreciation	Base Case
	0%
	1%
	2%
	3%
	4%
	5%

Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
73,500,000	100,800,000	504,000,000
73,500,000	100,800,000	-
-	100,800,000	-
20	40	20
44,100,000	60,480,000	126,000,000
500	2,000	1,000
65	5	25
14,000	20,000	20,000
5	7	5
0.0%	0.0%	0.0%
1.8	1.23	0.84
0	0	0
10.0%	10.0%	10.0%
0.0%	0.0%	0.0%
0.0%	0.0%	0.0%
2	3	1
2.31	2.31	2.31
0.21	0.21	0.21
0.1	0.1	0.1
-840000	0	0
2	2	2
0.0003392	0	0
85.0%	65.0%	30.0%
98.0%	85.0%	98.0%
5	8	12
4.0%	0.5%	0.5%
Base	Intermittent	Intermittent

1	2	3	4	5	6
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

1	2	3	4	5	6
-					
-	-	-	-	-	-
-	-	-	-	-	-
-					
-					

1	2	3	4	5	6
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
73,500,000	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
73,532,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
-	-	-	-	-	-

-	-	-	-	-	-
-	-	-	-	-	-
73,532,500	32,500	32,500	32,500	32,500	32,500
(73,532,500)	(32,500)	(32,500)	(32,500)	(32,500)	(32,500)
3,501,548	1,548	1,548	1,548	1,548	1,548
(3,501,548)	(1,548)	(1,548)	(1,548)	(1,548)	(1,548)
USD					
$ (6,452,319)					
#DIV/0!					

1	2	3	4	5	6
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
-	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
78,498,000	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
78,530,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
78,530,500	32,500	32,500	32,500	32,500	32,500
(78,530,500)	(872,500)	(872,500)	(872,500)	(872,500)	(872,500)
3,739,548	1,548	1,548	1,548	1,548	1,548
(3,739,548)	(41,548)	(41,548)	(41,548)	(41,548)	(41,548)
USD					
$ (7,154,940)					

#DIV/0!

1	2	3	4	5	6
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

1	2	3	4	5	6
-	-	8.00	7.96	7.92	7.88
-	-	5.20	5.17	5.15	5.12
-	-	4.42	4.40	4.38	4.35
-	-	38,719	38,526	38,333	38,141
-	-	-	-	-	-

1	2	3	4	5	6
-	-	89,441,352	88,994,145	88,549,175	88,106,429
-	-	8,131,032	8,090,377	8,049,925	8,009,675
-	-	418,167	416,077	413,996	411,926
-	-	689,512	686,064	682,634	679,220
-	-	98,680,063	98,186,663	97,695,729	97,207,251
100,800,000	100,800,000	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
-	-	-	-	-	-
100,810,000	100,810,000	10,000	10,000	10,000	10,000
-	-	47,624,616	47,386,493	47,149,560	46,913,813
-	-	-	-	-	-
-	-	4,181,674	4,160,765	4,139,961	4,119,262
-	-	51,806,290	51,547,258	51,289,522	51,033,074
100,810,000	100,810,000	51,816,290	51,557,258	51,299,522	51,043,074
(100,810,000)	(100,810,000)	46,863,773	46,629,404	46,396,207	46,164,176

4,800,476	4,800,476	2,467,442	2,455,108	2,442,834	2,430,623
(4,800,476)	(4,800,476)	2,231,608	2,220,448	2,209,343	2,198,294
USD					
$ (2,379,273)					
0.135					

1	2	3	4	5	6
-	-	125,217,893	124,591,803	123,968,844	123,349,000
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
-	(840,000)	124,377,893	123,751,803	123,128,844	122,509,000
107,654,400	107,654,400	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
-	-	-	-	-	-
107,664,400	107,664,400	10,000	10,000	10,000	10,000
-	-	48,636,639	48,393,456	48,151,489	47,910,731
-	-	-	-	-	-
-	-	-	-	-	-
-	-	48,636,639	48,393,456	48,151,489	47,910,731
107,664,400	107,664,400	48,646,639	48,403,456	48,161,489	47,920,731
(107,664,400)	(108,504,400)	75,731,254	75,348,347	74,967,356	74,588,269
5,126,876	5,126,876	2,316,507	2,304,926	2,293,404	2,281,940
(5,126,876)	(5,166,876)	3,606,250	3,588,017	3,569,874	3,551,822
USD					
$ 6,709,152					
0.12					

1	2	3	4	5	6
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

1	2	3	4	5	6
12.00	11.94	11.88	11.82	11.76	11.70
3.60	3.58	3.56	3.55	3.53	3.51
3.53	3.51	3.49	3.48	3.46	3.44
30,905	30,751	30,597	30,444	30,292	30,140
-	-	-	-	-	-

1	2	3	4	5	6
71,391,197	71,034,241	70,679,070	70,325,674	69,974,046	69,624,176
6,490,109	6,457,658	6,425,370	6,393,243	6,361,277	6,329,471
454,308	452,036	449,776	447,527	445,289	443,063
550,361	547,609	544,871	542,147	539,436	536,739
78,885,974	78,491,545	78,099,087	77,708,591	77,320,048	76,933,448
-	-	-	-	-	-
25,000	25,000	25,000	25,000	25,000	25,000
-	-	-	-	420,000	-
25,000	25,000	25,000	25,000	445,000	25,000
25,960,435	25,830,633	25,701,480	25,572,972	25,445,108	25,317,882
-	-	-	-	-	-
4,543,076	4,520,361	4,497,759	4,475,270	4,452,894	4,430,629
30,503,511	30,350,994	30,199,239	30,048,243	29,898,001	29,748,511
30,528,511	30,375,994	30,224,239	30,073,243	30,343,001	29,773,511
48,357,463	48,115,551	47,874,848	47,635,349	46,977,047	47,159,937
1,453,739	1,446,476	1,439,249	1,432,059	1,444,905	1,417,786
2,302,736	2,291,217	2,279,755	2,268,350	2,237,002	2,245,711
USD					
$ (9,665,946)					

0.173						

	1	2	3	4	5	6
	99,947,676	99,447,937	98,950,697	98,455,944	97,963,664	97,473,846
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
	99,947,676	98,607,937	98,110,697	97,615,944	97,123,664	96,633,846
	-	-	-	-	-	-
	25,000	25,000	25,000	25,000	25,000	25,000
	-	-	-	-	381,276	-
	25,000	25,000	25,000	25,000	406,276	25,000
	26,512,094	26,379,534	26,247,636	26,116,398	25,985,816	25,855,887
	-	-	-	-	-	-
	-	-	-	-	-	-
	26,512,094	26,379,534	26,247,636	26,116,398	25,985,816	25,855,887
	26,537,094	26,404,534	26,272,636	26,141,398	26,392,092	25,880,887
	73,410,581	72,203,403	71,838,061	71,474,546	70,731,572	70,752,959
	1,263,671	1,257,359	1,251,078	1,244,828	1,256,766	1,232,423
	3,495,742	3,438,257	3,420,860	3,403,550	3,368,170	3,369,189
USD						
$	18,604					
	0.15					

Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
(6,452,319)	(2,379,273)	(9,665,946)
-5.8%	11.9%	7.5%
#DIV/0!	0.13	0.17
-	174,940	188,368
-	-	-
#DIV/0!	258,699	258,699
#DIV/0!	(4,901,663)	(12,404,891)
#DIV/0!	18.95	47.95

nic Summary Tables

Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
(7,154,940)	6,709,152	18,604
-6.7%	18.3%	12.0%
#DIV/0!	0.12	0.15
-	217,593	224,056
-	-	-
#DIV/0!	258,699	258,699
#DIV/0!	687,402	(6,566,385.54)
#DIV/0!	(2.66)	25.38

NSITIVITY ANALYSES

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
1,695,791	20.5%	0.10	-	6,132,073	30.4%
595,791	16.6%	0.11	-	5,133,493	25.0%
(1,384,209)	12.0%	0.12	-	3,336,049	18.7%
(4,816,209)	7.1%	0.13	-	220,479	12.3%
(10,822,209)	2.4%	0.16	-	(5,231,768)	6.4%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,010,120	**22.2%**	**0.10**	**-**	**6,372,501**	**33.1%**
1,961,381	22.1%	0.10	-	6,316,465	33.0%
1,912,643	22.0%	0.10	-	6,260,429	32.9%
1,815,165	21.7%	0.10	-	6,148,356	32.6%
1,620,210	21.0%	0.10	-	5,924,211	32.2%
1,425,256	20.4%	0.10	-	5,700,066	31.7%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,181,412	22.8%	0.10	-	6,567,510	33.5%
2,135,040	22.7%	0.10	-	6,504,099	33.5%
1,404,436	21.3%	0.10	-	5,438,994	33.0%
(545,107)	#NUM!	0.11	-	2,533,373	4.8%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%

5,203,963	33.1%	0.08	-	12,985,201	53.6%
4,201,239	29.7%	0.09	-	10,852,125	47.0%
3,198,515	26.3%	0.09	-	8,719,049	40.3%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
1,193,067	19.3%	0.10	-	4,452,896	26.8%
190,343	15.7%	0.11	-	2,319,820	19.9%
(812,381)	12.0%	0.11	-	186,744	12.7%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,170,723	22.7%	0.10	-	6,552,246	33.4%
2,145,655	22.6%	0.10	-	6,518,519	33.3%
2,120,587	22.5%	0.10	-	6,484,793	33.2%
2,095,519	22.5%	0.10	-	6,451,066	33.1%
2,070,451	22.4%	0.10	-	6,417,339	33.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,095,519	22.5%	0.10	-	6,372,665	32.9%
1,995,247	22.1%	0.10	-	6,159,357	32.2%
1,894,974	21.8%	0.10	-	5,946,050	31.5%
1,794,702	21.4%	0.10	-	5,732,742	30.8%
1,694,429	21.1%	0.10	-	5,519,435	30.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
1,210,370	18.7%	0.10	-	5,283,240	26.2%
352,416	16.0%	0.11	-	4,117,970	21.8%
(394,171)	14.0%	0.11	-	3,076,262	18.8%
(1,043,923)	12.3%	0.12	-	2,144,865	16.5%
(1,609,476)	11.0%	0.13	-	1,311,946	14.7%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
(1,743,482)	8.4%	0.10	-	(679,498)	9.6%
226,155	15.8%	0.10	-	2,953,237	21.9%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
4,165,428	29.6%	0.10	-	10,218,708	45.0%
6,135,064	36.3%	0.10	-	13,851,444	56.4%
8,104,701	42.9%	0.10	-	17,484,179	67.7%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
(332,084)	13.8%	0.11	-	2,483,410	20.4%
510,541	16.9%	0.11	-	3,850,931	24.8%
1,353,166	19.9%	0.10	-	5,218,452	29.2%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,617,104	24.3%	0.10	-	7,269,733	35.7%
3,038,417	25.7%	0.10	-	7,953,494	37.9%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
(191,647)	14.3%	0.11	-	2,711,330	21.1%
604,166	17.2%	0.11	-	4,002,878	25.3%
1,399,979	20.0%	0.10	-	5,294,425	29.4%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,593,698	24.2%	0.10	-	7,231,746	35.6%
2,832,442	25.0%	0.10	-	7,619,211	36.8%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,013,937	22.3%	0.10	-	6,255,329	33.0%
1,839,640	21.8%	0.10	-	5,939,449	32.5%
1,672,520	21.3%	0.10	-	5,637,553	32.0%
1,512,216	20.8%	0.10	-	5,348,905	31.4%
1,358,389	20.4%	0.10	-	5,072,813	30.9%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
4,740,321	22.8%	0.09	-	6,585,973	33.5%
3,560,812	22.8%	0.09	-	6,585,973	33.5%
2,606,017	22.8%	0.10	-	6,585,973	33.5%

2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
1,173,514	22.8%	0.10	-	6,585,973	33.5%
628,319	22.8%	0.11	-	6,585,973	33.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	12,403,365	33.5%
2,195,791	22.8%	0.10	-	10,000,671	33.5%
2,195,791	22.8%	0.10	-	8,104,100	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,195,791	22.8%	0.10	-	5,354,530	33.5%
2,195,791	22.8%	0.10	-	4,824,701	33.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,074,679	22.5%	0.10	-	6,309,464	32.9%
1,955,942	22.1%	0.10	-	6,038,376	32.2%
1,839,510	21.8%	0.10	-	5,772,553	31.5%
1,725,318	21.4%	0.10	-	5,511,842	30.8%
1,613,300	21.1%	0.10	-	5,256,096	30.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(6,452,319)	-5.8%	#DIV/0!	#DIV/0!	(7,154,940)	-6.7%
(1,239,602)	**11.4%**	**0.13**	**53,140**	**6,178,712**	**25.2%**
(1,239,602)	11.4%	0.13	53,140	6,178,712	25.2%
(1,239,602)	11.4%	0.13	53,140	6,178,712	25.2%
(1,239,602)	11.4%	0.13	53,140	6,178,712	25.2%
(1,239,602)	11.4%	0.13	53,140	6,178,712	25.2%
(1,239,602)	11.4%	0.13	53,140	6,178,712	25.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(6,452,319)	-5.8%	#DIV/0!	#DIV/0!	(7,154,940)	-6.7%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,239,143)	11.4%	0.13	53,140	5,652,803	24.2%
(1,240,061)	11.4%	0.13	53,140	5,651,716	24.2%
(1,240,979)	11.4%	0.13	53,140	5,650,630	24.2%
(1,241,897)	11.4%	0.13	53,140	5,649,544	24.2%
(1,242,815)	11.4%	0.13	53,140	5,648,458	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR

(6,452,319)	-5.8%	#DIV/0!	#DIV/0!	(7,154,940)	-6.7%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,254,089)	11.4%	0.13	53,140	5,633,954	24.2%
(1,300,097)	11.2%	0.13	53,140	5,573,999	24.1%
(1,829,557)	8.6%	0.13	53,140	4,854,804	23.5%
(2,940,265)	#NUM!	0.14	53,140	3,319,533	22.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(6,452,319)	-5.8%	#DIV/0!	#DIV/0!	(7,154,940)	-6.7%
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%
1,739,998	**19.8%**	**0.11**	**53,140**	**10,166,981**	**32.9%**
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(6,452,319)	-5.8%	#DIV/0!	#DIV/0!	(7,154,940)	-6.7%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(6,452,319)	-5.8%	#DIV/0!	#DIV/0!	(7,154,940)	-6.7%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(2,081,496)	8.4%	0.13	53,140	4,431,549	22.3%
(2,998,609)	3.7%	0.14	53,140	3,093,565	19.9%
(3,997,555)	-7.2%	0.14	53,140	1,626,717	16.8%
(5,087,284)	#NUM!	0.15	53,140	16,145	12.1%
(6,277,822)	#NUM!	0.16	53,140	(1,754,862)	#NUM!

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(6,452,319)	-5.8%	#DIV/0!	#DIV/0!	(7,154,940)	-6.7%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%

(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(6,452,319)	-5.8%	#DIV/0!	#DIV/0!	(7,154,940)	-6.7%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,948,326)	9.8%	0.13	29,192	4,205,753	19.8%
(2,567,054)	8.6%	0.14	2,860	2,908,289	16.9%
(3,106,382)	7.6%	0.15	(26,021)	1,745,166	14.7%
(3,576,718)	6.8%	0.16	(57,612)	701,797	13.1%
(3,987,119)	6.0%	0.17	(92,071)	(234,852)	11.7%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(6,452,319)	-5.8%	#DIV/0!	#DIV/0!	(7,154,940)	-6.7%
(4,473,039)	1.2%	0.13	53,140	(281,809)	11.3%
(2,855,632)	6.5%	0.13	53,140	2,686,040	18.0%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
379,182	16.1%	0.13	53,140	8,621,738	30.1%
1,996,589	20.5%	0.13	53,140	11,589,587	35.7%
3,613,997	24.7%	0.13	53,140	14,557,436	41.1%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(6,452,319)	-5.8%	#DIV/0!	#DIV/0!	(7,154,940)	-6.7%
(1,245,076)	11.4%	0.13	53,140	5,653,889	24.2%
(1,241,651)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,231,374)	11.4%	0.13	53,140	5,653,889	24.2%
(1,224,523)	11.5%	0.13	53,140	5,653,889	24.2%
(1,210,821)	11.5%	0.13	53,140	5,653,889	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(6,452,319)	-5.8%	#DIV/0!	#DIV/0!	(7,154,940)	-6.7%
(3,078,494)	5.8%	0.15	53,140	1,133,126	14.6%
(2,465,071)	7.7%	0.14	53,140	2,640,047	17.9%
(1,851,648)	9.6%	0.13	53,140	4,146,968	21.1%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(931,514)	12.3%	0.13	53,140	6,407,349	25.7%
(624,802)	13.2%	0.12	53,140	7,160,810	27.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(6,452,319)	-5.8%	#DIV/0!	#DIV/0!	(7,154,940)	-6.7%
(2,461,941)	7.7%	0.14	53,140	2,647,735	17.9%
(1,929,891)	9.3%	0.13	53,140	3,954,758	20.7%

(1,663,865)	10.1%	0.13	53,140	4,608,270	22.1%
(1,397,840)	10.9%	0.13	53,140	5,261,782	23.4%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,185,020)	11.6%	0.13	53,140	5,784,591	24.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(6,452,319)	-5.8%	#DIV/0!	#DIV/0!	(7,154,940)	-6.7%
(718,242)	13.1%	0.12	37,848	7,087,220	26.0%
(988,596)	12.2%	0.13	45,710	6,339,893	25.1%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,355,876)	11.0%	0.13	56,695	5,332,000	23.8%
(1,469,052)	10.6%	0.13	60,146	5,023,262	23.3%
(1,682,806)	9.8%	0.13	66,740	4,442,684	22.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(6,452,319)	-5.8%	#DIV/0!	#DIV/0!	(7,154,940)	-6.7%
642,521	11.4%	0.12	54,802	5,653,889	24.2%
(236,782)	11.4%	0.12	54,354	5,653,889	24.2%
(939,409)	11.4%	0.13	53,612	5,653,889	24.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,972,751)	11.4%	0.13	51,363	5,653,889	24.2%
(2,357,040)	11.4%	0.14	49,914	5,653,889	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(6,452,319)	-5.8%	#DIV/0!	#DIV/0!	(7,154,940)	-6.7%
(1,238,225)	11.4%	0.13	53,140	12,331,284	24.2%
(1,238,225)	11.4%	0.13	53,140	9,573,138	24.2%
(1,238,225)	11.4%	0.13	53,140	7,396,060	24.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,238,225)	11.4%	0.13	53,140	4,241,775	24.2%
(1,238,225)	11.4%	0.13	53,140	3,634,809	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(6,452,319)	-5.8%	#DIV/0!	#DIV/0!	(7,154,940)	-6.7%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,225,785)	11.4%	0.13	53,140	5,597,802	24.2%
(1,213,589)	11.4%	0.13	53,140	5,542,815	24.2%
(1,201,629)	11.4%	0.12	53,140	5,488,896	24.2%
(1,189,900)	11.4%	0.12	53,140	5,436,014	24.2%
(1,178,394)	11.4%	0.12	53,140	5,384,139	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,380,308)	11.9%	0.13	258,699	6,707,959	18.3%
(2,381,343)	11.9%	0.13	258,699	6,706,766	18.3%
(2,382,377)	11.9%	0.13	258,699	6,705,574	18.3%
(2,383,412)	11.9%	0.13	258,699	6,704,381	18.3%
(2,384,446)	11.9%	0.13	258,699	6,703,188	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(409,804)	14.5%	0.12	258,699	9,458,291	20.7%
(1,460,491)	13.1%	0.13	258,699	7,991,660	19.4%
(1,651,525)	12.9%	0.13	258,699	7,725,000	19.2%
(2,606,695)	**11.6%**	**0.14**	**258,699**	**6,391,699**	**18.1%**
(3,561,865)	10.2%	0.14	258,699	5,058,399	16.9%
(4,517,035)	8.8%	0.15	258,699	3,725,098	15.6%
(5,472,205)	7.3%	0.15	258,699	2,391,798	14.4%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%

(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(3,803,602)	10.3%	0.15	258,699	4,203,424	15.7%
(5,042,696)	9.0%	0.16	258,699	1,964,610	13.6%
(6,120,719)	7.9%	0.18	258,699	(35,897)	12.0%
(7,058,684)	6.9%	0.20	258,699	(1,823,637)	10.6%
(7,874,860)	6.0%	0.22	258,699	(3,421,415)	9.4%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(5,881,563)	6.6%	0.13	258,699	7,290	12.0%
(4,130,418)	9.4%	0.13	258,699	3,358,221	15.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(628,129)	14.2%	0.14	258,699	10,060,083	21.2%
1,123,016	16.4%	0.14	258,699	13,411,014	23.8%
2,874,161	18.5%	0.14	258,699	16,761,945	26.4%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,416,361)	11.8%	0.13	258,699	6,709,152	18.3%

(2,397,817)	11.8%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,342,186)	11.9%	0.13	258,699	6,709,152	18.3%
(2,305,099)	12.0%	0.13	258,699	6,709,152	18.3%
(2,230,925)	12.1%	0.13	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(4,706,562)	8.5%	0.16	258,699	1,979,824	14.0%
(3,930,799)	9.7%	0.15	258,699	3,556,266	15.5%
(3,155,036)	10.8%	0.14	258,699	5,132,709	16.9%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(1,603,511)	12.9%	0.13	258,699	8,285,595	19.7%
(827,748)	13.9%	0.13	258,699	9,862,037	21.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(4,752,195)	8.4%	0.16	258,699	1,887,092	13.9%
(4,158,964)	9.3%	0.15	258,699	3,092,607	15.1%
(3,565,734)	10.2%	0.14	258,699	4,298,122	16.2%
(2,972,504)	11.0%	0.14	258,699	5,503,637	17.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(1,786,043)	12.7%	0.13	258,699	7,914,667	19.4%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,121,552)	12.3%	0.13	258,699	7,291,260	18.7%
(2,251,703)	12.1%	0.13	258,699	6,997,102	18.5%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,626,909)	11.5%	0.14	258,699	6,151,279	17.9%
(3,093,757)	10.7%	0.14	258,699	5,103,653	17.1%
(3,525,550)	10.0%	0.14	258,699	4,139,775	16.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
1,919,848	11.9%	0.11	258,699	6,709,152	18.3%
(119,049)	11.9%	0.12	258,699	6,709,152	18.3%
(1,713,464)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(3,974,584)	11.9%	0.15	258,699	6,709,152	18.3%
(4,778,910)	11.9%	0.16	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	19,880,374	18.3%
(2,379,273)	11.9%	0.13	258,699	14,336,854	18.3%
(2,379,273)	11.9%	0.13	258,699	10,055,350	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	4,064,771	18.3%
(2,379,273)	11.9%	0.13	258,699	2,951,042	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,354,350)	11.9%	0.13	258,699	6,642,607	18.3%
(2,329,915)	11.9%	0.13	258,699	6,577,366	18.3%
(2,305,955)	11.9%	0.13	258,699	6,513,392	18.3%
(2,282,455)	11.9%	0.13	258,699	6,450,649	18.3%
(2,259,403)	11.9%	0.13	258,699	6,389,101	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(12,065,946)	6.3%	0.19	258,699	(2,544,596)	10.6%
(17,345,946)	4.3%	0.21	258,699	(8,183,636)	8.1%
(26,849,946)	1.7%	0.26	258,699	(18,333,908)	4.9%
(43,323,546)	-1.2%	0.35	258,699	(35,927,712)	1.5%
(72,152,346)	-4.3%	0.50	258,699	(66,716,871)	-2.1%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,667,803)	7.5%	0.17	258,699	16,470	12.0%
(9,669,659)	7.5%	0.17	258,699	14,335	12.0%
(9,671,516)	7.5%	0.17	258,699	12,200	12.0%
(9,673,373)	7.5%	0.17	258,699	10,065	12.0%
(9,675,229)	7.5%	0.17	258,699	7,931	12.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,694,704)	7.4%	0.17	258,699	(18,321)	12.0%
(9,787,449)	7.3%	0.17	258,699	(145,143)	11.9%
(11,248,656)	3.2%	0.18	258,699	(2,275,354)	10.4%

(15,147,743)	#NUM!	0.20	258,699	(8,086,596)	#NUM!

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(8,088,927)	8.8%	0.16	258,699	2,123,726	13.3%
(8,843,153)	8.1%	0.17	258,699	1,116,929	12.7%
(8,980,285)	8.0%	0.17	258,699	933,875	12.6%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(10,351,606)	6.9%	0.18	258,699	(896,666)	11.5%
(11,037,267)	6.3%	0.18	258,699	(1,811,936)	10.9%
(11,722,928)	5.7%	0.18	258,699	(2,727,206)	10.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(10,114,226)	7.0%	0.18	258,699	(643,548)	11.6%
(10,605,119)	6.4%	0.18	258,699	(1,373,756)	11.1%
(11,143,585)	5.7%	0.18	258,699	(2,180,342)	10.6%
(11,735,211)	4.9%	0.18	258,699	(3,072,706)	10.0%
(12,386,284)	3.8%	0.19	258,699	(4,061,469)	9.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%

(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(11,605,378)	6.5%	0.19	258,699	(2,987,982)	10.3%
(13,293,463)	5.7%	0.22	258,699	(5,675,593)	9.0%
(14,761,925)	4.9%	0.24	258,699	(8,076,732)	7.9%
(16,039,413)	4.3%	0.28	258,699	(10,222,100)	7.0%
(17,150,840)	3.7%	0.32	258,699	(12,139,108)	6.1%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(13,437,079)	4.2%	0.17	258,699	(6,882,331)	7.7%
(11,551,512)	5.9%	0.17	258,699	(3,431,863)	9.9%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(7,780,379)	9.0%	0.17	258,699	3,469,072	14.1%
(5,894,813)	10.5%	0.18	258,699	6,919,540	16.1%
(4,009,246)	12.0%	0.18	258,699	10,370,008	18.1%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,705,880)	7.4%	0.17	258,699	18,604	12.0%
(9,685,913)	7.4%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,626,012)	7.5%	0.17	258,699	18,604	12.0%
(9,586,078)	7.5%	0.17	258,699	18,604	12.0%
(9,506,210)	7.6%	0.17	258,699	18,604	12.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(14,346,772)	3.4%	0.24	258,699	(8,432,054)	6.7%
(12,006,359)	5.5%	0.20	258,699	(4,206,725)	9.4%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(7,325,533)	9.4%	0.15	258,699	4,243,934	14.5%
(4,985,119)	11.2%	0.14	258,699	8,469,263	17.0%
(304,293)	14.8%	0.12	258,699	16,919,921	21.8%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(12,245,177)	5.3%	0.20	258,699	(4,637,881)	9.1%
(11,528,724)	5.9%	0.19	258,699	(3,344,413)	9.9%
(10,812,271)	6.5%	0.18	258,699	(2,050,945)	10.7%
(10,095,818)	7.1%	0.18	258,699	(757,477)	11.5%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,522,655)	7.6%	0.17	258,699	277,298	12.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,287,384)	7.9%	0.17	258,699	786,768	12.5%
(9,478,720)	7.7%	0.17	258,699	398,208	12.2%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(10,028,490)	7.1%	0.18	258,699	(714,692)	11.6%
(10,708,735)	6.3%	0.18	258,699	(2,083,985)	10.7%
(11,334,111)	5.5%	0.19	258,699	(3,334,715)	9.8%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(4,236,716)	7.5%	0.14	258,699	18,604	12.0%
(6,775,288)	7.5%	0.15	258,699	18,604	12.0%
(8,802,848)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(11,794,508)	7.5%	0.19	258,699	18,604	12.0%
(12,916,174)	7.5%	0.21	258,699	18,604	12.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	14,404,427	12.0%
(9,665,946)	7.5%	0.17	258,699	8,397,784	12.0%
(9,665,946)	7.5%	0.17	258,699	3,718,988	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,665,946)	7.5%	0.17	258,699	(2,950,722)	12.0%
(9,665,946)	7.5%	0.17	258,699	(4,218,755)	12.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,568,846)	7.5%	0.17	258,699	18,209	12.0%
(9,473,650)	7.5%	0.17	258,699	17,821	12.0%
(9,380,302)	7.5%	0.17	258,699	17,441	12.0%
(9,288,749)	7.5%	0.17	258,699	17,068	12.0%
(9,198,940)	7.5%	0.16	258,699	16,702	12.0%

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam

#DIV/0!	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(2,607,982)	**(3,784,657)**	**(11,290,754)**		**416,747**	**884,909**
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
#DIV/0!	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(6,026,689)	(7,207,929)	(14,711,157)		(4,571,520)	(4,218,674)
(4,923,693)	(6,104,932)	(13,608,160)		(2,225,136)	(1,872,290)
(4,723,148)	(5,904,387)	(13,407,616)		(1,798,521)	(1,445,675)
(3,720,424)	**(4,901,663)**	**(12,404,891)**		**334,555**	**687,402**
(2,717,700)	(3,898,939)	(11,402,167)		2,467,632	2,820,478
(1,714,976)	(2,896,215)	(10,399,443)		4,600,708	4,953,554
(712,252)	(1,893,491)	(9,396,719)		6,733,784	7,086,630

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
#DIV/0!	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(3,720,424)	**(4,901,663)**	**(12,404,891)**		**334,555**	**687,402**
(3,695,356)	(4,876,595)	(12,379,823)		368,282	721,128
(3,670,288)	(4,851,527)	(12,354,755)		402,009	754,855
(3,645,220)	(4,826,459)	(12,329,687)		435,735	788,582
(3,620,151)	(4,801,391)	(12,304,619)		469,462	822,308
(3,595,083)	(4,776,323)	(12,279,551)		503,189	856,035

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
#DIV/0!	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(2,607,982)	**(3,784,657)**	**(11,290,754)**		**416,747**	**884,909**
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
#DIV/0!	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909
(2,658,317)	**(3,834,992)**	**(11,341,089)**		**416,747**	**884,909**
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
#DIV/0!	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(3,720,424)	**(4,901,663)**	**(12,404,891)**		**334,555**	**687,402**
(3,322,517)	(4,503,757)	(12,006,985)		334,555	687,402
(2,924,611)	(4,105,851)	(11,609,079)		334,555	687,402
(2,526,705)	(3,707,944)	(11,211,172)		334,555	687,402
(2,128,798)	(3,310,038)	(10,813,266)		334,555	687,402
(1,730,892)	(2,912,132)	(10,415,360)		334,555	687,402

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
#DIV/0!	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(2,607,982)	**(3,784,657)**	**(11,290,754)**		**416,747**	**884,909**
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
#DIV/0!	(4,901,663)	(12,404,891)		#DIV/0!	687,402

(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909
(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909
(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909
(2,633,448)	**(3,810,123)**	**(11,316,220)**		**416,747**	**884,909**
(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909
(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909
(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
#DIV/0!	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(3,955,580)	(2,723,196)	(9,190,196)		334,555	687,402
(3,850,640)	(3,689,873)	(10,693,998)		334,555	687,402
(3,720,424)	**(4,901,663)**	**(12,404,891)**		**334,555**	**687,402**
(3,623,565)	(5,917,818)	(13,665,171)		334,555	687,402
(3,576,101)	(6,519,962)	(14,330,071)		334,555	687,402

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
#DIV/0!	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(2,607,982)	(3,784,657)	(11,290,754)		1,814,746	4,851,652
(2,607,982)	(3,784,657)	(11,290,754)		1,814,746	4,851,652
(2,607,982)	**(3,784,657)**	**(11,290,754)**		**1,814,746**	**4,851,652**
(2,607,982)	(3,784,657)	(11,290,754)		1,814,746	4,851,652
(2,607,982)	(3,784,657)	(11,290,754)		1,814,746	4,851,652

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
#DIV/0!	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(2,607,982)	**(3,784,657)**	**(11,290,754)**		**416,747**	**884,909**
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909

7	8	9	10	11	12
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

7	8	9	10	11	12
-	-	-	-	-	-
-	-	-	-	-	-

7	8	9	10	11	12
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
294,000	-	-	-	-	294,000
326,500	32,500	32,500	32,500	32,500	326,500
-	-	-	-	-	-
-	-	-	-	-	-

-	-	-	-	-	-
-	-	-	-	-	-
326,500	32,500	32,500	32,500	32,500	326,500
(326,500)	(32,500)	(32,500)	(32,500)	(32,500)	(326,500)
15,548	1,548	1,548	1,548	1,548	15,548
(15,548)	(1,548)	(1,548)	(1,548)	(1,548)	(15,548)

7	8	9	10	11	12
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
266,893	-	-	-	-	266,893
299,393	32,500	32,500	32,500	32,500	299,393
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
299,393	32,500	32,500	32,500	32,500	299,393
(1,139,393)	(872,500)	(872,500)	(872,500)	(872,500)	(1,139,393)
14,257	1,548	1,548	1,548	1,548	14,257
(54,257)	(41,548)	(41,548)	(41,548)	(41,548)	(54,257)

7	8	9	10	11	12
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

7	8	9	10	11	12
7.84	7.80	7.76	7.72	7.69	7.65
5.10	5.07	5.05	5.02	5.00	4.97
4.33	4.31	4.29	4.27	4.25	4.23
37,951	37,761	37,572	37,384	37,197	37,011
-	-	-	-	-	-

7	8	9	10	11	12
87,665,896	87,227,567	86,791,429	86,357,472	85,925,685	85,496,056
7,969,627	7,929,779	7,890,130	7,850,679	7,811,426	7,772,369
409,867	407,817	405,778	403,749	401,730	399,722
675,824	672,445	669,083	665,738	662,409	659,097
96,721,214	96,237,608	95,756,420	95,277,638	94,801,250	94,327,244
-	-	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
420,000	-	-	-	-	-
430,000	10,000	10,000	10,000	10,000	10,000
46,679,244	46,445,847	46,213,618	45,982,550	45,752,637	45,523,874
-	-	-	-	-	-
4,098,665	4,078,172	4,057,781	4,037,492	4,017,305	3,997,218
50,777,909	50,524,019	50,271,399	50,020,042	49,769,942	49,521,092
51,207,909	50,534,019	50,281,399	50,030,042	49,779,942	49,531,092
45,513,305	45,703,589	45,475,021	45,247,596	45,021,308	44,796,151

2,438,472	2,406,382	2,394,352	2,382,383	2,370,473	2,358,623
2,167,300	2,176,361	2,165,477	2,154,647	2,143,872	2,133,150

7	8	9	10	11	12
122,732,255	122,118,594	121,508,001	120,900,461	120,295,959	119,694,479
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
121,892,255	121,278,594	120,668,001	120,060,461	119,455,959	118,854,479
-	-	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
381,276	-	-	-	-	-
391,276	10,000	10,000	10,000	10,000	10,000
47,671,178	47,432,822	47,195,658	46,959,679	46,724,881	46,491,256
-	-	-	-	-	-
-	-	-	-	-	-
47,671,178	47,432,822	47,195,658	46,959,679	46,724,881	46,491,256
48,062,454	47,442,822	47,205,658	46,969,679	46,734,881	46,501,256
73,829,802	73,835,772	73,462,343	73,090,782	72,721,078	72,353,222
2,288,688	2,259,182	2,247,888	2,236,651	2,225,471	2,214,346
3,515,705	3,515,989	3,498,207	3,480,513	3,462,908	3,445,392

7	8	9	10	11	12
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

7	8	9	10	11	12
11.64	11.59	11.53	11.47	11.41	11.36
3.49	3.48	3.46	3.44	3.42	3.41
3.42	3.41	3.39	3.37	3.36	3.34
29,990	29,840	29,690	29,542	29,394	29,247
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7	8	9	10	11	12
69,276,055	68,929,675	68,585,026	68,242,101	67,900,891	67,561,386
6,297,823	6,266,334	6,235,002	6,203,827	6,172,808	6,141,944
440,848	438,643	436,450	434,268	432,097	429,936
534,055	531,385	528,728	526,085	523,454	520,837
76,548,781	76,166,037	75,785,207	75,406,281	75,029,249	74,654,103
-	-	-	-	-	-
25,000	25,000	25,000	25,000	25,000	25,000
-	-	-	420,000	-	-
25,000	25,000	25,000	445,000	25,000	25,000
25,191,293	25,065,336	24,940,010	24,815,309	24,691,233	24,567,777
-	-	-	-	-	-
4,408,476	4,386,434	4,364,502	4,342,679	4,320,966	4,299,361
29,599,769	29,451,770	29,304,511	29,157,989	29,012,199	28,867,138
29,624,769	29,476,770	29,329,511	29,602,989	29,037,199	28,892,138
46,924,012	46,689,267	46,455,696	45,803,292	45,992,051	45,761,966
1,410,703	1,403,656	1,396,643	1,409,666	1,382,724	1,375,816
2,234,477	2,223,298	2,212,176	2,181,109	2,190,098	2,179,141

7	8	9	10	11	12
96,986,477	96,501,544	96,019,037	95,538,941	95,061,247	94,585,940
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(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
96,146,477	95,661,544	95,179,037	94,698,941	94,221,247	93,745,940
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25,000	25,000	25,000	25,000	25,000	25,000
-	-	-	381,276	-	-
25,000	25,000	25,000	406,276	25,000	25,000
25,726,608	25,597,975	25,469,985	25,342,635	25,215,922	25,089,842
-	-	-	-	-	-
-	-	-	-	-	-
25,726,608	25,597,975	25,469,985	25,342,635	25,215,922	25,089,842
25,751,608	25,622,975	25,494,985	25,748,911	25,240,922	25,114,842
70,394,869	70,038,570	69,684,052	68,950,031	68,980,325	68,631,098
1,226,267	1,220,142	1,214,047	1,226,139	1,201,949	1,195,945
3,352,137	3,335,170	3,318,288	3,283,335	3,284,777	3,268,148

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Econ. LCOE
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NPV		Financial CEA (USD/tCO2 mitigated)		
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines

(6,566,386)		#DIV/0!	18.9	48.0
(6,259,834)		**49.1**	**14.6**	**43.6**
(6,259,834)		49.1	14.6	43.6
(6,259,834)		49.1	14.6	43.6
(6,259,834)		49.1	14.6	43.6
(6,259,834)		49.1	14.6	43.6
(6,259,834)		49.1	14.6	43.6

NPV		Financial CEA (USD/tCO2 mitigated)		
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
(6,566,386)		#DIV/0!	18.9	48.0
(11,472,461)		113.4	27.9	56.9
(9,126,077)		92.7	23.6	52.6
(8,699,462)		88.9	22.8	51.8
(6,566,386)		**70.0**	**18.9**	**48.0**
(4,433,309)		51.1	15.1	44.1
(2,300,233)		32.3	11.2	40.2
(167,157)		13.4	7.3	36.3

NPV		Financial CEA (USD/tCO2 mitigated)		
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
(6,566,386)		#DIV/0!	18.9	48.0
(6,566,386)		**70.0**	**18.9**	**48.0**
(6,532,659)		69.5	18.9	47.9
(6,498,932)		69.1	18.8	47.8
(6,465,206)		68.6	18.7	47.7
(6,431,479)		68.1	18.6	47.6
(6,397,752)		67.7	18.5	47.5

NPV		Financial CEA (USD/tCO2 mitigated)		
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
(6,566,386)		#DIV/0!	18.9	48.0
(6,259,834)		**49.1**	**14.6**	**43.6**
(6,259,834)		49.1	14.6	43.6
(6,259,834)		49.1	14.6	43.6
(6,259,834)		49.1	14.6	43.6
(6,259,834)		49.1	14.6	43.6
(6,259,834)		49.1	14.6	43.6

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		#DIV/0!	18.9	48.0	
(6,259,834)		50.0	14.8	43.8	
(6,259,834)		50.0	14.8	43.8	
(6,259,834)		50.0	14.8	43.8	
(6,259,834)		**50.0**	**14.8**	**43.8**	
(6,259,834)		50.0	14.8	43.8	
(6,259,834)		50.0	14.8	43.8	
(6,259,834)		50.0	14.8	43.8	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		#DIV/0!	18.9	48.0	
(6,566,386)		**70.0**	**18.9**	**48.0**	
(6,566,386)		62.5	17.4	46.4	
(6,566,386)		55.0	15.9	44.9	
(6,566,386)		47.5	14.3	43.3	
(6,566,386)		40.1	12.8	41.8	
(6,566,386)		32.6	11.3	40.3	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		#DIV/0!	18.9	48.0	
(6,259,834)		**49.1**	**14.6**	**43.6**	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		#DIV/0!	18.9	48.0	

(6,259,834)		186.9	17.3	51.5	
(6,259,834)		186.9	17.3	51.5	
(6,259,834)		186.9	17.3	51.5	
(6,259,834)		**186.9**	**17.3**	**51.5**	
(6,259,834)		186.9	17.3	51.5	
(6,259,834)		186.9	17.3	51.5	
(6,259,834)		186.9	17.3	51.5	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		#DIV/0!	18.9	48.0	
(6,566,386)		72.2	10.5	35.5	
(6,566,386)		70.8	14.3	41.3	
(6,566,386)		**70.0**	**18.9**	**48.0**	
(6,566,386)		70.5	22.9	52.8	
(6,566,386)		71.6	25.2	55.4	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		#DIV/0!	18.9	48.0	
(795,615)		49.1	14.6	43.6	
(795,615)		49.1	14.6	43.6	
(795,615)		**49.1**	**14.6**	**43.6**	
(795,615)		49.1	14.6	43.6	
(795,615)		49.1	14.6	43.6	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		#DIV/0!	18.9	48.0	
(6,259,834)		**49.1**	**14.6**	**43.6**	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	

13	14	15	16	17	18
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

13	14	15	16	17	18
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-	-	-	-	-	-

13	14	15	16	17	18
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	294,000	-
32,500	32,500	32,500	32,500	326,500	32,500
-	-	-	-	-	-
-	-	-	-	-	-

-	-	-	-	-	-
-	-	-	-	-	-
32,500	32,500	32,500	32,500	326,500	32,500
(32,500)	(32,500)	(32,500)	(32,500)	(326,500)	(32,500)
1,548	1,548	1,548	1,548	15,548	1,548
(1,548)	(1,548)	(1,548)	(1,548)	(15,548)	(1,548)

13	14	15	16	17	18
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-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	266,893	-
32,500	32,500	32,500	32,500	299,393	32,500
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
32,500	32,500	32,500	32,500	299,393	32,500
(872,500)	(872,500)	(872,500)	(872,500)	(1,139,393)	(872,500)
1,548	1,548	1,548	1,548	14,257	1,548
(41,548)	(41,548)	(41,548)	(41,548)	(54,257)	(41,548)

13	14	15	16	17	18
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

13	14	15	16	17	18
7.61	7.57	7.53	7.50	7.46	7.42
4.95	4.92	4.90	4.87	4.85	4.82
4.20	4.18	4.16	4.14	4.12	4.10
36,826	36,642	36,459	36,277	36,095	35,915
-	-	-	-	-	-

13	14	15	16	17	18
85,068,576	84,643,233	84,220,017	83,798,917	83,379,922	82,963,023
7,733,507	7,694,839	7,656,365	7,618,083	7,579,993	7,542,093
397,723	395,735	393,756	391,787	389,828	387,879
655,801	652,522	649,260	646,013	642,783	639,569
93,855,607	93,386,329	92,919,398	92,454,801	91,992,527	91,532,564
-	-	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
-	420,000	-	-	-	-
10,000	430,000	10,000	10,000	10,000	10,000
45,296,255	45,069,773	44,844,425	44,620,202	44,397,101	44,175,116
-	-	-	-	-	-
3,977,232	3,957,346	3,937,559	3,917,871	3,898,282	3,878,791
49,273,487	49,027,119	48,781,984	48,538,074	48,295,384	48,053,907
49,283,487	49,457,119	48,791,984	48,548,074	48,305,384	48,063,907
44,572,121	43,929,210	44,127,414	43,906,727	43,687,143	43,468,658

2,346,833	2,355,101	2,323,428	2,311,813	2,300,256	2,288,757
2,122,482	2,091,867	2,101,305	2,090,797	2,080,340	2,069,936

13	14	15	16	17	18
119,096,006	118,500,526	117,908,024	117,318,484	116,731,891	116,148,232
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
118,256,006	117,660,526	117,068,024	116,478,484	115,891,891	115,308,232
-	-	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
-	381,276	-	-	-	-
10,000	391,276	10,000	10,000	10,000	10,000
46,258,800	46,027,506	45,797,369	45,568,382	45,340,540	45,113,837
-	-	-	-	-	-
-	-	-	-	-	-
46,258,800	46,027,506	45,797,369	45,568,382	45,340,540	45,113,837
46,268,800	46,418,782	45,807,369	45,578,382	45,350,540	45,123,837
71,987,206	71,241,744	71,260,655	70,900,102	70,541,351	70,184,395
2,203,276	2,210,418	2,181,303	2,170,399	2,159,550	2,148,754
3,427,962	3,392,464	3,393,365	3,376,195	3,359,112	3,342,114

13	14	15	16	17	18
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

13	14	15	16	17	18
11.30	11.24	11.19	11.13	11.08	11.02
3.39	3.37	3.36	3.34	3.32	3.31
3.32	3.31	3.29	3.27	3.26	3.24
29,101	28,956	28,811	28,667	28,523	28,381
-	-	-	-	-	-

13	14	15	16	17	18
67,223,579	66,887,461	66,553,024	66,220,259	65,889,158	65,559,712
6,111,234	6,080,678	6,050,275	6,020,024	5,989,923	5,959,974
427,786	425,647	423,519	421,402	419,295	417,198
518,233	515,642	513,063	510,498	507,946	505,406
74,280,833	73,909,429	73,539,881	73,172,182	72,806,321	72,442,289
-	-	-	-	-	-
25,000	25,000	25,000	25,000	25,000	25,000
-	-	420,000	-	-	-
25,000	25,000	445,000	25,000	25,000	25,000
24,444,938	24,322,713	24,201,100	24,080,094	23,959,694	23,839,895
-	-	-	-	-	-
4,277,864	4,256,475	4,235,192	4,214,016	4,192,946	4,171,982
28,722,802	28,579,188	28,436,292	28,294,111	28,152,640	28,011,877
28,747,802	28,604,188	28,881,292	28,319,111	28,177,640	28,036,877
45,533,031	45,305,241	44,658,589	44,853,071	44,628,681	44,405,413
1,368,943	1,362,104	1,375,300	1,348,529	1,341,792	1,335,089
2,168,240	2,157,392	2,126,599	2,135,861	2,125,175	2,114,543

13	14	15	16	17	18
94,113,011	93,642,446	93,174,233	92,708,362	92,244,821	91,783,596
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
93,273,011	92,802,446	92,334,233	91,868,362	91,404,821	90,943,596
-	-	-	-	-	-
25,000	25,000	25,000	25,000	25,000	25,000
-	-	381,276	-	-	-
25,000	25,000	406,276	25,000	25,000	25,000
24,964,393	24,839,571	24,715,373	24,591,796	24,468,837	24,346,493
-	-	-	-	-	-
-	-	-	-	-	-
24,964,393	24,839,571	24,715,373	24,591,796	24,468,837	24,346,493
24,989,393	24,864,571	25,121,649	24,616,796	24,493,837	24,371,493
68,283,618	67,937,875	67,212,585	67,251,566	66,910,983	66,572,103
1,189,971	1,184,027	1,196,269	1,172,228	1,166,373	1,160,547
3,251,601	3,235,137	3,200,599	3,202,456	3,186,237	3,170,100

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines

#DIV/0!	(2.7)	25.4
(7.7)	**(3.4)**	**24.2**
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
84.1	16.3	44.3
40.9	7.2	35.3
33.1	5.6	33.6
(6.2)	**(2.7)**	**25.4**
(45.4)	(10.9)	17.1
(84.6)	(19.1)	8.9
(123.9)	(27.4)	0.6

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
(6.2)	**(2.7)**	**25.4**
(6.8)	(2.8)	25.3
(7.4)	(2.9)	25.1
(8.0)	(3.0)	25.0
(8.6)	(3.2)	24.9
(9.3)	(3.3)	24.7

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
(7.7)	**(3.4)**	**24.2**
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	**(3.4)**	**24.2**
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
(6.2)	**(2.7)**	**25.4**
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
(7.7)	**(3.4)**	**24.2**
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4

(27.2)	(4.0)	28.5
(27.2)	(4.0)	28.5
(27.2)	(4.0)	28.5
(27.2)	**(4.0)**	**28.5**
(27.2)	(4.0)	28.5
(27.2)	(4.0)	28.5
(27.2)	(4.0)	28.5

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4
(6.2)	**(2.7)**	**25.4**
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
(33.0)	(18.8)	3.1
(33.0)	(18.8)	3.1
(33.0)	**(18.8)**	**3.1**
(33.0)	(18.8)	3.1
(33.0)	(18.8)	3.1

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
(7.7)	**(3.4)**	**24.2**
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2

19	20	21
1.0	1.0	1.0
1.0	1.0	1.0
21.0	21.0	21.0

19	20	21
-	-	-
-	-	-

19	20	21
-	-	-
-	-	-
-	-	-
-	-	-
-	-	-
-	-	(44,100,000)
32,500	32,500	-
-	-	-
32,500	32,500	(44,100,000)
-	-	-
-	-	-

-	-	-
-	-	-
32,500	32,500	(44,100,000)
(32,500)	(32,500)	44,100,000
1,548	1,548	(2,100,000)
(1,548)	(1,548)	2,100,000

19	20	21
-	-	-
-	-	-
-	-	-
-	-	-
(840,000)	(840,000)	-
(840,000)	(840,000)	-
-	-	(47,098,800)
32,500	32,500	-
-	-	-
32,500	32,500	(47,098,800)
-	-	-
-	-	-
-	-	-
-	-	-
32,500	32,500	(47,098,800)
(872,500)	(872,500)	47,098,800
1,548	1,548	(2,242,800)
(41,548)	(41,548)	2,242,800

19	20	21
1.0	1.0	1.0
1.0	1.0	1.0
1.0	1.0	1.0
21.0	21.0	21.0

19	20	21
7.38	7.35	-
4.80	4.78	-
4.08	4.06	-
35,735	35,556	-
-	-	-

19	20	21
82,548,208	82,135,466	-
7,504,383	7,466,861	-
385,940	384,010	-
636,372	633,190	-
91,074,901	90,619,527	-
-	-	(60,480,000)
10,000	10,000	-
-	-	-
10,000	10,000	(60,480,000)
43,954,240	43,734,469	-
-	-	-
3,859,397	3,840,100	-
47,813,637	47,574,569	-
47,823,637	47,584,569	(60,480,000)
43,251,264	43,034,958	60,480,000

2,277,316	2,265,932	(2,880,000)
2,059,584	2,049,284	2,880,000

19	20	21
115,567,491	114,989,653	-
-	-	-
-	-	-
-	-	-
(840,000)	(840,000)	-
114,727,491	114,149,653	-
-	-	(64,592,640)
10,000	10,000	-
-	-	-
10,000	10,000	(64,592,640)
44,888,268	44,663,827	-
-	-	-
-	-	-
44,888,268	44,663,827	-
44,898,268	44,673,827	(64,592,640)
69,829,223	69,475,826	64,592,640
2,138,013	2,127,325	(3,075,840)
3,325,201	3,308,373	3,075,840

19	20	21
1.0	1.0	1.0
1.0	1.0	1.0
1.0	1.0	1.0
21.0	21.0	21.0

19	20	21
10.96	10.91	-
3.29	3.27	-
3.22	3.21	-
28,239	28,098	-
-	-	-

19	20	21
65,231,913	64,905,754	-
5,930,174	5,900,523	-
415,112	413,037	-
502,879	500,364	-
72,080,078	71,719,678	-
-	-	(126,000,000)
25,000	25,000	-
-	420,000	-
25,000	445,000	(126,000,000)
23,720,696	23,602,092	-
-	-	-
4,151,122	4,130,366	-
27,871,817	27,732,458	-
27,896,817	28,177,458	(126,000,000)
44,183,261	43,542,219	126,000,000
1,328,420	1,341,784	(6,000,000)
2,103,965	2,073,439	6,000,000

19	20	21
91,324,678	90,868,055	-
-	-	-
-	-	-
-	-	-
(840,000)	(840,000)	-
90,484,678	90,028,055	-
-	-	(134,568,000)
25,000	25,000	-
-	381,276	-
25,000	406,276	(134,568,000)
24,224,760	24,103,637	-
-	-	-
-	-	-
24,224,760	24,103,637	-
24,249,760	24,509,913	(134,568,000)
66,234,918	65,518,142	134,568,000
1,154,750	1,167,139	(6,408,000)
3,154,044	3,119,912	6,408,000

Table of Parameters

	Units	Option 1: Diesel Generation Plant
Cost Components		
Fixed Costs		
Investment cost, y1	1000 VND	105,000,000
Investment cost, y2	1000 VND	-
Investment cost, y3	1000 VND	-
Life of fixed asset	years	40
Fixed asset residual value	1000 VND	21,000,000
Land rental price	1000 VND/ha	2,000
Land area required	ha	15
Recurring costs	USD	10,000
Recurring cost period	years	5
Recurring cost growth	% per year	0.0%
Variable Costs		
Operations and maintenance	1000 VND per kWh	0.294
Fuel	USD per kWh	0.056
Taxes	% of revenues less O&M	10.0%
O&M cost growth	% per year	0.0%
Fuel cost growth	% per year	0.0%
First year of operation		1
Benefit Components		
Wholesale price of electricity	1000 VND per kWh	2.31
Production tax credit (subsidy)	1000 VND per kWh	0
Income tax credit	% of tax liability	0
Annual environmental externality	1000 VND	-1575000
Carbon credit payments	USD per ton of CO2 avoided	2
Technical Components		
Greenhouse gas emissions	tons of CO2 equivalent per kWh	0.000424
Capacity factor	% of annual capacity	85.0%
Availability factor	% of annual capacity	90.0%
Rated capacity	MW	5
Capacity decline	% decline per year	1.0%
Power type		Base
Economic Components		
Financial discount rate	%	15.0%

Economic discount rate	%	12.0%
Exchange rate	1000 VND per USD	21
Real exchange rate adjustment	%	0.0%
Foreign exchange premium	%	8.5%
Unit Conversions		
kWh per MWh		1000
Days per year		365
Hours per day		24
Pounds per ton		2000

Option 2: Landfill Gas Plant

Preliminary Tables

Table A: Indices	Year	0
Recurring cost growth		1.0
O&M cost growth		1.0
Fuel cost growth		1.0
Exchange rate		21.0

Table B: Production	Year	0
Rated capacity less capacity decline		-
After capacity factor		-
After availability factor		-
Total annual production (MWh)		-
GHG production (tCO2e)		-

Financial Cash Flows

Table 1: Financial Analysis, firm perspective	Year	0
Revenues		
Value of production		
Production tax credit		-
Income tax credit		-
Carbon credit payments		-
Total revenues		
Costs		
Investment cost		
Land rental		32,500
Recurring costs		-
Fixed costs subtotal		32,500
Operations and maintenance		-
Fuel		-

Taxes		-
Variable costs subtotal		-
Total costs		
Net cash flows		
Total costs (USD)		-
Net cash flows (USD)		-
		1000 VND
NPV		
IRR		#NUM!
Discounted MWh		161,579.14
tCO2 generated		166,944
Financial LCOE (cost per kWh)		-

Economic Resource Flows

Table 2: Economic Analysis, economy perspective	Conversion factor	Year	0
Benefits			
Value of production	1.40		-
Production tax credit	0.00		-
Income tax credit	0.00		-
Carbon credit payments	0.00		-
Environmental externality	1.00		-
Total benefits			-
Costs			
Investment cost	1.07		-
Land rental	1.00		32,500
Recurring costs	0.91		-
Fixed costs subtotal			32,500
Operations and maintenance	1.02		-
Fuel	1.61		-
Taxes	0.00		-
Variable costs subtotal			-
Total costs			32,500
Net cash flows			(32,500)
Total costs (USD)			1,548
Net cash flows (USD)			(1,548)
			1000 VND
NPV			(1,668,248)

IRR	9.2%
Discounted MWh	192,717
tCO2 generated	166,944
Economic LCOE (cost per kWh)	(0.02)

Option 3: Hydro-dam

Preliminary Tables

Table A: Indices	Year	0
Recurring cost growth		1.0
O&M cost growth		1.0
Fuel cost growth		1.0
Exchange rate		21.0

Table B: Production	Year	0
Rated capacity less capacity decline		-
After capacity factor		-
After availability factor		-
Total annual production (MWh)		-
GHG production (tCO2e)		-

Financial Cash Flows

Table 1: Financial Analysis, firm perspective	Year	0
Revenues		
Value of production		-
Production tax credit		-
Income tax credit		-
Carbon credit payments		-
Total revenues		-
Costs		
Investment cost		100,800,000
Land rental		10,000
Recurring costs		-
Fixed costs subtotal		100,810,000
Operations and maintenance		-
Fuel		-
Taxes		-
Variable costs subtotal		-
Total costs		100,810,000
Net cash flows		(100,810,000)

Total costs (USD)			4,800,476
Net cash flows (USD)			(4,800,476)
			1000 VND
NPV			(49,964,743.05)
IRR			11.9%
Discounted MWh			174,939.55
tCO2 generated			-
Financial LCOE (cost per kWh)			2.83

Economic Resource Flows

Table 2: Economic Analysis, economy perspective	Conversion factor	Year	0
Benefits			
Value of production	1.40		-
Production tax credit	0.00		-
Income tax credit	0.00		-
Carbon credit payments	0.00		-
Environmental externality	1.00		-
Total benefits			-
Costs			
Investment cost	1.07		107,654,400
Land rental	1.00		10,000
Recurring costs	0.91		-
Fixed costs subtotal			107,664,400
Operations and maintenance	1.02		-
Fuel	1.61		-
Taxes	0.00		-
Variable costs subtotal			-
Total costs			107,664,400
Net cash flows			(107,664,400)
Total costs (USD)			5,126,876
Net cash flows (USD)			(5,126,876)
			1000 VND
NPV			140,892,191
IRR			18.3%
Discounted MWh			217,593
tCO2 generated			-
Economic LCOE (cost per kWh)			2.56

Option 4: Wind Turbines

Preliminary Tables

Table A: Indices	Year	0
Recurring cost growth		1.0
O&M cost growth		1.0
Fuel cost growth		1.0
Exchange rate		21.0

Table B: Production	Year	0
Rated capacity less capacity decline		-
After capacity factor		-
After availability factor		-
Total annual production (MWh)		-
GHG production (tCO2e)		-

Financial Cash Flows

Table 1: Financial Analysis, firm perspective	Year	0
Revenues		
Value of production		-
Production tax credit		-
Income tax credit		-
Carbon credit payments		-
Total revenues		-
Costs		
Investment cost		504,000,000
Land rental		25,000
Recurring costs		-
Fixed costs subtotal		504,025,000
Operations and maintenance		-
Fuel		-
Taxes		-
Variable costs subtotal		-
Total costs		504,025,000
Net cash flows		(504,025,000)
Total costs (USD)		24,001,190
Net cash flows (USD)		(24,001,190)
		1000 VND
NPV		#############

IRR			7.5%
Discounted MWh			188,368.29
tCO2 generated			-
Financial LCOE (cost per kWh)			3.63

Economic Resource Flows

Table 2: Economic Analysis, economy perspective	Conversion factor	Year	0
Benefits			
Value of production	1.40		-
Production tax credit	0.00		-
Income tax credit	0.00		-
Carbon credit payments	0.00		-
Environmental externality	1.00		-
Total benefits			-
Costs			
Investment cost	1.07		538,272,000
Land rental	1.00		25,000
Recurring costs	0.91		-
Fixed costs subtotal			538,297,000
Operations and maintenance	1.02		-
Fuel	1.61		-
Taxes	0.00		-
Variable costs subtotal			-
Total costs			538,297,000
Net cash flows			(538,297,000)
Total costs (USD)			25,633,190
Net cash flows (USD)			(25,633,190)
			1000 VND
NPV			390,691
IRR			12.0%
Discounted MWh			224,056
tCO2 generated			-
Economic LCOE (cost per kWh)			3.21

Financi

	Option 1: Diesel Generation Plant
FNPV (USD)	2,195,791
IRR	22.8%
Financial LCOE (USD per kWh)	0.10
Discounted MWh generated	198,953
tCO2 generated	258,699
tCO2 mitgated (relative to Option 1)	-
Incremental FNPV (USD)	
USD/tCO2 mitigated	

	Econon
	Option 1: Diesel Generation Plant
ENPV (USD)	6,585,973
EIRR	33.5%
Economic LCOE (USD per kWh)	0.12
Discounted MWh generated	235,892
tCO2 generated	258,699
tCO2 mitgated	-
Incremental ENPV (USD)	
USD/tCO2 mitigated	

SEI

Option 1: Diesel Generation Plant

Total Investment cost
105,000,000
115,500,000
138,600,000
180,180,000
252,252,000
378,378,000

Recurring costs
210,000
262,500
315,000
420,000
630,000
840,000

Recurring cost growth
-
10%
20%
40%
50%

Operations and maintenance
0.21
0.24
0.26
0.29
0.32
0.37
0.44

Fuel cost

0.039
0.045
0.050
0.056
0.062
0.067
0.073

O&M cost growth
-
1%
2%
3%
4%
5%

Fuel cost growth
-
1%
2%
3%
4%
5%

First year of operation
1
2
3
4
5
6

Wholesale price of electricity
1.85
2.08
2.31
2.54
2.77
3.00

Carbon credit payments
1.50
1.75
2.00
2.50
3.00
4.00

Capacity factor
55%
65%
75%
85%
90%
95%

Availability factor
60%
70%
80%
90%
95%
98%

Capacity decline
1.0%
1.5%
2.0%
2.5%
3.0%
3.5%

Financial discount rate
10.0%
12.0%
14.0%

15.0%
18.0%
20.0%

Economic discount rate
6.0%
8.0%
10.0%
12.0%
14.0%
15.0%

Real exchange rate depreciation
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%

Option 2: Landfill Gas Plant

Total Investment cost
147,000,000
161,700,000
176,400,000
191,100,000
205,800,000
220,500,000

Recurring costs (USD)
14,000
15,400
16,800
18,200
19,600
21,000

Recurring cost growth
-
10%
20%
40%
50%

Operations and maintenance
1.37
1.57
1.61
1.79
1.96
2.14
2.32

Fuel cost
-
-
-
-
-
-
-

O&M cost growth
0.0%
1%
2%
3%
4%
5%

Fuel cost growth
0.0%
1%
2%
3%
4%

5%

First year of operation
2
3
4
5
6
7

Wholesale price of electricity
1.85
2.08
2.31
2.54
2.77
3.00

Carbon credit payments
1.50
1.75
2.00
2.50
3.00
4.00

Capacity factor
55%
65%
75%
85%
90%
95%

Availability factor
75%
85%

90%
95%
98%
99%

Capacity decline
2.0%
3.0%
4.0%
4.5%
5.0%
6.0%

Financial discount rate
10.0%
12.0%
14.0%
15.0%
18.0%
20.0%

Economic discount rate
6.0%
8.0%
10.0%
12.0%
14.0%
15.0%

Real exchange rate depreciation
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%

Option 3: Hydro-dam

Total Investment cost
302,400,000
332,640,000
362,880,000
393,120,000
423,360,000
453,600,000

Recurring costs (USD)
20,000
22,000
24,000
26,000
28,000
30,000

Recurring cost growth
-
10%
20%
40%
50%

Operations and maintenance
0.97
1.11
1.13
1.26
1.39
1.51
1.64

Fuel cost
-
-
-
-
-

-
-

O&M cost growth
0.0%
1%
2%
3%
4%
5%

Fuel cost growth
0.0%
1%
2%
3%
4%
5%

First year of operation
3
4
5
6
7
8

Wholesale price of electricity
1.85
2.08
2.31
2.54
2.77
3.00

Carbon credit payments
1.50

1.75
2.00
2.50
3.00
4.00

Capacity factor
50%
55%
60%
65%
70%
75%

Availability factor
65%
70%
75%
80%
85%
90%

Capacity decline
0.0%
0.25%
0.5%
1.0%
2.0%
3.0%

Financial discount rate
10.0%
12.0%
14.0%
15.0%
18.0%
20.0%

Economic discount rate
6.0%
8.0%
10.0%
12.0%
14.0%
15.0%

Real exchange rate depreciation
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%

Option 4: Wind Turbines

Total Investment cost
504,000,000
554,400,000
604,800,000
655,200,000
705,600,000
756,000,000

Recurring costs (USD)
20,000
22,000
24,000
26,000
28,000
30,000

Recurring cost growth
-
10%
20%
40%

50%

Operations and maintenance
0.65
0.74
0.76
0.84
0.92
1.01
1.09

Fuel cost
-
-
-
-
-
-
-

O&M cost growth
0.0%
1%
2%
3%
4%
5%

Fuel cost growth
0.0%
1%
2%
3%
4%
5%

First year of operation

1
2
3
4
5
6

Wholesale price of electricity
1.85
2.08
2.31
2.54
2.77
3.00

Carbon credit payments
1.50
1.75
2.00
2.50
3.00
4.00

Capacity factor
20%
25%
30%
35%
40%
50%

Availability factor
80%
85%
90%
95%
98%
99%

Capacity decline
0.0%
0.25%
0.5%
1.0%
2.0%
3.0%

Financial discount rate
10.0%
12.0%
14.0%
15.0%
18.0%
20.0%

Economic discount rate
6.0%
8.0%
10.0%
12.0%
14.0%
15.0%

Real exchange rate depreciation
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%

Incremental Sensitivity Analysis

Recurring cost growth	Base Case
	0%
	1%
	2%
	3%
	4%
	5%

Fuel	Base Case
	0.043
	0.049
	0.050
	0.056
	0.062
	0.067
	0.073

O&M cost growth	Base Case
	0%
	1%
	2%
	3%
	4%
	5%

Fuel cost growth	Base Case
	0%
	1%
	2%
	3%
	4%
	5%

Wholesale price of electricity	Base Case
	1.78
	2.03
	2.08
	2.31
	2.54
	2.77
	3.00

Production tax credit (subsidy)	Base Case
	0.21
	0.25
	0.29
	0.34
	0.38
	0.42

Carbon credit payments	Base Case
	2.00
	2.25
	2.50
	3.00
	4.00
	5.00

Greenhouse gas emissions	Base Case

0.00036
0.00037
0.00038
0.00042
0.00047
0.00051
0.00055

Financial discount rate	Base Case
	10%
	12%
	15%
	18%
	20%

Economic discount rate	Base Case
	8%
	10%
	12%
	14%
	15%

Real exchange rate depreciation	Base Case
	0%
	1%
	2%
	3%
	4%
	5%

Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
73,500,000	100,800,000	504,000,000
73,500,000	100,800,000	-
-	100,800,000	-
20	40	20
44,100,000	60,480,000	126,000,000
500	2,000	1,000
65	5	25
14,000	20,000	20,000
5	7	5
0.0%	0.0%	0.0%
1.8	1.23	0.84
0	0	0
10.0%	10.0%	10.0%
0.0%	0.0%	0.0%
0.0%	0.0%	0.0%
2	3	1
2.31	2.31	2.31
0.21	0.21	0.21
0.1	0.1	0.1
-840000	0	0
2	2	2
0.0003392	0	0
85.0%	65.0%	30.0%
98.0%	85.0%	98.0%
5	8	12
4.0%	0.5%	0.5%
Base	Intermittent	Intermittent

1	2	3	4	5	6
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

1	2	3	4	5	6
-	5.00	4.80	4.61	4.42	4.25
-	4.25	4.08	3.92	3.76	3.61
-	4.17	4.00	3.84	3.68	3.54
-	36,485	35,026	33,625	32,280	30,989
-	12,376	11,881	11,406	10,949	10,511

1	2	3	4	5	6
-	7,661,934	7,355,457	7,061,238	6,778,789	6,507,637
-	-	-	-	-	-
-	129,946	124,749	119,759	114,968	110,370
	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-					
-	-	-	-	-	-

-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
USD					
$ -					
-					

1	2	3	4	5	6
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
-	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
(32,500)	(872,500)	(872,500)	(872,500)	(872,500)	(872,500)
1,548	1,548	1,548	1,548	1,548	1,548
(1,548)	(41,548)	(41,548)	(41,548)	(41,548)	(41,548)
USD					
$ (79,440)					

(0.00)

1	2	3	4	5	6
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

1	2	3	4	5	6
-	-	8.00	7.96	7.92	7.88
-	-	5.20	5.17	5.15	5.12
-	-	4.42	4.40	4.38	4.35
-	-	38,719	38,526	38,333	38,141
-	-	-	-	-	-

1	2	3	4	5	6
-	-	89,441,352	88,994,145	88,549,175	88,106,429
-	-	8,131,032	8,090,377	8,049,925	8,009,675
-	-	418,167	416,077	413,996	411,926
-	-	689,512	686,064	682,634	679,220
-	-	98,680,063	98,186,663	97,695,729	97,207,251
100,800,000	100,800,000	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
-	-	-	-	-	-
100,810,000	100,810,000	10,000	10,000	10,000	10,000
-	-	47,624,616	47,386,493	47,149,560	46,913,813
-	-	-	-	-	-
-	-	4,181,674	4,160,765	4,139,961	4,119,262
-	-	51,806,290	51,547,258	51,289,522	51,033,074
100,810,000	100,810,000	51,816,290	51,557,258	51,299,522	51,043,074
(100,810,000)	(100,810,000)	46,863,773	46,629,404	46,396,207	46,164,176

4,800,476	4,800,476	2,467,442	2,455,108	2,442,834	2,430,623
(4,800,476)	(4,800,476)	2,231,608	2,220,448	2,209,343	2,198,294
USD					
$ (2,379,273)					
0.135					

1	2	3	4	5	6
-	-	125,217,893	124,591,803	123,968,844	123,349,000
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
-	(840,000)	124,377,893	123,751,803	123,128,844	122,509,000
107,654,400	107,654,400	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
-	-	-	-	-	-
107,664,400	107,664,400	10,000	10,000	10,000	10,000
-	-	48,636,639	48,393,456	48,151,489	47,910,731
-	-	-	-	-	-
-	-	-	-	-	-
-	-	48,636,639	48,393,456	48,151,489	47,910,731
107,664,400	107,664,400	48,646,639	48,403,456	48,161,489	47,920,731
(107,664,400)	(108,504,400)	75,731,254	75,348,347	74,967,356	74,588,269
5,126,876	5,126,876	2,316,507	2,304,926	2,293,404	2,281,940
(5,126,876)	(5,166,876)	3,606,250	3,588,017	3,569,874	3,551,822
USD					
$ 6,709,152					
0.12					

1	2	3	4	5	6
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

1	2	3	4	5	6
12.00	11.94	11.88	11.82	11.76	11.70
3.60	3.58	3.56	3.55	3.53	3.51
3.53	3.51	3.49	3.48	3.46	3.44
30,905	30,751	30,597	30,444	30,292	30,140
-	-	-	-	-	-

1	2	3	4	5	6
71,391,197	71,034,241	70,679,070	70,325,674	69,974,046	69,624,176
6,490,109	6,457,658	6,425,370	6,393,243	6,361,277	6,329,471
454,308	452,036	449,776	447,527	445,289	443,063
550,361	547,609	544,871	542,147	539,436	536,739
78,885,974	78,491,545	78,099,087	77,708,591	77,320,048	76,933,448
-	-	-	-	-	-
25,000	25,000	25,000	25,000	25,000	25,000
-	-	-	-	420,000	-
25,000	25,000	25,000	25,000	445,000	25,000
25,960,435	25,830,633	25,701,480	25,572,972	25,445,108	25,317,882
-	-	-	-	-	-
4,543,076	4,520,361	4,497,759	4,475,270	4,452,894	4,430,629
30,503,511	30,350,994	30,199,239	30,048,243	29,898,001	29,748,511
30,528,511	30,375,994	30,224,239	30,073,243	30,343,001	29,773,511
48,357,463	48,115,551	47,874,848	47,635,349	46,977,047	47,159,937
1,453,739	1,446,476	1,439,249	1,432,059	1,444,905	1,417,786
2,302,736	2,291,217	2,279,755	2,268,350	2,237,002	2,245,711
USD					
$ (9,665,946)					

0.173						

	1	2	3	4	5	6
	99,947,676	99,447,937	98,950,697	98,455,944	97,963,664	97,473,846
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
	99,947,676	98,607,937	98,110,697	97,615,944	97,123,664	96,633,846
	-	-	-	-	-	-
	25,000	25,000	25,000	25,000	25,000	25,000
	-	-	-	-	381,276	-
	25,000	25,000	25,000	25,000	406,276	25,000
	26,512,094	26,379,534	26,247,636	26,116,398	25,985,816	25,855,887
	-	-	-	-	-	-
	-	-	-	-	-	-
	26,512,094	26,379,534	26,247,636	26,116,398	25,985,816	25,855,887
	26,537,094	26,404,534	26,272,636	26,141,398	26,392,092	25,880,887
	73,410,581	72,203,403	71,838,061	71,474,546	70,731,572	70,752,959
	1,263,671	1,257,359	1,251,078	1,244,828	1,256,766	1,232,423
	3,495,742	3,438,257	3,420,860	3,403,550	3,368,170	3,369,189
USD						
$	18,604					
	0.15					

Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
-	(2,379,273)	(9,665,946)
#NUM!	11.9%	7.5%
-	0.13	0.17
161,579	174,940	188,368
166,944	-	-
53,140	258,699	258,699
(2,195,791)	(4,901,663)	(12,404,891)
41.32	18.95	47.95

nic Summary Tables

Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
(79,440)	6,709,152	18,604
9.2%	18.3%	12.0%
(0.00)	0.12	0.15
192,717	217,593	224,056
166,944	-	-
54,354	258,699	258,699
(6,683,210)	687,402	(6,566,385.54)
122.96	(2.66)	25.38

NSITIVITY ANALYSES

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
1,695,791	20.5%	0.10	-	6,132,073	30.4%
595,791	16.6%	0.11	-	5,133,493	25.0%
(1,384,209)	12.0%	0.12	-	3,336,049	18.7%
(4,816,209)	7.1%	0.13	-	220,479	12.3%
(10,822,209)	2.4%	0.16	-	(5,231,768)	6.4%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,010,120	**22.2%**	**0.10**	**-**	**6,372,501**	**33.1%**
1,961,381	22.1%	0.10	-	6,316,465	33.0%
1,912,643	22.0%	0.10	-	6,260,429	32.9%
1,815,165	21.7%	0.10	-	6,148,356	32.6%
1,620,210	21.0%	0.10	-	5,924,211	32.2%
1,425,256	20.4%	0.10	-	5,700,066	31.7%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,181,412	22.8%	0.10	-	6,567,510	33.5%
2,135,040	22.7%	0.10	-	6,504,099	33.5%
1,404,436	21.3%	0.10	-	5,438,994	33.0%
(545,107)	#NUM!	0.11	-	2,533,373	4.8%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%

5,203,963	33.1%	0.08	-	12,985,201	53.6%
4,201,239	29.7%	0.09	-	10,852,125	47.0%
3,198,515	26.3%	0.09	-	8,719,049	40.3%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
1,193,067	19.3%	0.10	-	4,452,896	26.8%
190,343	15.7%	0.11	-	2,319,820	19.9%
(812,381)	12.0%	0.11	-	186,744	12.7%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,170,723	22.7%	0.10	-	6,552,246	33.4%
2,145,655	22.6%	0.10	-	6,518,519	33.3%
2,120,587	22.5%	0.10	-	6,484,793	33.2%
2,095,519	22.5%	0.10	-	6,451,066	33.1%
2,070,451	22.4%	0.10	-	6,417,339	33.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,095,519	22.5%	0.10	-	6,372,665	32.9%
1,995,247	22.1%	0.10	-	6,159,357	32.2%
1,894,974	21.8%	0.10	-	5,946,050	31.5%
1,794,702	21.4%	0.10	-	5,732,742	30.8%
1,694,429	21.1%	0.10	-	5,519,435	30.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
1,210,370	18.7%	0.10	-	5,283,240	26.2%
352,416	16.0%	0.11	-	4,117,970	21.8%
(394,171)	14.0%	0.11	-	3,076,262	18.8%
(1,043,923)	12.3%	0.12	-	2,144,865	16.5%
(1,609,476)	11.0%	0.13	-	1,311,946	14.7%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
(1,743,482)	8.4%	0.10	-	(679,498)	9.6%
226,155	15.8%	0.10	-	2,953,237	21.9%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
4,165,428	29.6%	0.10	-	10,218,708	45.0%
6,135,064	36.3%	0.10	-	13,851,444	56.4%
8,104,701	42.9%	0.10	-	17,484,179	67.7%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
(332,084)	13.8%	0.11	-	2,483,410	20.4%
510,541	16.9%	0.11	-	3,850,931	24.8%
1,353,166	19.9%	0.10	-	5,218,452	29.2%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,617,104	24.3%	0.10	-	7,269,733	35.7%
3,038,417	25.7%	0.10	-	7,953,494	37.9%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
(191,647)	14.3%	0.11	-	2,711,330	21.1%
604,166	17.2%	0.11	-	4,002,878	25.3%
1,399,979	20.0%	0.10	-	5,294,425	29.4%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,593,698	24.2%	0.10	-	7,231,746	35.6%
2,832,442	25.0%	0.10	-	7,619,211	36.8%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,013,937	22.3%	0.10	-	6,255,329	33.0%
1,839,640	21.8%	0.10	-	5,939,449	32.5%
1,672,520	21.3%	0.10	-	5,637,553	32.0%
1,512,216	20.8%	0.10	-	5,348,905	31.4%
1,358,389	20.4%	0.10	-	5,072,813	30.9%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
4,740,321	22.8%	0.09	-	6,585,973	33.5%
3,560,812	22.8%	0.09	-	6,585,973	33.5%
2,606,017	22.8%	0.10	-	6,585,973	33.5%

2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
1,173,514	22.8%	0.10	-	6,585,973	33.5%
628,319	22.8%	0.11	-	6,585,973	33.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	12,403,365	33.5%
2,195,791	22.8%	0.10	-	10,000,671	33.5%
2,195,791	22.8%	0.10	-	8,104,100	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,195,791	22.8%	0.10	-	5,354,530	33.5%
2,195,791	22.8%	0.10	-	4,824,701	33.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,074,679	22.5%	0.10	-	6,309,464	32.9%
1,955,942	22.1%	0.10	-	6,038,376	32.2%
1,839,510	21.8%	0.10	-	5,772,553	31.5%
1,725,318	21.4%	0.10	-	5,511,842	30.8%
1,613,300	21.1%	0.10	-	5,256,096	30.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	#NUM!	-	53,140	(79,440)	9.2%
(1,239,602)	**11.4%**	**0.13**	**53,140**	**6,178,712**	**25.2%**
(1,239,602)	11.4%	0.13	53,140	6,178,712	25.2%
(1,239,602)	11.4%	0.13	53,140	6,178,712	25.2%
(1,239,602)	11.4%	0.13	53,140	6,178,712	25.2%
(1,239,602)	11.4%	0.13	53,140	6,178,712	25.2%
(1,239,602)	11.4%	0.13	53,140	6,178,712	25.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	#NUM!	-	53,140	(79,440)	9.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,239,143)	11.4%	0.13	53,140	5,652,803	24.2%
(1,240,061)	11.4%	0.13	53,140	5,651,716	24.2%
(1,240,979)	11.4%	0.13	53,140	5,650,630	24.2%
(1,241,897)	11.4%	0.13	53,140	5,649,544	24.2%
(1,242,815)	11.4%	0.13	53,140	5,648,458	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR

-	#NUM!	-	53,140	(79,440)	9.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,254,089)	11.4%	0.13	53,140	5,633,954	24.2%
(1,300,097)	11.2%	0.13	53,140	5,573,999	24.1%
(1,829,557)	8.6%	0.13	53,140	4,854,804	23.5%
(2,940,265)	#NUM!	0.14	53,140	3,319,533	22.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	#NUM!	-	53,140	(79,440)	9.2%
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%
1,739,998	**19.8%**	**0.11**	**53,140**	**10,166,981**	**32.9%**
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	#NUM!	-	53,140	(79,440)	9.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	#NUM!	-	53,140	(79,440)	9.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(2,081,496)	8.4%	0.13	53,140	4,431,549	22.3%
(2,998,609)	3.7%	0.14	53,140	3,093,565	19.9%
(3,997,555)	-7.2%	0.14	53,140	1,626,717	16.8%
(5,087,284)	#NUM!	0.15	53,140	16,145	12.1%
(6,277,822)	#NUM!	0.16	53,140	(1,754,862)	#NUM!

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	#NUM!	-	53,140	(79,440)	9.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%

(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	#NUM!	-	53,140	(79,440)	9.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,948,326)	9.8%	0.13	29,192	4,205,753	19.8%
(2,567,054)	8.6%	0.14	2,860	2,908,289	16.9%
(3,106,382)	7.6%	0.15	(26,021)	1,745,166	14.7%
(3,576,718)	6.8%	0.16	(57,612)	701,797	13.1%
(3,987,119)	6.0%	0.17	(92,071)	(234,852)	11.7%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	#NUM!	-	53,140	(79,440)	9.2%
(4,473,039)	1.2%	0.13	53,140	(281,809)	11.3%
(2,855,632)	6.5%	0.13	53,140	2,686,040	18.0%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
379,182	16.1%	0.13	53,140	8,621,738	30.1%
1,996,589	20.5%	0.13	53,140	11,589,587	35.7%
3,613,997	24.7%	0.13	53,140	14,557,436	41.1%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	#NUM!	-	53,140	(79,440)	9.2%
(1,245,076)	11.4%	0.13	53,140	5,653,889	24.2%
(1,241,651)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,231,374)	11.4%	0.13	53,140	5,653,889	24.2%
(1,224,523)	11.5%	0.13	53,140	5,653,889	24.2%
(1,210,821)	11.5%	0.13	53,140	5,653,889	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	#NUM!	-	53,140	(79,440)	9.2%
(3,078,494)	5.8%	0.15	53,140	1,133,126	14.6%
(2,465,071)	7.7%	0.14	53,140	2,640,047	17.9%
(1,851,648)	9.6%	0.13	53,140	4,146,968	21.1%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(931,514)	12.3%	0.13	53,140	6,407,349	25.7%
(624,802)	13.2%	0.12	53,140	7,160,810	27.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	#NUM!	-	53,140	(79,440)	9.2%
(2,461,941)	7.7%	0.14	53,140	2,647,735	17.9%
(1,929,891)	9.3%	0.13	53,140	3,954,758	20.7%

(1,663,865)	10.1%	0.13	53,140	4,608,270	22.1%
(1,397,840)	10.9%	0.13	53,140	5,261,782	23.4%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,185,020)	11.6%	0.13	53,140	5,784,591	24.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	#NUM!	-	53,140	(79,440)	9.2%
(718,242)	13.1%	0.12	37,848	7,087,220	26.0%
(988,596)	12.2%	0.13	45,710	6,339,893	25.1%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,355,876)	11.0%	0.13	56,695	5,332,000	23.8%
(1,469,052)	10.6%	0.13	60,146	5,023,262	23.3%
(1,682,806)	9.8%	0.13	66,740	4,442,684	22.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	#NUM!	-	53,140	(79,440)	9.2%
642,521	11.4%	0.12	54,802	5,653,889	24.2%
(236,782)	11.4%	0.12	54,354	5,653,889	24.2%
(939,409)	11.4%	0.13	53,612	5,653,889	24.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,972,751)	11.4%	0.13	51,363	5,653,889	24.2%
(2,357,040)	11.4%	0.14	49,914	5,653,889	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	#NUM!	-	53,140	(79,440)	9.2%
(1,238,225)	11.4%	0.13	53,140	12,331,284	24.2%
(1,238,225)	11.4%	0.13	53,140	9,573,138	24.2%
(1,238,225)	11.4%	0.13	53,140	7,396,060	24.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,238,225)	11.4%	0.13	53,140	4,241,775	24.2%
(1,238,225)	11.4%	0.13	53,140	3,634,809	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	#NUM!	-	53,140	(79,440)	9.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,225,785)	11.4%	0.13	53,140	5,597,802	24.2%
(1,213,589)	11.4%	0.13	53,140	5,542,815	24.2%
(1,201,629)	11.4%	0.12	53,140	5,488,896	24.2%
(1,189,900)	11.4%	0.12	53,140	5,436,014	24.2%
(1,178,394)	11.4%	0.12	53,140	5,384,139	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,380,308)	11.9%	0.13	258,699	6,707,959	18.3%
(2,381,343)	11.9%	0.13	258,699	6,706,766	18.3%
(2,382,377)	11.9%	0.13	258,699	6,705,574	18.3%
(2,383,412)	11.9%	0.13	258,699	6,704,381	18.3%
(2,384,446)	11.9%	0.13	258,699	6,703,188	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(409,804)	14.5%	0.12	258,699	9,458,291	20.7%
(1,460,491)	13.1%	0.13	258,699	7,991,660	19.4%
(1,651,525)	12.9%	0.13	258,699	7,725,000	19.2%
(2,606,695)	**11.6%**	**0.14**	**258,699**	**6,391,699**	**18.1%**
(3,561,865)	10.2%	0.14	258,699	5,058,399	16.9%
(4,517,035)	8.8%	0.15	258,699	3,725,098	15.6%
(5,472,205)	7.3%	0.15	258,699	2,391,798	14.4%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%

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FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
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(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
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(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(3,803,602)	10.3%	0.15	258,699	4,203,424	15.7%
(5,042,696)	9.0%	0.16	258,699	1,964,610	13.6%
(6,120,719)	7.9%	0.18	258,699	(35,897)	12.0%
(7,058,684)	6.9%	0.20	258,699	(1,823,637)	10.6%
(7,874,860)	6.0%	0.22	258,699	(3,421,415)	9.4%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(5,881,563)	6.6%	0.13	258,699	7,290	12.0%
(4,130,418)	9.4%	0.13	258,699	3,358,221	15.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(628,129)	14.2%	0.14	258,699	10,060,083	21.2%
1,123,016	16.4%	0.14	258,699	13,411,014	23.8%
2,874,161	18.5%	0.14	258,699	16,761,945	26.4%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,416,361)	11.8%	0.13	258,699	6,709,152	18.3%

(2,397,817)	11.8%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,342,186)	11.9%	0.13	258,699	6,709,152	18.3%
(2,305,099)	12.0%	0.13	258,699	6,709,152	18.3%
(2,230,925)	12.1%	0.13	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(4,706,562)	8.5%	0.16	258,699	1,979,824	14.0%
(3,930,799)	9.7%	0.15	258,699	3,556,266	15.5%
(3,155,036)	10.8%	0.14	258,699	5,132,709	16.9%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(1,603,511)	12.9%	0.13	258,699	8,285,595	19.7%
(827,748)	13.9%	0.13	258,699	9,862,037	21.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(4,752,195)	8.4%	0.16	258,699	1,887,092	13.9%
(4,158,964)	9.3%	0.15	258,699	3,092,607	15.1%
(3,565,734)	10.2%	0.14	258,699	4,298,122	16.2%
(2,972,504)	11.0%	0.14	258,699	5,503,637	17.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(1,786,043)	12.7%	0.13	258,699	7,914,667	19.4%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,121,552)	12.3%	0.13	258,699	7,291,260	18.7%
(2,251,703)	12.1%	0.13	258,699	6,997,102	18.5%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,626,909)	11.5%	0.14	258,699	6,151,279	17.9%
(3,093,757)	10.7%	0.14	258,699	5,103,653	17.1%
(3,525,550)	10.0%	0.14	258,699	4,139,775	16.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
1,919,848	11.9%	0.11	258,699	6,709,152	18.3%
(119,049)	11.9%	0.12	258,699	6,709,152	18.3%
(1,713,464)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(3,974,584)	11.9%	0.15	258,699	6,709,152	18.3%
(4,778,910)	11.9%	0.16	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	19,880,374	18.3%
(2,379,273)	11.9%	0.13	258,699	14,336,854	18.3%
(2,379,273)	11.9%	0.13	258,699	10,055,350	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	4,064,771	18.3%
(2,379,273)	11.9%	0.13	258,699	2,951,042	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,354,350)	11.9%	0.13	258,699	6,642,607	18.3%
(2,329,915)	11.9%	0.13	258,699	6,577,366	18.3%
(2,305,955)	11.9%	0.13	258,699	6,513,392	18.3%
(2,282,455)	11.9%	0.13	258,699	6,450,649	18.3%
(2,259,403)	11.9%	0.13	258,699	6,389,101	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(12,065,946)	6.3%	0.19	258,699	(2,544,596)	10.6%
(17,345,946)	4.3%	0.21	258,699	(8,183,636)	8.1%
(26,849,946)	1.7%	0.26	258,699	(18,333,908)	4.9%
(43,323,546)	-1.2%	0.35	258,699	(35,927,712)	1.5%
(72,152,346)	-4.3%	0.50	258,699	(66,716,871)	-2.1%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,667,803)	7.5%	0.17	258,699	16,470	12.0%
(9,669,659)	7.5%	0.17	258,699	14,335	12.0%
(9,671,516)	7.5%	0.17	258,699	12,200	12.0%
(9,673,373)	7.5%	0.17	258,699	10,065	12.0%
(9,675,229)	7.5%	0.17	258,699	7,931	12.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,694,704)	7.4%	0.17	258,699	(18,321)	12.0%
(9,787,449)	7.3%	0.17	258,699	(145,143)	11.9%
(11,248,656)	3.2%	0.18	258,699	(2,275,354)	10.4%

(15,147,743)	#NUM!	0.20	258,699	(8,086,596)	#NUM!

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(8,088,927)	8.8%	0.16	258,699	2,123,726	13.3%
(8,843,153)	8.1%	0.17	258,699	1,116,929	12.7%
(8,980,285)	8.0%	0.17	258,699	933,875	12.6%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(10,351,606)	6.9%	0.18	258,699	(896,666)	11.5%
(11,037,267)	6.3%	0.18	258,699	(1,811,936)	10.9%
(11,722,928)	5.7%	0.18	258,699	(2,727,206)	10.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(10,114,226)	7.0%	0.18	258,699	(643,548)	11.6%
(10,605,119)	6.4%	0.18	258,699	(1,373,756)	11.1%
(11,143,585)	5.7%	0.18	258,699	(2,180,342)	10.6%
(11,735,211)	4.9%	0.18	258,699	(3,072,706)	10.0%
(12,386,284)	3.8%	0.19	258,699	(4,061,469)	9.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%

(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(11,605,378)	6.5%	0.19	258,699	(2,987,982)	10.3%
(13,293,463)	5.7%	0.22	258,699	(5,675,593)	9.0%
(14,761,925)	4.9%	0.24	258,699	(8,076,732)	7.9%
(16,039,413)	4.3%	0.28	258,699	(10,222,100)	7.0%
(17,150,840)	3.7%	0.32	258,699	(12,139,108)	6.1%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(13,437,079)	4.2%	0.17	258,699	(6,882,331)	7.7%
(11,551,512)	5.9%	0.17	258,699	(3,431,863)	9.9%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(7,780,379)	9.0%	0.17	258,699	3,469,072	14.1%
(5,894,813)	10.5%	0.18	258,699	6,919,540	16.1%
(4,009,246)	12.0%	0.18	258,699	10,370,008	18.1%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,705,880)	7.4%	0.17	258,699	18,604	12.0%
(9,685,913)	7.4%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,626,012)	7.5%	0.17	258,699	18,604	12.0%
(9,586,078)	7.5%	0.17	258,699	18,604	12.0%
(9,506,210)	7.6%	0.17	258,699	18,604	12.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(14,346,772)	3.4%	0.24	258,699	(8,432,054)	6.7%
(12,006,359)	5.5%	0.20	258,699	(4,206,725)	9.4%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(7,325,533)	9.4%	0.15	258,699	4,243,934	14.5%
(4,985,119)	11.2%	0.14	258,699	8,469,263	17.0%
(304,293)	14.8%	0.12	258,699	16,919,921	21.8%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(12,245,177)	5.3%	0.20	258,699	(4,637,881)	9.1%
(11,528,724)	5.9%	0.19	258,699	(3,344,413)	9.9%
(10,812,271)	6.5%	0.18	258,699	(2,050,945)	10.7%
(10,095,818)	7.1%	0.18	258,699	(757,477)	11.5%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,522,655)	7.6%	0.17	258,699	277,298	12.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,287,384)	7.9%	0.17	258,699	786,768	12.5%
(9,478,720)	7.7%	0.17	258,699	398,208	12.2%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(10,028,490)	7.1%	0.18	258,699	(714,692)	11.6%
(10,708,735)	6.3%	0.18	258,699	(2,083,985)	10.7%
(11,334,111)	5.5%	0.19	258,699	(3,334,715)	9.8%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(4,236,716)	7.5%	0.14	258,699	18,604	12.0%
(6,775,288)	7.5%	0.15	258,699	18,604	12.0%
(8,802,848)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(11,794,508)	7.5%	0.19	258,699	18,604	12.0%
(12,916,174)	7.5%	0.21	258,699	18,604	12.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	14,404,427	12.0%
(9,665,946)	7.5%	0.17	258,699	8,397,784	12.0%
(9,665,946)	7.5%	0.17	258,699	3,718,988	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,665,946)	7.5%	0.17	258,699	(2,950,722)	12.0%
(9,665,946)	7.5%	0.17	258,699	(4,218,755)	12.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,568,846)	7.5%	0.17	258,699	18,209	12.0%
(9,473,650)	7.5%	0.17	258,699	17,821	12.0%
(9,380,302)	7.5%	0.17	258,699	17,441	12.0%
(9,288,749)	7.5%	0.17	258,699	17,068	12.0%
(9,198,940)	7.5%	0.16	258,699	16,702	12.0%

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam

(2,195,791)	(4,901,663)	(12,404,891)		(6,683,210)	687,402
(2,607,982)	**(3,784,657)**	**(11,290,754)**		**416,747**	**884,909**
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		(6,683,210)	687,402
(6,026,689)	(7,207,929)	(14,711,157)		(4,571,520)	(4,218,674)
(4,923,693)	(6,104,932)	(13,608,160)		(2,225,136)	(1,872,290)
(4,723,148)	(5,904,387)	(13,407,616)		(1,798,521)	(1,445,675)
(3,720,424)	**(4,901,663)**	**(12,404,891)**		**334,555**	**687,402**
(2,717,700)	(3,898,939)	(11,402,167)		2,467,632	2,820,478
(1,714,976)	(2,896,215)	(10,399,443)		4,600,708	4,953,554
(712,252)	(1,893,491)	(9,396,719)		6,733,784	7,086,630

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		(6,683,210)	687,402
(3,720,424)	**(4,901,663)**	**(12,404,891)**		**334,555**	**687,402**
(3,695,356)	(4,876,595)	(12,379,823)		368,282	721,128
(3,670,288)	(4,851,527)	(12,354,755)		402,009	754,855
(3,645,220)	(4,826,459)	(12,329,687)		435,735	788,582
(3,620,151)	(4,801,391)	(12,304,619)		469,462	822,308
(3,595,083)	(4,776,323)	(12,279,551)		503,189	856,035

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		(6,683,210)	687,402
(2,607,982)	**(3,784,657)**	**(11,290,754)**		**416,747**	**884,909**
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		(6,683,210)	687,402
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909
(2,658,317)	**(3,834,992)**	**(11,341,089)**		**416,747**	**884,909**
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		(6,683,210)	687,402
(3,720,424)	**(4,901,663)**	**(12,404,891)**		**334,555**	**687,402**
(3,322,517)	(4,503,757)	(12,006,985)		334,555	687,402
(2,924,611)	(4,105,851)	(11,609,079)		334,555	687,402
(2,526,705)	(3,707,944)	(11,211,172)		334,555	687,402
(2,128,798)	(3,310,038)	(10,813,266)		334,555	687,402
(1,730,892)	(2,912,132)	(10,415,360)		334,555	687,402

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		(6,683,210)	687,402
(2,607,982)	**(3,784,657)**	**(11,290,754)**		**416,747**	**884,909**
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		(6,683,210)	687,402

(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909
(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909
(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909
(2,633,448)	**(3,810,123)**	**(11,316,220)**		**416,747**	**884,909**
(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909
(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909
(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		(6,683,210)	687,402
(3,955,580)	(2,723,196)	(9,190,196)		334,555	687,402
(3,850,640)	(3,689,873)	(10,693,998)		334,555	687,402
(3,720,424)	**(4,901,663)**	**(12,404,891)**		**334,555**	**687,402**
(3,623,565)	(5,917,818)	(13,665,171)		334,555	687,402
(3,576,101)	(6,519,962)	(14,330,071)		334,555	687,402

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		(6,683,210)	687,402
(2,607,982)	(3,784,657)	(11,290,754)		1,814,746	4,851,652
(2,607,982)	(3,784,657)	(11,290,754)		1,814,746	4,851,652
(2,607,982)	**(3,784,657)**	**(11,290,754)**		**1,814,746**	**4,851,652**
(2,607,982)	(3,784,657)	(11,290,754)		1,814,746	4,851,652
(2,607,982)	(3,784,657)	(11,290,754)		1,814,746	4,851,652

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		(6,683,210)	687,402
(2,607,982)	**(3,784,657)**	**(11,290,754)**		**416,747**	**884,909**
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909

7	8	9	10	11	12
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

7	8	9	10	11	12
4.08	3.91	3.76	3.61	3.46	3.32
3.47	3.33	3.19	3.07	2.94	2.83
3.40	3.26	3.13	3.00	2.88	2.77
29,749	28,559	27,417	26,320	25,267	24,257
10,091	9,687	9,300	8,928	8,571	8,228

7	8	9	10	11	12
6,247,332	5,997,439	5,757,541	5,527,239	5,306,150	5,093,904
-	-	-	-	-	-
105,955	101,717	97,648	93,742	89,992	86,393
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
294,000	-	-	-	-	294,000
326,500	32,500	32,500	32,500	32,500	326,500
-	-	-	-	-	-

-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-

7	8	9	10	11	12
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
266,893	-	-	-	-	266,893
299,393	32,500	32,500	32,500	32,500	299,393
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
299,393	32,500	32,500	32,500	32,500	299,393
(1,139,393)	(872,500)	(872,500)	(872,500)	(872,500)	(1,139,393)
14,257	1,548	1,548	1,548	1,548	14,257
(54,257)	(41,548)	(41,548)	(41,548)	(41,548)	(54,257)

7	8	9	10	11	12
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

7	8	9	10	11	12
7.84	7.80	7.76	7.72	7.69	7.65
5.10	5.07	5.05	5.02	5.00	4.97
4.33	4.31	4.29	4.27	4.25	4.23
37,951	37,761	37,572	37,384	37,197	37,011
-	-	-	-	-	-

7	8	9	10	11	12
87,665,896	87,227,567	86,791,429	86,357,472	85,925,685	85,496,056
7,969,627	7,929,779	7,890,130	7,850,679	7,811,426	7,772,369
409,867	407,817	405,778	403,749	401,730	399,722
675,824	672,445	669,083	665,738	662,409	659,097
96,721,214	96,237,608	95,756,420	95,277,638	94,801,250	94,327,244
-	-	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
420,000	-	-	-	-	-
430,000	10,000	10,000	10,000	10,000	10,000
46,679,244	46,445,847	46,213,618	45,982,550	45,752,637	45,523,874
-	-	-	-	-	-
4,098,665	4,078,172	4,057,781	4,037,492	4,017,305	3,997,218
50,777,909	50,524,019	50,271,399	50,020,042	49,769,942	49,521,092
51,207,909	50,534,019	50,281,399	50,030,042	49,779,942	49,531,092
45,513,305	45,703,589	45,475,021	45,247,596	45,021,308	44,796,151

2,438,472	2,406,382	2,394,352	2,382,383	2,370,473	2,358,623
2,167,300	2,176,361	2,165,477	2,154,647	2,143,872	2,133,150

7	8	9	10	11	12
122,732,255	122,118,594	121,508,001	120,900,461	120,295,959	119,694,479
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
121,892,255	121,278,594	120,668,001	120,060,461	119,455,959	118,854,479
-	-	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
381,276	-	-	-	-	-
391,276	10,000	10,000	10,000	10,000	10,000
47,671,178	47,432,822	47,195,658	46,959,679	46,724,881	46,491,256
-	-	-	-	-	-
-	-	-	-	-	-
47,671,178	47,432,822	47,195,658	46,959,679	46,724,881	46,491,256
48,062,454	47,442,822	47,205,658	46,969,679	46,734,881	46,501,256
73,829,802	73,835,772	73,462,343	73,090,782	72,721,078	72,353,222
2,288,688	2,259,182	2,247,888	2,236,651	2,225,471	2,214,346
3,515,705	3,515,989	3,498,207	3,480,513	3,462,908	3,445,392

7	8	9	10	11	12
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

7	8	9	10	11	12
11.64	11.59	11.53	11.47	11.41	11.36
3.49	3.48	3.46	3.44	3.42	3.41
3.42	3.41	3.39	3.37	3.36	3.34
29,990	29,840	29,690	29,542	29,394	29,247
-	-	-	-	-	-

7	8	9	10	11	12
69,276,055	68,929,675	68,585,026	68,242,101	67,900,891	67,561,386
6,297,823	6,266,334	6,235,002	6,203,827	6,172,808	6,141,944
440,848	438,643	436,450	434,268	432,097	429,936
534,055	531,385	528,728	526,085	523,454	520,837
76,548,781	76,166,037	75,785,207	75,406,281	75,029,249	74,654,103
-	-	-	-	-	-
25,000	25,000	25,000	25,000	25,000	25,000
-	-	-	420,000	-	-
25,000	25,000	25,000	445,000	25,000	25,000
25,191,293	25,065,336	24,940,010	24,815,309	24,691,233	24,567,777
-	-	-	-	-	-
4,408,476	4,386,434	4,364,502	4,342,679	4,320,966	4,299,361
29,599,769	29,451,770	29,304,511	29,157,989	29,012,199	28,867,138
29,624,769	29,476,770	29,329,511	29,602,989	29,037,199	28,892,138
46,924,012	46,689,267	46,455,696	45,803,292	45,992,051	45,761,966
1,410,703	1,403,656	1,396,643	1,409,666	1,382,724	1,375,816
2,234,477	2,223,298	2,212,176	2,181,109	2,190,098	2,179,141

7	8	9	10	11	12
96,986,477	96,501,544	96,019,037	95,538,941	95,061,247	94,585,940
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
96,146,477	95,661,544	95,179,037	94,698,941	94,221,247	93,745,940
-	-	-	-	-	-
25,000	25,000	25,000	25,000	25,000	25,000
-	-	-	381,276	-	-
25,000	25,000	25,000	406,276	25,000	25,000
25,726,608	25,597,975	25,469,985	25,342,635	25,215,922	25,089,842
-	-	-	-	-	-
-	-	-	-	-	-
25,726,608	25,597,975	25,469,985	25,342,635	25,215,922	25,089,842
25,751,608	25,622,975	25,494,985	25,748,911	25,240,922	25,114,842
70,394,869	70,038,570	69,684,052	68,950,031	68,980,325	68,631,098
1,226,267	1,220,142	1,214,047	1,226,139	1,201,949	1,195,945
3,352,137	3,335,170	3,318,288	3,283,335	3,284,777	3,268,148

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Econ. LCOE
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Econ. LCOE
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Econ. LCOE
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Econ. LCOE
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Econ. LCOE
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Econ. LCOE
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Econ. LCOE
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Econ. LCOE
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NPV		Financial CEA (USD/tCO2 mitigated)		
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines

(6,566,386)		41.3	18.9	48.0	
(6,259,834)		**49.1**	**14.6**	**43.6**	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		41.3	18.9	48.0	
(11,472,461)		113.4	27.9	56.9	
(9,126,077)		92.7	23.6	52.6	
(8,699,462)		88.9	22.8	51.8	
(6,566,386)		**70.0**	**18.9**	**48.0**	
(4,433,309)		51.1	15.1	44.1	
(2,300,233)		32.3	11.2	40.2	
(167,157)		13.4	7.3	36.3	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		41.3	18.9	48.0	
(6,566,386)		**70.0**	**18.9**	**48.0**	
(6,532,659)		69.5	18.9	47.9	
(6,498,932)		69.1	18.8	47.8	
(6,465,206)		68.6	18.7	47.7	
(6,431,479)		68.1	18.6	47.6	
(6,397,752)		67.7	18.5	47.5	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		41.3	18.9	48.0	
(6,259,834)		**49.1**	**14.6**	**43.6**	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		41.3	18.9	48.0	
(6,259,834)		50.0	14.8	43.8	
(6,259,834)		50.0	14.8	43.8	
(6,259,834)		50.0	14.8	43.8	
(6,259,834)		**50.0**	**14.8**	**43.8**	
(6,259,834)		50.0	14.8	43.8	
(6,259,834)		50.0	14.8	43.8	
(6,259,834)		50.0	14.8	43.8	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		41.3	18.9	48.0	
(6,566,386)		**70.0**	**18.9**	**48.0**	
(6,566,386)		62.5	17.4	46.4	
(6,566,386)		55.0	15.9	44.9	
(6,566,386)		47.5	14.3	43.3	
(6,566,386)		40.1	12.8	41.8	
(6,566,386)		32.6	11.3	40.3	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		41.3	18.9	48.0	
(6,259,834)		**49.1**	**14.6**	**43.6**	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		41.3	18.9	48.0	

(6,259,834)		186.9	17.3	51.5
(6,259,834)		186.9	17.3	51.5
(6,259,834)		186.9	17.3	51.5
(6,259,834)		**186.9**	**17.3**	**51.5**
(6,259,834)		186.9	17.3	51.5
(6,259,834)		186.9	17.3	51.5
(6,259,834)		186.9	17.3	51.5

NPV		Financial CEA (USD/tCO2 mitigated)		
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
(6,566,386)		41.3	18.9	48.0
(6,566,386)		72.2	10.5	35.5
(6,566,386)		70.8	14.3	41.3
(6,566,386)		**70.0**	**18.9**	**48.0**
(6,566,386)		70.5	22.9	52.8
(6,566,386)		71.6	25.2	55.4

NPV		Financial CEA (USD/tCO2 mitigated)		
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
(6,566,386)		41.3	18.9	48.0
(795,615)		49.1	14.6	43.6
(795,615)		49.1	14.6	43.6
(795,615)		**49.1**	**14.6**	**43.6**
(795,615)		49.1	14.6	43.6
(795,615)		49.1	14.6	43.6

NPV		Financial CEA (USD/tCO2 mitigated)		
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
(6,566,386)		41.3	18.9	48.0
(6,259,834)		**49.1**	**14.6**	**43.6**
(6,259,834)		49.1	14.6	43.6
(6,259,834)		49.1	14.6	43.6
(6,259,834)		49.1	14.6	43.6
(6,259,834)		49.1	14.6	43.6
(6,259,834)		49.1	14.6	43.6

13	14	15	16	17	18
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

13	14	15	16	17	18
3.19	3.06	2.94	2.82	2.71	2.60
2.71	2.60	2.50	2.40	2.30	2.21
2.66	2.55	2.45	2.35	2.26	2.17
23,286	22,355	21,461	20,602	19,778	18,987
7,899	7,583	7,279	6,988	6,709	6,440

13	14	15	16	17	18
4,890,148	4,694,542	4,506,760	4,326,490	4,153,430	3,987,293
-	-	-	-	-	-
82,937	79,619	76,435	73,377	70,442	67,624
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	294,000	-
32,500	32,500	32,500	32,500	326,500	32,500
-	-	-	-	-	-

-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-

13	14	15	16	17	18
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	266,893	-
32,500	32,500	32,500	32,500	299,393	32,500
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
32,500	32,500	32,500	32,500	299,393	32,500
(872,500)	(872,500)	(872,500)	(872,500)	(1,139,393)	(872,500)
1,548	1,548	1,548	1,548	14,257	1,548
(41,548)	(41,548)	(41,548)	(41,548)	(54,257)	(41,548)

13	14	15	16	17	18
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

13	14	15	16	17	18
7.61	7.57	7.53	7.50	7.46	7.42
4.95	4.92	4.90	4.87	4.85	4.82
4.20	4.18	4.16	4.14	4.12	4.10
36,826	36,642	36,459	36,277	36,095	35,915
-	-	-	-	-	-

13	14	15	16	17	18
85,068,576	84,643,233	84,220,017	83,798,917	83,379,922	82,963,023
7,733,507	7,694,839	7,656,365	7,618,083	7,579,993	7,542,093
397,723	395,735	393,756	391,787	389,828	387,879
655,801	652,522	649,260	646,013	642,783	639,569
93,855,607	93,386,329	92,919,398	92,454,801	91,992,527	91,532,564
-	-	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
-	420,000	-	-	-	-
10,000	430,000	10,000	10,000	10,000	10,000
45,296,255	45,069,773	44,844,425	44,620,202	44,397,101	44,175,116
-	-	-	-	-	-
3,977,232	3,957,346	3,937,559	3,917,871	3,898,282	3,878,791
49,273,487	49,027,119	48,781,984	48,538,074	48,295,384	48,053,907
49,283,487	49,457,119	48,791,984	48,548,074	48,305,384	48,063,907
44,572,121	43,929,210	44,127,414	43,906,727	43,687,143	43,468,658

2,346,833	2,355,101	2,323,428	2,311,813	2,300,256	2,288,757
2,122,482	2,091,867	2,101,305	2,090,797	2,080,340	2,069,936

13	14	15	16	17	18
119,096,006	118,500,526	117,908,024	117,318,484	116,731,891	116,148,232
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
118,256,006	117,660,526	117,068,024	116,478,484	115,891,891	115,308,232
-	-	-	-	-	-
10,000	10,000	10,000	10,000	10,000	10,000
-	381,276	-	-	-	-
10,000	391,276	10,000	10,000	10,000	10,000
46,258,800	46,027,506	45,797,369	45,568,382	45,340,540	45,113,837
-	-	-	-	-	-
-	-	-	-	-	-
46,258,800	46,027,506	45,797,369	45,568,382	45,340,540	45,113,837
46,268,800	46,418,782	45,807,369	45,578,382	45,350,540	45,123,837
71,987,206	71,241,744	71,260,655	70,900,102	70,541,351	70,184,395
2,203,276	2,210,418	2,181,303	2,170,399	2,159,550	2,148,754
3,427,962	3,392,464	3,393,365	3,376,195	3,359,112	3,342,114

13	14	15	16	17	18
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

13	14	15	16	17	18
11.30	11.24	11.19	11.13	11.08	11.02
3.39	3.37	3.36	3.34	3.32	3.31
3.32	3.31	3.29	3.27	3.26	3.24
29,101	28,956	28,811	28,667	28,523	28,381
-	-	-	-	-	-

13	14	15	16	17	18
67,223,579	66,887,461	66,553,024	66,220,259	65,889,158	65,559,712
6,111,234	6,080,678	6,050,275	6,020,024	5,989,923	5,959,974
427,786	425,647	423,519	421,402	419,295	417,198
518,233	515,642	513,063	510,498	507,946	505,406
74,280,833	73,909,429	73,539,881	73,172,182	72,806,321	72,442,289
-	-	-	-	-	-
25,000	25,000	25,000	25,000	25,000	25,000
-	-	420,000	-	-	-
25,000	25,000	445,000	25,000	25,000	25,000
24,444,938	24,322,713	24,201,100	24,080,094	23,959,694	23,839,895
-	-	-	-	-	-
4,277,864	4,256,475	4,235,192	4,214,016	4,192,946	4,171,982
28,722,802	28,579,188	28,436,292	28,294,111	28,152,640	28,011,877
28,747,802	28,604,188	28,881,292	28,319,111	28,177,640	28,036,877
45,533,031	45,305,241	44,658,589	44,853,071	44,628,681	44,405,413
1,368,943	1,362,104	1,375,300	1,348,529	1,341,792	1,335,089
2,168,240	2,157,392	2,126,599	2,135,861	2,125,175	2,114,543

13	14	15	16	17	18
94,113,011	93,642,446	93,174,233	92,708,362	92,244,821	91,783,596
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
93,273,011	92,802,446	92,334,233	91,868,362	91,404,821	90,943,596
-	-	-	-	-	-
25,000	25,000	25,000	25,000	25,000	25,000
-	-	381,276	-	-	-
25,000	25,000	406,276	25,000	25,000	25,000
24,964,393	24,839,571	24,715,373	24,591,796	24,468,837	24,346,493
-	-	-	-	-	-
-	-	-	-	-	-
24,964,393	24,839,571	24,715,373	24,591,796	24,468,837	24,346,493
24,989,393	24,864,571	25,121,649	24,616,796	24,493,837	24,371,493
68,283,618	67,937,875	67,212,585	67,251,566	66,910,983	66,572,103
1,189,971	1,184,027	1,196,269	1,172,228	1,166,373	1,160,547
3,251,601	3,235,137	3,200,599	3,202,456	3,186,237	3,170,100

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines

123.0	(2.7)	25.4
(7.7)	**(3.4)**	**24.2**
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
123.0	(2.7)	25.4
84.1	16.3	44.3
40.9	7.2	35.3
33.1	5.6	33.6
(6.2)	**(2.7)**	**25.4**
(45.4)	(10.9)	17.1
(84.6)	(19.1)	8.9
(123.9)	(27.4)	0.6

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
123.0	(2.7)	25.4
(6.2)	**(2.7)**	**25.4**
(6.8)	(2.8)	25.3
(7.4)	(2.9)	25.1
(8.0)	(3.0)	25.0
(8.6)	(3.2)	24.9
(9.3)	(3.3)	24.7

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
123.0	(2.7)	25.4
(7.7)	**(3.4)**	**24.2**
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
123.0	(2.7)	25.4
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	**(3.4)**	**24.2**
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
123.0	(2.7)	25.4
(6.2)	**(2.7)**	**25.4**
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
123.0	(2.7)	25.4
(7.7)	**(3.4)**	**24.2**
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
123.0	(2.7)	25.4

(27.2)	(4.0)	28.5
(27.2)	(4.0)	28.5
(27.2)	(4.0)	28.5
(27.2)	**(4.0)**	**28.5**
(27.2)	(4.0)	28.5
(27.2)	(4.0)	28.5
(27.2)	(4.0)	28.5

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
123.0	(2.7)	25.4
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4
(6.2)	**(2.7)**	**25.4**
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
123.0	(2.7)	25.4
(33.0)	(18.8)	3.1
(33.0)	(18.8)	3.1
(33.0)	**(18.8)**	**3.1**
(33.0)	(18.8)	3.1
(33.0)	(18.8)	3.1

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
123.0	(2.7)	25.4
(7.7)	**(3.4)**	**24.2**
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2

19	20	21
1.0	1.0	1.0
1.0	1.0	1.0
1.0	1.0	1.0
21.0	21.0	21.0

19	20	21
2.50	2.40	-
2.12	2.04	-
2.08	2.00	-
18,228	17,499	-
6,183	5,935	-

19	20	21
3,827,801	3,674,689	-
-	-	-
64,920	62,323	-
-	-	(44,100,000)
32,500	32,500	-
-	-	-
32,500	32,500	(44,100,000)
-	-	-

-	-	-
-	-	-
-	-	-
-	-	-

19	20	21
-	-	-
-	-	-
-	-	-
-	-	-
(840,000)	(840,000)	-
(840,000)	(840,000)	-
-	-	(47,098,800)
32,500	32,500	-
-	-	-
32,500	32,500	(47,098,800)
-	-	-
-	-	-
-	-	-
-	-	-
32,500	32,500	(47,098,800)
(872,500)	(872,500)	47,098,800
1,548	1,548	(2,242,800)
(41,548)	(41,548)	2,242,800

19	20	21
1.0	1.0	1.0
1.0	1.0	1.0
1.0	1.0	1.0
21.0	21.0	21.0

19	20	21
7.38	7.35	-
4.80	4.78	-
4.08	4.06	-
35,735	35,556	-
-	-	-

19	20	21
82,548,208	82,135,466	-
7,504,383	7,466,861	-
385,940	384,010	-
636,372	633,190	-
91,074,901	90,619,527	-
-	-	(60,480,000)
10,000	10,000	-
-	-	-
10,000	10,000	(60,480,000)
43,954,240	43,734,469	-
-	-	-
3,859,397	3,840,100	-
47,813,637	47,574,569	-
47,823,637	47,584,569	(60,480,000)
43,251,264	43,034,958	60,480,000

2,277,316	2,265,932	(2,880,000)
2,059,584	2,049,284	2,880,000

19	20	21
115,567,491	114,989,653	-
-	-	-
-	-	-
-	-	-
(840,000)	(840,000)	-
114,727,491	114,149,653	-
-	-	(64,592,640)
10,000	10,000	-
-	-	-
10,000	10,000	(64,592,640)
44,888,268	44,663,827	-
-	-	-
-	-	-
44,888,268	44,663,827	-
44,898,268	44,673,827	(64,592,640)
69,829,223	69,475,826	64,592,640
2,138,013	2,127,325	(3,075,840)
3,325,201	3,308,373	3,075,840

19	20	21
1.0	1.0	1.0
1.0	1.0	1.0
1.0	1.0	1.0
21.0	21.0	21.0

19	20	21
10.96	10.91	-
3.29	3.27	-
3.22	3.21	-
28,239	28,098	-
-	-	-

19	20	21
65,231,913	64,905,754	-
5,930,174	5,900,523	-
415,112	413,037	-
502,879	500,364	-
72,080,078	71,719,678	-
-	-	(126,000,000)
25,000	25,000	-
-	420,000	-
25,000	445,000	(126,000,000)
23,720,696	23,602,092	-
-	-	-
4,151,122	4,130,366	-
27,871,817	27,732,458	-
27,896,817	28,177,458	(126,000,000)
44,183,261	43,542,219	126,000,000
1,328,420	1,341,784	(6,000,000)
2,103,965	2,073,439	6,000,000

19	20	21
91,324,678	90,868,055	-
-	-	-
-	-	-
-	-	-
(840,000)	(840,000)	-
90,484,678	90,028,055	-
-	-	(134,568,000)
25,000	25,000	-
-	381,276	-
25,000	406,276	(134,568,000)
24,224,760	24,103,637	-
-	-	-
-	-	-
24,224,760	24,103,637	-
24,249,760	24,509,913	(134,568,000)
66,234,918	65,518,142	134,568,000
1,154,750	1,167,139	(6,408,000)
3,154,044	3,119,912	6,408,000

Table of Parameters

	Units	Option 1: Diesel Generation Plant
Cost Components		
Fixed Costs		
Investment cost, y1	1000 VND	105,000,000
Investment cost, y2	1000 VND	-
Investment cost, y3	1000 VND	-
Life of fixed asset	years	40
Fixed asset residual value	1000 VND	21,000,000
Land rental price	1000 VND/ha	2,000
Land area required	ha	15
Recurring costs	USD	10,000
Recurring cost period	years	5
Recurring cost growth	% per year	0.0%
Variable Costs		
Operations and maintenance	1000 VND per kWh	0.294
Fuel	USD per kWh	0.056
Taxes	% of revenues less O&M	10.0%
O&M cost growth	% per year	0.0%
Fuel cost growth	% per year	0.0%
First year of operation		1
Benefit Components		
Wholesale price of electricity	1000 VND per kWh	2.31
Production tax credit (subsidy)	1000 VND per kWh	0
Income tax credit	% of tax liability	0
Annual environmental externality	1000 VND	-1575000
Carbon credit payments	USD per ton of CO2 avoided	2
Technical Components		
Greenhouse gas emissions	tons of CO2 equivalent per kWh	0.000424
Capacity factor	% of annual capacity	85.0%
Availability factor	% of annual capacity	90.0%
Rated capacity	MW	5
Capacity decline	% decline per year	1.0%
Power type		Base
Economic Components		
Financial discount rate	%	15.0%

Economic discount rate	%	12.0%
Exchange rate	1000 VND per USD	21
Real exchange rate adjustment	%	0.0%
Foreign exchange premium	%	8.5%
Unit Conversions		
kWh per MWh		1000
Days per year		365
Hours per day		24
Pounds per ton		2000

Option 2: Landfill Gas Plant

Preliminary Tables

Table A: Indices	Year	0
Recurring cost growth		1.0
O&M cost growth		1.0
Fuel cost growth		1.0
Exchange rate		21.0

Table B: Production	Year	0
Rated capacity less capacity decline		-
After capacity factor		-
After availability factor		-
Total annual production (MWh)		-
GHG production (tCO2e)		-

Financial Cash Flows

Table 1: Financial Analysis, firm perspective	Year	0
Revenues		
Value of production		-
Production tax credit		-
Income tax credit		-
Carbon credit payments		-
Total revenues		-
Costs		
Investment cost		73,500,000
Land rental		32,500
Recurring costs		-
Fixed costs subtotal		73,532,500
Operations and maintenance		-
Fuel		-

Taxes		-
Variable costs subtotal		-
Total costs		73,532,500
Net cash flows		(73,532,500)
Total costs (USD)		3,501,548
Net cash flows (USD)		(3,501,548)
		1000 VND
NPV		(26,002,725.55)
IRR		11.4%
Discounted MWh		161,579.14
tCO2 generated		166,944
Financial LCOE (cost per kWh)		2.69

Economic Resource Flows

Table 2: Economic Analysis, economy perspective	Conversion factor	Year	0
Benefits			
Value of production	1.40		
Production tax credit	0.00		-
Income tax credit	0.00		-
Carbon credit payments	0.00		-
Environmental externality	1.00		-
Total benefits			-
Costs			
Investment cost	1.07		78,498,000
Land rental	1.00		32,500
Recurring costs	0.91		-
Fixed costs subtotal			78,530,500
Operations and maintenance	1.02		-
Fuel	1.61		-
Taxes	0.00		-
Variable costs subtotal			-
Total costs			78,530,500
Net cash flows			
Total costs (USD)			3,739,548
Net cash flows (USD)			-
			1000 VND
NPV			

IRR	
Discounted MWh	
tCO2 generated	166,944
Economic LCOE (cost per kWh)	#DIV/0!

	Financi
	Option 1: Diesel Generation Plant
FNPV (USD)	2,195,791
IRR	22.8%
Financial LCOE (USD per kWh)	0.10
Discounted MWh generated	198,953
tCO2 generated	258,699
tCO2 mitgated (relative to Option 1)	-
Incremental FNPV (USD)	
USD/tCO2 mitigated	

	Econon
	Option 1: Diesel Generation Plant
ENPV (USD)	6,585,973
EIRR	33.5%
Economic LCOE (USD per kWh)	0.12
Discounted MWh generated	235,892
tCO2 generated	258,699
tCO2 mitgated	-
Incremental ENPV (USD)	
USD/tCO2 mitigated	

SEI

Option 1: Diesel Generation Plant

Total Investment cost
105,000,000
115,500,000
138,600,000
180,180,000
252,252,000
378,378,000

Recurring costs
210,000
262,500
315,000
420,000
630,000
840,000

Recurring cost growth
-
10%
20%
40%
50%

Operations and maintenance
0.21
0.24
0.26

0.29
0.32
0.37
0.44

Fuel cost
0.039
0.045
0.050
0.056
0.062
0.067
0.073

O&M cost growth
-
1%
2%
3%
4%
5%

Fuel cost growth
-
1%
2%
3%
4%
5%

First year of operation
1
2
3
4
5
6

Wholesale price of electricity
1.85
2.08
2.31
2.54
2.77
3.00

Carbon credit payments
1.50
1.75
2.00
2.50
3.00
4.00

Capacity factor
55%
65%
75%
85%
90%
95%

Availability factor
60%
70%
80%
90%
95%
98%

Capacity decline
1.0%
1.5%
2.0%
2.5%
3.0%

3.5%

Financial discount rate
10.0%
12.0%
14.0%
15.0%
18.0%
20.0%

Economic discount rate
6.0%
8.0%
10.0%
12.0%
14.0%
15.0%

Real exchange rate depreciation
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%

Option 2: Landfill Gas Plant

Total Investment cost
147,000,000
161,700,000
176,400,000
191,100,000
205,800,000
220,500,000

Recurring costs (USD)
14,000

15,400
16,800
18,200
19,600
21,000

Recurring cost growth
-
10%
20%
40%
50%

Operations and maintenance
1.37
1.57
1.61
1.79
1.96
2.14
2.32

Fuel cost
-
-
-
-
-
-
-

O&M cost growth
0.0%
1%
2%
3%
4%
5%

Fuel cost growth
0.0%
1%
2%
3%
4%
5%

First year of operation
2
3
4
5
6
7

Wholesale price of electricity
1.85
2.08
2.31
2.54
2.77
3.00

Carbon credit payments
1.50
1.75
2.00
2.50
3.00
4.00

Capacity factor
55%
65%
75%
85%

90%
95%

Availability factor
75%
85%
90%
95%
98%
99%

Capacity decline
2.0%
3.0%
4.0%
4.5%
5.0%
6.0%

Financial discount rate
10.0%
12.0%
14.0%
15.0%
18.0%
20.0%

Economic discount rate
6.0%
8.0%
10.0%
12.0%
14.0%
15.0%

Real exchange rate depreciation
0.0%

1.0%
2.0%
3.0%
4.0%
5.0%

Option 3: Hydro-dam
Total Investment cost
302,400,000
332,640,000
362,880,000
393,120,000
423,360,000
453,600,000

Recurring costs (USD)
20,000
22,000
24,000
26,000
28,000
30,000

Recurring cost growth
-
10%
20%
40%
50%

Operations and maintenance
0.97
1.11
1.13
1.26
1.39
1.51
1.64

Fuel cost
-
-
-
-
-
-
-

O&M cost growth
0.0%
1%
2%
3%
4%
5%

Fuel cost growth
0.0%
1%
2%
3%
4%
5%

First year of operation
3
4
5
6
7
8

Wholesale price of electricity
1.85
2.08
2.31

2.54
2.77
3.00

Carbon credit payments
1.50
1.75
2.00
2.50
3.00
4.00

Capacity factor
50%
55%
60%
65%
70%
75%

Availability factor
65%
70%
75%
80%
85%
90%

Capacity decline
0.0%
0.25%
0.5%
1.0%
2.0%
3.0%

Financial discount rate

10.0%
12.0%
14.0%
15.0%
18.0%
20.0%

Economic discount rate
6.0%
8.0%
10.0%
12.0%
14.0%
15.0%

Real exchange rate depreciation
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%

Option 4: Wind Turbines

Total Investment cost
504,000,000
554,400,000
604,800,000
655,200,000
705,600,000
756,000,000

Recurring costs (USD)
20,000
22,000
24,000
26,000
28,000
30,000

Recurring cost growth
-
10%
20%
40%
50%

Operations and maintenance
0.65
0.74
0.76
0.84
0.92
1.01
1.09

Fuel cost
-
-
-
-
-
-
-

O&M cost growth
0.0%
1%
2%
3%
4%
5%

Fuel cost growth
0.0%
1%

2%
3%
4%
5%

First year of operation
1
2
3
4
5
6

Wholesale price of electricity
1.85
2.08
2.31
2.54
2.77
3.00

Carbon credit payments
1.50
1.75
2.00
2.50
3.00
4.00

Capacity factor
20%
25%
30%
35%
40%
50%

Availability factor
80%
85%
90%
95%
98%
99%

Capacity decline
0.0%
0.25%
0.5%
1.0%
2.0%
3.0%

Financial discount rate
10.0%
12.0%
14.0%
15.0%
18.0%
20.0%

Economic discount rate
6.0%
8.0%
10.0%
12.0%
14.0%
15.0%

Real exchange rate depreciation
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%

Incremental Sensitivity Analysis

Recurring cost growth	Base Case
	0%
	1%
	2%
	3%
	4%
	5%

Fuel	Base Case
	0.043
	0.049
	0.050
	0.056
	0.062
	0.067
	0.073

O&M cost growth	Base Case
	0%
	1%
	2%
	3%
	4%
	5%

Fuel cost growth	Base Case
	0%
	1%
	2%
	3%
	4%
	5%

Wholesale price of electricity	Base Case
	1.78
	2.03
	2.08
	2.31
	2.54
	2.77
	3.00

Production tax credit (subsidy)	Base Case
	0.21
	0.25
	0.29
	0.34
	0.38
	0.42

Carbon credit payments	Base Case
	2.00
	2.25
	2.50

3.00
4.00
5.00

Greenhouse gas emissions	Base Case
	0.00036
	0.00037
	0.00038
	0.00042
	0.00047
	0.00051
	0.00055

Financial discount rate	Base Case
	10%
	12%
	15%
	18%
	20%

Economic discount rate	Base Case
	8%
	10%
	12%
	14%
	15%

Real exchange rate depreciation	Base Case
	0%
	1%
	2%
	3%
	4%
	5%

Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
73,500,000	100,800,000	504,000,000
73,500,000	100,800,000	-
-	100,800,000	-
20	40	20
44,100,000	60,480,000	126,000,000
500	2,000	1,000
65	5	25
14,000	20,000	20,000
5	7	5
0.0%	0.0%	0.0%
1.8	1.23	0.84
0	0	0
10.0%	10.0%	10.0%
0.0%	0.0%	0.0%
0.0%	0.0%	0.0%
2	3	1
2.31	2.31	2.31
0.21	0.21	0.21
0.1	0.1	0.1
-840000	0	0
2	2	2
0.0003392	0	0
85.0%	65.0%	30.0%
98.0%	85.0%	98.0%
5	8	12
4.0%	0.5%	0.5%
Base	Intermittent	Intermittent

1	2	3	4	5	6
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

1	2	3	4	5	6
-	5.00	4.80	4.61	4.42	4.25
-	4.25	4.08	3.92	3.76	3.61
-	4.17	4.00	3.84	3.68	3.54
-	36,485	35,026	33,625	32,280	30,989
-	12,376	11,881	11,406	10,949	10,511

1	2	3	4	5	6
-	84,281,274	80,910,023	77,673,622	74,566,677	71,584,010
-	7,661,934	7,355,457	7,061,238	6,778,789	6,507,637
-	186,076	178,633	171,487	164,628	158,043
-	129,946	124,749	119,759	114,968	110,370
-	92,259,230	88,568,861	85,026,106	81,625,062	78,360,060
73,500,000	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
73,532,500	32,500	32,500	32,500	32,500	32,500
-	65,673,720	63,046,771	60,524,900	58,103,904	55,779,748
-	-	-	-	-	-

-	1,860,755	1,786,325	1,714,872	1,646,277	1,580,426
-	67,534,475	64,833,096	62,239,773	59,750,182	57,360,174
73,532,500	67,566,975	64,865,596	62,272,273	59,782,682	57,392,674
(73,532,500)	24,692,255	23,703,264	22,753,834	21,842,380	20,967,385
3,501,548	3,217,475	3,088,838	2,965,346	2,846,794	2,732,984
(3,501,548)	1,175,822	1,128,727	1,083,516	1,040,113	998,447
USD					
$ (1,238,225)					
0.128					

1	2	3	4	5	6
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
-	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
78,498,000	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	-	-
78,530,500	32,500	32,500	32,500	32,500	32,500
-	67,069,287	64,386,515	61,811,054	59,338,612	56,965,068
-	-	-	-	-	-
-	-	-	-	-	-
-	67,069,287	64,386,515	61,811,054	59,338,612	56,965,068
78,530,500	67,101,787	64,419,015	61,843,554	59,371,112	56,997,568
3,739,548	3,195,323	3,067,572	2,944,931	2,827,196	2,714,170
-	-	-	-	-	-
USD					

#DIV/0!

ial Summary Tables

Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
	(2,379,273)	(9,665,946)
11.4%	11.9%	7.5%
0.13	0.13	0.17
161,579	174,940	188,368
166,944	-	-
53,140	258,699	258,699
(2,195,791.33)	(4,901,663)	(12,404,891)
	18.95	47.95

nic Summary Tables

Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
-	6,709,152	18,604
0.0%	18.3%	12.0%
#DIV/0!	0.12	0.15
-	217,593	224,056
166,944	-	-
#DIV/0!	258,699	258,699
#DIV/0!	687,402	(6,566,385.54)
#DIV/0!	(2.66)	25.38

NSITIVITY ANALYSES

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
1,695,791	20.5%	0.10	-	6,132,073	30.4%
595,791	16.6%	0.11	-	5,133,493	25.0%
(1,384,209)	12.0%	0.12	-	3,336,049	18.7%
(4,816,209)	7.1%	0.13	-	220,479	12.3%
(10,822,209)	2.4%	0.16	-	(5,231,768)	6.4%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,010,120	**22.2%**	**0.10**	**-**	**6,372,501**	**33.1%**
1,961,381	22.1%	0.10	-	6,316,465	33.0%
1,912,643	22.0%	0.10	-	6,260,429	32.9%
1,815,165	21.7%	0.10	-	6,148,356	32.6%
1,620,210	21.0%	0.10	-	5,924,211	32.2%
1,425,256	20.4%	0.10	-	5,700,066	31.7%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,181,412	22.8%	0.10	-	6,567,510	33.5%
2,135,040	22.7%	0.10	-	6,504,099	33.5%
1,404,436	21.3%	0.10	-	5,438,994	33.0%
(545,107)	#NUM!	0.11	-	2,533,373	4.8%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%

2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
5,203,963	33.1%	0.08	-	12,985,201	53.6%
4,201,239	29.7%	0.09	-	10,852,125	47.0%
3,198,515	26.3%	0.09	-	8,719,049	40.3%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
1,193,067	19.3%	0.10	-	4,452,896	26.8%
190,343	15.7%	0.11	-	2,319,820	19.9%
(812,381)	12.0%	0.11	-	186,744	12.7%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,170,723	22.7%	0.10	-	6,552,246	33.4%
2,145,655	22.6%	0.10	-	6,518,519	33.3%
2,120,587	22.5%	0.10	-	6,484,793	33.2%
2,095,519	22.5%	0.10	-	6,451,066	33.1%
2,070,451	22.4%	0.10	-	6,417,339	33.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,095,519	22.5%	0.10	-	6,372,665	32.9%
1,995,247	22.1%	0.10	-	6,159,357	32.2%
1,894,974	21.8%	0.10	-	5,946,050	31.5%
1,794,702	21.4%	0.10	-	5,732,742	30.8%
1,694,429	21.1%	0.10	-	5,519,435	30.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
1,210,370	18.7%	0.10	-	5,283,240	26.2%
352,416	16.0%	0.11	-	4,117,970	21.8%
(394,171)	14.0%	0.11	-	3,076,262	18.8%
(1,043,923)	12.3%	0.12	-	2,144,865	16.5%
(1,609,476)	11.0%	0.13	-	1,311,946	14.7%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
(1,743,482)	8.4%	0.10	-	(679,498)	9.6%
226,155	15.8%	0.10	-	2,953,237	21.9%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
4,165,428	29.6%	0.10	-	10,218,708	45.0%
6,135,064	36.3%	0.10	-	13,851,444	56.4%
8,104,701	42.9%	0.10	-	17,484,179	67.7%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	6,585,973	33.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
(332,084)	13.8%	0.11	-	2,483,410	20.4%
510,541	16.9%	0.11	-	3,850,931	24.8%
1,353,166	19.9%	0.10	-	5,218,452	29.2%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,617,104	24.3%	0.10	-	7,269,733	35.7%
3,038,417	25.7%	0.10	-	7,953,494	37.9%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
(191,647)	14.3%	0.11	-	2,711,330	21.1%
604,166	17.2%	0.11	-	4,002,878	25.3%
1,399,979	20.0%	0.10	-	5,294,425	29.4%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,593,698	24.2%	0.10	-	7,231,746	35.6%
2,832,442	25.0%	0.10	-	7,619,211	36.8%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,013,937	22.3%	0.10	-	6,255,329	33.0%
1,839,640	21.8%	0.10	-	5,939,449	32.5%
1,672,520	21.3%	0.10	-	5,637,553	32.0%
1,512,216	20.8%	0.10	-	5,348,905	31.4%

1,358,389	20.4%	0.10	-	5,072,813	30.9%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
4,740,321	22.8%	0.09	-	6,585,973	33.5%
3,560,812	22.8%	0.09	-	6,585,973	33.5%
2,606,017	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
1,173,514	22.8%	0.10	-	6,585,973	33.5%
628,319	22.8%	0.11	-	6,585,973	33.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	22.8%	0.10	-	12,403,365	33.5%
2,195,791	22.8%	0.10	-	10,000,671	33.5%
2,195,791	22.8%	0.10	-	8,104,100	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,195,791	22.8%	0.10	-	5,354,530	33.5%
2,195,791	22.8%	0.10	-	4,824,701	33.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
2,195,791	22.8%	0.10	-	6,585,973	33.5%
2,195,791	**22.8%**	**0.10**	**-**	**6,585,973**	**33.5%**
2,074,679	22.5%	0.10	-	6,309,464	32.9%
1,955,942	22.1%	0.10	-	6,038,376	32.2%
1,839,510	21.8%	0.10	-	5,772,553	31.5%
1,725,318	21.4%	0.10	-	5,511,842	30.8%
1,613,300	21.1%	0.10	-	5,256,096	30.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	11.4%	0.13	53,140	-	0.0%
(1,239,602)	**11.4%**	**0.13**	**53,140**	**6,178,712**	**25.2%**
(1,239,602)	11.4%	0.13	53,140	6,178,712	25.2%
(1,239,602)	11.4%	0.13	53,140	6,178,712	25.2%
(1,239,602)	11.4%	0.13	53,140	6,178,712	25.2%
(1,239,602)	11.4%	0.13	53,140	6,178,712	25.2%
(1,239,602)	11.4%	0.13	53,140	6,178,712	25.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	11.4%	0.13	53,140	-	0.0%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**

(1,239,143)	11.4%	0.13	53,140	5,652,803	24.2%
(1,240,061)	11.4%	0.13	53,140	5,651,716	24.2%
(1,240,979)	11.4%	0.13	53,140	5,650,630	24.2%
(1,241,897)	11.4%	0.13	53,140	5,649,544	24.2%
(1,242,815)	11.4%	0.13	53,140	5,648,458	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	11.4%	0.13	53,140	-	0.0%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,254,089)	11.4%	0.13	53,140	5,633,954	24.2%
(1,300,097)	11.2%	0.13	53,140	5,573,999	24.1%
(1,829,557)	8.6%	0.13	53,140	4,854,804	23.5%
(2,940,265)	#NUM!	0.14	53,140	3,319,533	22.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	11.4%	0.13	53,140	-	0.0%
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%
1,739,998	**19.8%**	**0.11**	**53,140**	**10,166,981**	**32.9%**
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%
1,739,998	19.8%	0.11	53,140	10,166,981	32.9%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	11.4%	0.13	53,140	-	0.0%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	11.4%	0.13	53,140	-	0.0%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(2,081,496)	8.4%	0.13	53,140	4,431,549	22.3%
(2,998,609)	3.7%	0.14	53,140	3,093,565	19.9%
(3,997,555)	-7.2%	0.14	53,140	1,626,717	16.8%
(5,087,284)	#NUM!	0.15	53,140	16,145	12.1%
(6,277,822)	#NUM!	0.16	53,140	(1,754,862)	#NUM!

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	11.4%	0.13	53,140	-	0.0%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	11.4%	0.13	53,140	5,653,889	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	11.4%	0.13	53,140	-	0.0%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,948,326)	9.8%	0.13	29,192	4,205,753	19.8%
(2,567,054)	8.6%	0.14	2,860	2,908,289	16.9%
(3,106,382)	7.6%	0.15	(26,021)	1,745,166	14.7%
(3,576,718)	6.8%	0.16	(57,612)	701,797	13.1%
(3,987,119)	6.0%	0.17	(92,071)	(234,852)	11.7%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	11.4%	0.13	53,140	-	0.0%
(4,473,039)	1.2%	0.13	53,140	(281,809)	11.3%
(2,855,632)	6.5%	0.13	53,140	2,686,040	18.0%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
379,182	16.1%	0.13	53,140	8,621,738	30.1%
1,996,589	20.5%	0.13	53,140	11,589,587	35.7%
3,613,997	24.7%	0.13	53,140	14,557,436	41.1%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	11.4%	0.13	53,140	-	0.0%
(1,245,076)	11.4%	0.13	53,140	5,653,889	24.2%
(1,241,651)	11.4%	0.13	53,140	5,653,889	24.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,231,374)	11.4%	0.13	53,140	5,653,889	24.2%
(1,224,523)	11.5%	0.13	53,140	5,653,889	24.2%
(1,210,821)	11.5%	0.13	53,140	5,653,889	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	11.4%	0.13	53,140	-	0.0%
(3,078,494)	5.8%	0.15	53,140	1,133,126	14.6%
(2,465,071)	7.7%	0.14	53,140	2,640,047	17.9%
(1,851,648)	9.6%	0.13	53,140	4,146,968	21.1%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**

(931,514)	12.3%	0.13	53,140	6,407,349	25.7%
(624,802)	13.2%	0.12	53,140	7,160,810	27.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	11.4%	0.13	53,140	-	0.0%
(2,461,941)	7.7%	0.14	53,140	2,647,735	17.9%
(1,929,891)	9.3%	0.13	53,140	3,954,758	20.7%
(1,663,865)	10.1%	0.13	53,140	4,608,270	22.1%
(1,397,840)	10.9%	0.13	53,140	5,261,782	23.4%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,185,020)	11.6%	0.13	53,140	5,784,591	24.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	11.4%	0.13	53,140	-	0.0%
(718,242)	13.1%	0.12	37,848	7,087,220	26.0%
(988,596)	12.2%	0.13	45,710	6,339,893	25.1%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,355,876)	11.0%	0.13	56,695	5,332,000	23.8%
(1,469,052)	10.6%	0.13	60,146	5,023,262	23.3%
(1,682,806)	9.8%	0.13	66,740	4,442,684	22.5%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	11.4%	0.13	53,140	-	0.0%
642,521	11.4%	0.12	54,802	5,653,889	24.2%
(236,782)	11.4%	0.12	54,354	5,653,889	24.2%
(939,409)	11.4%	0.13	53,612	5,653,889	24.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,972,751)	11.4%	0.13	51,363	5,653,889	24.2%
(2,357,040)	11.4%	0.14	49,914	5,653,889	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	11.4%	0.13	53,140	-	0.0%
(1,238,225)	11.4%	0.13	53,140	12,331,284	24.2%
(1,238,225)	11.4%	0.13	53,140	9,573,138	24.2%
(1,238,225)	11.4%	0.13	53,140	7,396,060	24.2%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**
(1,238,225)	11.4%	0.13	53,140	4,241,775	24.2%
(1,238,225)	11.4%	0.13	53,140	3,634,809	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
-	11.4%	0.13	53,140	-	0.0%
(1,238,225)	**11.4%**	**0.13**	**53,140**	**5,653,889**	**24.2%**

(1,225,785)	11.4%	0.13	53,140	5,597,802	24.2%
(1,213,589)	11.4%	0.13	53,140	5,542,815	24.2%
(1,201,629)	11.4%	0.12	53,140	5,488,896	24.2%
(1,189,900)	11.4%	0.12	53,140	5,436,014	24.2%
(1,178,394)	11.4%	0.12	53,140	5,384,139	24.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,380,308)	11.9%	0.13	258,699	6,707,959	18.3%
(2,381,343)	11.9%	0.13	258,699	6,706,766	18.3%
(2,382,377)	11.9%	0.13	258,699	6,705,574	18.3%
(2,383,412)	11.9%	0.13	258,699	6,704,381	18.3%
(2,384,446)	11.9%	0.13	258,699	6,703,188	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(409,804)	14.5%	0.12	258,699	9,458,291	20.7%
(1,460,491)	13.1%	0.13	258,699	7,991,660	19.4%
(1,651,525)	12.9%	0.13	258,699	7,725,000	19.2%
(2,606,695)	**11.6%**	**0.14**	**258,699**	**6,391,699**	**18.1%**
(3,561,865)	10.2%	0.14	258,699	5,058,399	16.9%
(4,517,035)	8.8%	0.15	258,699	3,725,098	15.6%
(5,472,205)	7.3%	0.15	258,699	2,391,798	14.4%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(3,803,602)	10.3%	0.15	258,699	4,203,424	15.7%
(5,042,696)	9.0%	0.16	258,699	1,964,610	13.6%
(6,120,719)	7.9%	0.18	258,699	(35,897)	12.0%
(7,058,684)	6.9%	0.20	258,699	(1,823,637)	10.6%
(7,874,860)	6.0%	0.22	258,699	(3,421,415)	9.4%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(5,881,563)	6.6%	0.13	258,699	7,290	12.0%
(4,130,418)	9.4%	0.13	258,699	3,358,221	15.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**

(628,129)	14.2%	0.14	258,699	10,060,083	21.2%
1,123,016	16.4%	0.14	258,699	13,411,014	23.8%
2,874,161	18.5%	0.14	258,699	16,761,945	26.4%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,416,361)	11.8%	0.13	258,699	6,709,152	18.3%
(2,397,817)	11.8%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,342,186)	11.9%	0.13	258,699	6,709,152	18.3%
(2,305,099)	12.0%	0.13	258,699	6,709,152	18.3%
(2,230,925)	12.1%	0.13	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(4,706,562)	8.5%	0.16	258,699	1,979,824	14.0%
(3,930,799)	9.7%	0.15	258,699	3,556,266	15.5%
(3,155,036)	10.8%	0.14	258,699	5,132,709	16.9%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(1,603,511)	12.9%	0.13	258,699	8,285,595	19.7%
(827,748)	13.9%	0.13	258,699	9,862,037	21.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(4,752,195)	8.4%	0.16	258,699	1,887,092	13.9%
(4,158,964)	9.3%	0.15	258,699	3,092,607	15.1%
(3,565,734)	10.2%	0.14	258,699	4,298,122	16.2%
(2,972,504)	11.0%	0.14	258,699	5,503,637	17.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(1,786,043)	12.7%	0.13	258,699	7,914,667	19.4%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,121,552)	12.3%	0.13	258,699	7,291,260	18.7%
(2,251,703)	12.1%	0.13	258,699	6,997,102	18.5%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,626,909)	11.5%	0.14	258,699	6,151,279	17.9%
(3,093,757)	10.7%	0.14	258,699	5,103,653	17.1%
(3,525,550)	10.0%	0.14	258,699	4,139,775	16.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%

1,919,848	11.9%	0.11	258,699	6,709,152	18.3%
(119,049)	11.9%	0.12	258,699	6,709,152	18.3%
(1,713,464)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(3,974,584)	11.9%	0.15	258,699	6,709,152	18.3%
(4,778,910)	11.9%	0.16	258,699	6,709,152	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	11.9%	0.13	258,699	19,880,374	18.3%
(2,379,273)	11.9%	0.13	258,699	14,336,854	18.3%
(2,379,273)	11.9%	0.13	258,699	10,055,350	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,379,273)	11.9%	0.13	258,699	4,064,771	18.3%
(2,379,273)	11.9%	0.13	258,699	2,951,042	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(2,379,273)	11.9%	0.13	258,699	6,709,152	18.3%
(2,379,273)	**11.9%**	**0.13**	**258,699**	**6,709,152**	**18.3%**
(2,354,350)	11.9%	0.13	258,699	6,642,607	18.3%
(2,329,915)	11.9%	0.13	258,699	6,577,366	18.3%
(2,305,955)	11.9%	0.13	258,699	6,513,392	18.3%
(2,282,455)	11.9%	0.13	258,699	6,450,649	18.3%
(2,259,403)	11.9%	0.13	258,699	6,389,101	18.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(12,065,946)	6.3%	0.19	258,699	(2,544,596)	10.6%
(17,345,946)	4.3%	0.21	258,699	(8,183,636)	8.1%
(26,849,946)	1.7%	0.26	258,699	(18,333,908)	4.9%
(43,323,546)	-1.2%	0.35	258,699	(35,927,712)	1.5%
(72,152,346)	-4.3%	0.50	258,699	(66,716,871)	-2.1%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,667,803)	7.5%	0.17	258,699	16,470	12.0%
(9,669,659)	7.5%	0.17	258,699	14,335	12.0%
(9,671,516)	7.5%	0.17	258,699	12,200	12.0%
(9,673,373)	7.5%	0.17	258,699	10,065	12.0%
(9,675,229)	7.5%	0.17	258,699	7,931	12.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,694,704)	7.4%	0.17	258,699	(18,321)	12.0%
(9,787,449)	7.3%	0.17	258,699	(145,143)	11.9%
(11,248,656)	3.2%	0.18	258,699	(2,275,354)	10.4%
(15,147,743)	#NUM!	0.20	258,699	(8,086,596)	#NUM!

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(8,088,927)	8.8%	0.16	258,699	2,123,726	13.3%
(8,843,153)	8.1%	0.17	258,699	1,116,929	12.7%
(8,980,285)	8.0%	0.17	258,699	933,875	12.6%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(10,351,606)	6.9%	0.18	258,699	(896,666)	11.5%
(11,037,267)	6.3%	0.18	258,699	(1,811,936)	10.9%
(11,722,928)	5.7%	0.18	258,699	(2,727,206)	10.3%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
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FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(10,114,226)	7.0%	0.18	258,699	(643,548)	11.6%
(10,605,119)	6.4%	0.18	258,699	(1,373,756)	11.1%
(11,143,585)	5.7%	0.18	258,699	(2,180,342)	10.6%
(11,735,211)	4.9%	0.18	258,699	(3,072,706)	10.0%
(12,386,284)	3.8%	0.19	258,699	(4,061,469)	9.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%

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FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(11,605,378)	6.5%	0.19	258,699	(2,987,982)	10.3%
(13,293,463)	5.7%	0.22	258,699	(5,675,593)	9.0%
(14,761,925)	4.9%	0.24	258,699	(8,076,732)	7.9%
(16,039,413)	4.3%	0.28	258,699	(10,222,100)	7.0%
(17,150,840)	3.7%	0.32	258,699	(12,139,108)	6.1%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(13,437,079)	4.2%	0.17	258,699	(6,882,331)	7.7%
(11,551,512)	5.9%	0.17	258,699	(3,431,863)	9.9%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(7,780,379)	9.0%	0.17	258,699	3,469,072	14.1%
(5,894,813)	10.5%	0.18	258,699	6,919,540	16.1%
(4,009,246)	12.0%	0.18	258,699	10,370,008	18.1%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,705,880)	7.4%	0.17	258,699	18,604	12.0%
(9,685,913)	7.4%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,626,012)	7.5%	0.17	258,699	18,604	12.0%
(9,586,078)	7.5%	0.17	258,699	18,604	12.0%
(9,506,210)	7.6%	0.17	258,699	18,604	12.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(14,346,772)	3.4%	0.24	258,699	(8,432,054)	6.7%
(12,006,359)	5.5%	0.20	258,699	(4,206,725)	9.4%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(7,325,533)	9.4%	0.15	258,699	4,243,934	14.5%
(4,985,119)	11.2%	0.14	258,699	8,469,263	17.0%
(304,293)	14.8%	0.12	258,699	16,919,921	21.8%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR

(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(12,245,177)	5.3%	0.20	258,699	(4,637,881)	9.1%
(11,528,724)	5.9%	0.19	258,699	(3,344,413)	9.9%
(10,812,271)	6.5%	0.18	258,699	(2,050,945)	10.7%
(10,095,818)	7.1%	0.18	258,699	(757,477)	11.5%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,522,655)	7.6%	0.17	258,699	277,298	12.2%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,287,384)	7.9%	0.17	258,699	786,768	12.5%
(9,478,720)	7.7%	0.17	258,699	398,208	12.2%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(10,028,490)	7.1%	0.18	258,699	(714,692)	11.6%
(10,708,735)	6.3%	0.18	258,699	(2,083,985)	10.7%
(11,334,111)	5.5%	0.19	258,699	(3,334,715)	9.8%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(4,236,716)	7.5%	0.14	258,699	18,604	12.0%
(6,775,288)	7.5%	0.15	258,699	18,604	12.0%
(8,802,848)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(11,794,508)	7.5%	0.19	258,699	18,604	12.0%
(12,916,174)	7.5%	0.21	258,699	18,604	12.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	7.5%	0.17	258,699	14,404,427	12.0%
(9,665,946)	7.5%	0.17	258,699	8,397,784	12.0%
(9,665,946)	7.5%	0.17	258,699	3,718,988	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,665,946)	7.5%	0.17	258,699	(2,950,722)	12.0%
(9,665,946)	7.5%	0.17	258,699	(4,218,755)	12.0%

FNPV	FIRR	Fin. LCOE	tCO2 mitigated	ENPV	EIRR
(9,665,946)	7.5%	0.17	258,699	18,604	12.0%
(9,665,946)	**7.5%**	**0.17**	**258,699**	**18,604**	**12.0%**
(9,568,846)	7.5%	0.17	258,699	18,209	12.0%
(9,473,650)	7.5%	0.17	258,699	17,821	12.0%
(9,380,302)	7.5%	0.17	258,699	17,441	12.0%
(9,288,749)	7.5%	0.17	258,699	17,068	12.0%
(9,198,940)	7.5%	0.16	258,699	16,702	12.0%

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(2,607,982)	**(3,784,657)**	**(11,290,754)**		**416,747**	**884,909**
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(6,026,689)	(7,207,929)	(14,711,157)		(4,571,520)	(4,218,674)
(4,923,693)	(6,104,932)	(13,608,160)		(2,225,136)	(1,872,290)
(4,723,148)	(5,904,387)	(13,407,616)		(1,798,521)	(1,445,675)
(3,720,424)	**(4,901,663)**	**(12,404,891)**		**334,555**	**687,402**
(2,717,700)	(3,898,939)	(11,402,167)		2,467,632	2,820,478
(1,714,976)	(2,896,215)	(10,399,443)		4,600,708	4,953,554
(712,252)	(1,893,491)	(9,396,719)		6,733,784	7,086,630

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(3,720,424)	**(4,901,663)**	**(12,404,891)**		**334,555**	**687,402**
(3,695,356)	(4,876,595)	(12,379,823)		368,282	721,128
(3,670,288)	(4,851,527)	(12,354,755)		402,009	754,855
(3,645,220)	(4,826,459)	(12,329,687)		435,735	788,582
(3,620,151)	(4,801,391)	(12,304,619)		469,462	822,308
(3,595,083)	(4,776,323)	(12,279,551)		503,189	856,035

Financial Incremental NPV		Economic Incremental

Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(2,607,982)	**(3,784,657)**	**(11,290,754)**		**416,747**	**884,909**
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909
(2,658,317)	**(3,834,992)**	**(11,341,089)**		**416,747**	**884,909**
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909
(2,658,317)	(3,834,992)	(11,341,089)		416,747	884,909

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(3,720,424)	**(4,901,663)**	**(12,404,891)**		**334,555**	**687,402**
(3,322,517)	(4,503,757)	(12,006,985)		334,555	687,402
(2,924,611)	(4,105,851)	(11,609,079)		334,555	687,402
(2,526,705)	(3,707,944)	(11,211,172)		334,555	687,402
(2,128,798)	(3,310,038)	(10,813,266)		334,555	687,402
(1,730,892)	(2,912,132)	(10,415,360)		334,555	687,402

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(2,607,982)	**(3,784,657)**	**(11,290,754)**		**416,747**	**884,909**
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909

(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909
(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909
(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909
(2,633,448)	**(3,810,123)**	**(11,316,220)**		**416,747**	**884,909**
(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909
(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909
(2,633,448)	(3,810,123)	(11,316,220)		416,747	884,909

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(3,955,580)	(2,723,196)	(9,190,196)		334,555	687,402
(3,850,640)	(3,689,873)	(10,693,998)		334,555	687,402
(3,720,424)	**(4,901,663)**	**(12,404,891)**		**334,555**	**687,402**
(3,623,565)	(5,917,818)	(13,665,171)		334,555	687,402
(3,576,101)	(6,519,962)	(14,330,071)		334,555	687,402

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam
(2,195,791)	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(2,607,982)	(3,784,657)	(11,290,754)		1,814,746	4,851,652
(2,607,982)	(3,784,657)	(11,290,754)		1,814,746	4,851,652
(2,607,982)	**(3,784,657)**	**(11,290,754)**		**1,814,746**	**4,851,652**
(2,607,982)	(3,784,657)	(11,290,754)		1,814,746	4,851,652
(2,607,982)	(3,784,657)	(11,290,754)		1,814,746	4,851,652

Financial Incremental NPV				Economic Incremental	
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam

(2,195,791)	(4,901,663)	(12,404,891)		#DIV/0!	687,402
(2,607,982)	**(3,784,657)**	**(11,290,754)**		**416,747**	**884,909**
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909
(2,607,982)	(3,784,657)	(11,290,754)		416,747	884,909

7	8	9	10	11	12
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

7	8	9	10	11	12
4.08	3.91	3.76	3.61	3.46	3.32
3.47	3.33	3.19	3.07	2.94	2.83
3.40	3.26	3.13	3.00	2.88	2.77
29,749	28,559	27,417	26,320	25,267	24,257
10,091	9,687	9,300	8,928	8,571	8,228

7	8	9	10	11	12
68,720,650	65,971,824	63,332,951	60,799,633	58,367,647	56,032,942
6,247,332	5,997,439	5,757,541	5,527,239	5,306,150	5,093,904
151,721	145,652	139,826	134,233	128,864	123,709
105,955	101,717	97,648	93,742	89,992	86,393
75,225,657	72,216,631	69,327,966	66,554,847	63,892,653	61,336,947
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
294,000	-	-	-	-	294,000
326,500	32,500	32,500	32,500	32,500	326,500
53,548,558	51,406,616	49,350,351	47,376,337	45,481,284	43,662,032
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1,517,209	1,456,521	1,398,260	1,342,330	1,288,636	1,237,091
55,065,767	52,863,137	50,748,611	48,718,667	46,769,920	44,899,123
55,392,267	52,895,637	50,781,111	48,751,167	46,802,420	45,225,623
19,833,390	19,320,994	18,546,854	17,803,680	17,090,233	16,111,324
2,637,727	2,518,840	2,418,148	2,321,484	2,228,687	2,153,601
944,447	920,047	883,184	847,794	813,821	767,206

7	8	9	10	11	12
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-	-	-	-	-	-
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
266,893	-	-	-	-	266,893
299,393	32,500	32,500	32,500	32,500	299,393
54,686,465	52,499,006	50,399,046	48,383,084	46,447,761	44,589,851
-	-	-	-	-	-
-	-	-	-	-	-
54,686,465	52,499,006	50,399,046	48,383,084	46,447,761	44,589,851
54,985,858	52,531,506	50,431,546	48,415,584	46,480,261	44,889,244
2,618,374	2,501,500	2,401,502	2,305,504	2,213,346	2,137,583
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Econ. LCOE
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Econ. LCOE
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Econ. LCOE
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Econ. LCOE
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Econ. LCOE
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Econ. LCOE
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Econ. LCOE
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Econ. LCOE
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Econ. LCOE
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Econ. LCOE
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Econ. LCOE

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Econ. LCOE
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Econ. LCOE
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Econ. LCOE
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0.17
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Econ. LCOE
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NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		-	18.9	48.0	
(6,259,834)		**49.1**	**14.6**	**43.6**	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		-	18.9	48.0	
(11,472,461)		113.4	27.9	56.9	
(9,126,077)		92.7	23.6	52.6	
(8,699,462)		88.9	22.8	51.8	
(6,566,386)		**70.0**	**18.9**	**48.0**	
(4,433,309)		51.1	15.1	44.1	
(2,300,233)		32.3	11.2	40.2	
(167,157)		13.4	7.3	36.3	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		-	18.9	48.0	
(6,566,386)		**70.0**	**18.9**	**48.0**	
(6,532,659)		69.5	18.9	47.9	
(6,498,932)		69.1	18.8	47.8	
(6,465,206)		68.6	18.7	47.7	
(6,431,479)		68.1	18.6	47.6	
(6,397,752)		67.7	18.5	47.5	

NPV		Financial CEA (USD/tCO2 mitigated)	

Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		-	18.9	48.0	
(6,259,834)		**49.1**	**14.6**	**43.6**	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		-	18.9	48.0	
(6,259,834)		50.0	14.8	43.8	
(6,259,834)		50.0	14.8	43.8	
(6,259,834)		50.0	14.8	43.8	
(6,259,834)		**50.0**	**14.8**	**43.8**	
(6,259,834)		50.0	14.8	43.8	
(6,259,834)		50.0	14.8	43.8	
(6,259,834)		50.0	14.8	43.8	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		-	18.9	48.0	
(6,566,386)		**70.0**	**18.9**	**48.0**	
(6,566,386)		62.5	17.4	46.4	
(6,566,386)		55.0	15.9	44.9	
(6,566,386)		47.5	14.3	43.3	
(6,566,386)		40.1	12.8	41.8	
(6,566,386)		32.6	11.3	40.3	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		-	18.9	48.0	
(6,259,834)		**49.1**	**14.6**	**43.6**	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	

(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		-	18.9	48.0	
(6,259,834)		186.9	17.3	51.5	
(6,259,834)		186.9	17.3	51.5	
(6,259,834)		186.9	17.3	51.5	
(6,259,834)		**186.9**	**17.3**	**51.5**	
(6,259,834)		186.9	17.3	51.5	
(6,259,834)		186.9	17.3	51.5	
(6,259,834)		186.9	17.3	51.5	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		-	18.9	48.0	
(6,566,386)		72.2	10.5	35.5	
(6,566,386)		70.8	14.3	41.3	
(6,566,386)		**70.0**	**18.9**	**48.0**	
(6,566,386)		70.5	22.9	52.8	
(6,566,386)		71.6	25.2	55.4	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	
(6,566,386)		-	18.9	48.0	
(795,615)		49.1	14.6	43.6	
(795,615)		49.1	14.6	43.6	
(795,615)		**49.1**	**14.6**	**43.6**	
(795,615)		49.1	14.6	43.6	
(795,615)		49.1	14.6	43.6	

NPV		Financial CEA (USD/tCO2 mitigated)			
Option 4: Wind Turbines		Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines	

(6,566,386)		-	18.9	48.0	
(6,259,834)		**49.1**	**14.6**	**43.6**	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	
(6,259,834)		49.1	14.6	43.6	

13	14	15	16	17	18
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
21.0	21.0	21.0	21.0	21.0	21.0

13	14	15	16	17	18
3.19	3.06	2.94	2.82	2.71	2.60
2.71	2.60	2.50	2.40	2.30	2.21
2.66	2.55	2.45	2.35	2.26	2.17
23,286	22,355	21,461	20,602	19,778	18,987
7,899	7,583	7,279	6,988	6,709	6,440

13	14	15	16	17	18
53,791,624	51,639,959	49,574,361	47,591,386	45,687,731	43,860,221
4,890,148	4,694,542	4,506,760	4,326,490	4,153,430	3,987,293
118,761	114,010	109,450	105,072	100,869	96,834
82,937	79,619	76,435	73,377	70,442	67,624
58,883,469	56,528,130	54,267,005	52,096,325	50,012,472	48,011,973
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	294,000	-
32,500	32,500	32,500	32,500	326,500	32,500
41,915,551	40,238,929	38,629,372	37,084,197	35,600,829	34,176,796
-	-	-	-	-	-

1,187,607	1,140,103	1,094,499	1,050,719	1,008,690	968,343
43,103,158	41,379,032	39,723,871	38,134,916	36,609,519	35,145,139
43,135,658	41,411,532	39,756,371	38,167,416	36,936,019	35,177,639
15,747,811	15,116,598	14,510,634	13,928,909	13,076,453	12,834,335
2,054,079	1,971,978	1,893,161	1,817,496	1,758,858	1,675,126
749,896	719,838	690,983	663,281	622,688	611,159

13	14	15	16	17	18
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
(840,000)	(840,000)	(840,000)	(840,000)	(840,000)	(840,000)
-	-	-	-	-	-
32,500	32,500	32,500	32,500	32,500	32,500
-	-	-	-	266,893	-
32,500	32,500	32,500	32,500	299,393	32,500
42,806,257	41,094,006	39,450,246	37,872,236	36,357,347	34,903,053
-	-	-	-	-	-
-	-	-	-	-	-
42,806,257	41,094,006	39,450,246	37,872,236	36,357,347	34,903,053
42,838,757	41,126,506	39,482,746	37,904,736	36,656,740	34,935,553
2,039,941	1,958,405	1,880,131	1,804,987	1,745,559	1,663,598
-	-	-	-	-	-

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
(7.7)	**(3.4)**	**24.2**
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
84.1	16.3	44.3
40.9	7.2	35.3
33.1	5.6	33.6
(6.2)	**(2.7)**	**25.4**
(45.4)	(10.9)	17.1
(84.6)	(19.1)	8.9
(123.9)	(27.4)	0.6

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
(6.2)	**(2.7)**	**25.4**
(6.8)	(2.8)	25.3
(7.4)	(2.9)	25.1
(8.0)	(3.0)	25.0
(8.6)	(3.2)	24.9
(9.3)	(3.3)	24.7

Economic CEA (USD/tCO2 mitigated)

Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
(7.7)	**(3.4)**	**24.2**
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	**(3.4)**	**24.2**
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
(6.2)	**(2.7)**	**25.4**
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
(7.7)	**(3.4)**	**24.2**
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2

(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
(27.2)	(4.0)	28.5
(27.2)	(4.0)	28.5
(27.2)	(4.0)	28.5
(27.2)	**(4.0)**	**28.5**
(27.2)	(4.0)	28.5
(27.2)	(4.0)	28.5
(27.2)	(4.0)	28.5

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4
(6.2)	**(2.7)**	**25.4**
(6.2)	(2.7)	25.4
(6.2)	(2.7)	25.4

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines
#DIV/0!	(2.7)	25.4
(33.0)	(18.8)	3.1
(33.0)	(18.8)	3.1
(33.0)	**(18.8)**	**3.1**
(33.0)	(18.8)	3.1
(33.0)	(18.8)	3.1

Economic CEA (USD/tCO2 mitigated)		
Option 2: Landfill Gas Plant	Option 3: Hydro-dam	Option 4: Wind Turbines

#DIV/0!	(2.7)	25.4
(7.7)	**(3.4)**	**24.2**
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2
(7.7)	(3.4)	24.2

19	20	21
1.0	1.0	1.0
1.0	1.0	1.0
1.0	1.0	1.0
21.0	21.0	21.0

19	20	21
2.50	2.40	-
2.12	2.04	-
2.08	2.00	-
18,228	17,499	-
6,183	5,935	-

19	20	21
42,105,813	40,421,580	-
3,827,801	3,674,689	-
92,961	89,242	-
64,920	62,323	-
46,091,494	44,247,834	-
-	-	(44,100,000)
32,500	32,500	-
-	-	-
32,500	32,500	(44,100,000)
32,809,724	31,497,335	-
-	-	-

929,609	892,424	-
33,739,333	32,389,760	-
33,771,833	32,422,260	(44,100,000)
12,319,661	11,825,575	44,100,000
1,608,183	1,543,917	(2,100,000)
586,651	563,123	2,100,000

19	20	21
-	-	-
-	-	-
-	-	-
(840,000)	(840,000)	-
(840,000)	(840,000)	-
-	-	(47,098,800)
32,500	32,500	-
-	-	-
32,500	32,500	(47,098,800)
33,506,931	32,166,654	-
-	-	-
-	-	-
33,506,931	32,166,654	-
33,539,431	32,199,154	(47,098,800)
1,597,116	1,533,293	(2,242,800)
-	-	-

Foreign exchange premium	8.50%

	Financial value	% traded
Value of production	2.31	0%
Investment cost (diesel)	1	80%
Investment cost (renewables)	1	80%
Recurring costs	1	80%
Operations and maintenance	1	25%
Fuel	1	90%

Effective subsidy/tax	Economic value	CF
40%	3.23	1.40
-15%	0.91	0.91
0%	1.07	1.07
-15%	0.91	0.91
0%	1.02	1.02
50%	1.61	1.61

Mitigation Pre-day Case Study Handout

Strategic Context

This case study is a fictional (although realistic) example of clean energy project alternatives in the context of Vietnam. The situation that this analysis would reflect is as follows:

The mission has XX million dollars to spend on GCC mitigation activities, and is trying to determine how to spend it. One option which has been proposed is to provide loan guarantees or co-financing to a power company which is exploring clean energy alternatives to diesel-based electricity production. The company is considering three alternatives: landfill gas, wind and small-scale hydro (run-of-the-river) power. The following analysis will attempt to answer several questions:

- Which alternative has the greatest potential to reduce GHG emissions?
- Which alternative has the greatest cost-effectiveness (USD invested/ton of CO2e mitigated)?
- What kind of incentives could induce the energy producer to switch to the preferred technology?

The analysis evaluates three clean energy technologies against a counterfactual which assumes that the energy produced by the project would instead be produced by a small-scale diesel-powered turbine electrical plant. The following paragraphs provide the relevant information on each energy generation technology that you will need for the case study.

Notes about the model:

- The model has been left partially blank, so you will need to fill in the blanks in order to complete the model and evaluate each intervention
- Cells in dark grey are blanks that need to be filled in during the course of the case-study. All other cells that need to be filled in for the model have already been completed.
- Cells highlighted in yellow are input cells, and can be hard-coded. All cells outside of the table of inputs should only use references, not hard-coding. If you enter any hard numbers in other cells in the model, it will not generate correct answers (particularly when you perform sensitivity analysis)
- Cells which are light grey should not be filled in.

General Parameters

The electricity generated as a result of this project will be fed into the grid and the firm will be paid a fixed price of 2,310 Vietnamese Duong (VND) per kilowatt-hour (kWh) generated by the utility, no matter how it is generated. The firm will pay a corporate income tax rate of 10% of the difference between revenues (the quantity of electricity generated * the price of electricity) and operations and maintenance costs. The financial discount rate for the firm is 15% per year, and the economic discount rate for the analysis is 12%. The exchange rate is 21,000 VND per US dollar. For each technology type, the recurring costs and fuel costs, if applicable, are in USD, since it is necessary to import these. The Vietnamese government provides a number of incentives to encourage clean energy production. These

include a production tax credit of 210 VND per kWh generated using certified clean energy methods (including LFG, wind and hydro), a 10% reduction in total income tax liability. Additionally, if the firm generates its electricity using clean energy, it is eligible to receive a payment for $2 per ton of CO2 equivalent (tCO2e) mitigated.

Project Flow Tables

Diesel Generator – counterfactual

The diesel generator costs 105,000,000,000 VND to purchase and requires one year to bring online (it is purchased and installed in year 0 and begins to produce electricity at the beginning of year 1). It has a useful life of 40 years, and at the end of the 20-year analysis period, it has a residual value of 21,000,000,000 VND. In addition to the initial investment, the generator requires recurring investments of 10,000 USD every five years, beginning in year 5 of operations. Operations and maintenance costs for the generator are 294 VND/kWh, and fuel costs are 5.6 cents/kWh.

The diesel generator has a nameplate capacity of 5 megawatts (MW), with a capacity factor of 85% and an availability factor of 90%. The capacity of the plant is projected to decline by 1% per year. The plant will produce 0.000424 tCO2e per kWh generated. The generator creates a negative environmental externality of 1,575,000,000 VND per year.

Landfill Gas Plant

The landfill gas plant (LFG) costs 147,000,000,000 VND over two years to purchase and requires two years to bring online (it is purchased and installed over years 0 and 1 and begins to produce electricity at the beginning of year 2). It has a useful life of 20 years, and at the end of the 20-year analysis period, it has a residual value of 41,100,000,000 VND. In addition to the initial investment, the plant requires recurring investments of 14,000 USD every five years, beginning in year 5 of operations. Operations and maintenance costs for the plant are 1,800 VND/kWh.

The LFG plant has a nameplate capacity of 5 megawatts (MW), with a capacity factor of 85% and an availability factor of 98%. The capacity of the plant is projected to decline by 4% per year. The plant will produce 0.0003392 tons of CO2 equivalent (tCO2e) per kWh generated. The plant generates a negative environmental externality of 840,000,000 VND per year.

Small Hydro Plant

The small hydro plant costs 302,400,000,000 VND over three years to purchase and requires three years to bring online (it is purchased and installed in years 0 through 2 and begins to produce electricity at the beginning of year 3). It has a useful life of 40 years, and at the end of the 20-year analysis period, it has a residual value of 60,480,000,000 VND. In addition to the initial investment, the plant requires recurring investments of 20,000 USD every seven years, beginning in year 7 of operations. Operations and maintenance costs for the plant are 1,230 VND/kWh.

The LFG plant has a nameplate capacity of 8 megawatts (MW), with a capacity factor of 65% and an availability factor of 85%. The capacity of the plant is projected to decline by 0.5% per year. The plant produces no CO2, and no negative environmental externality.

Wind Turbines

The wind turbines cost 504,000,000,000 VND to purchase and require one year to bring online (they are purchased and installed in year 0 and begin to produce electricity at the beginning of year 1). They have a useful life of 20 years, and at the end of the 20-year analysis period, they have a residual value of 126,000,000,000 VND. In addition to the initial investment, the turbines require recurring investments of 20,000 USD every five years, beginning in year 5 of operations. Operations and maintenance costs for the plant are 840 VND/kWh.

The LFG plant has a nameplate capacity of 12 megawatts (MW), with a capacity factor of 30% and an availability factor of 98%. The capacity of the plant is projected to decline by 0.5% per year. The plant produces no CO2, and no negative environmental externality.

<u>Questions based on the case:</u>

- What is the incremental financial NPV of each clean energy option? What do these NPVs indicate about the likelihood that these projects will be undertaken absent public intervention?
- What is the incremental economic NPV of each clean energy option? What do these NPVs indicate about the benefit to society of each of these alternatives?
- Given the financial and economic NPVs of each of these projects, would you recommend undertaking any of these alternative projects?
- Which alternative will decrease CO2 emissions by the greatest amount?
- Not including the benefits of reduced CO2 emissions, which alternative will have the greatest positive economic impact?
- In terms of the financial analysis of these alternatives, what would the market price of reduced CO2 emissions need to be (in USD/tCO2 mitigated) in order to make each alternative financially viable?
- In terms of the economic analysis of these alternatives, what would the economic value of reduced CO2 emissions need to be (in USD/tCO2 mitigated in order to make each alternative beneficial to society?
- For each alternative, what are some ways we might structure an intervention in order to make the alternative financially viable from the perspective of the power producer?
- Without having yet performed a sensitivity analysis, what do you think are some of the variables that most impact the value of each of the project alternatives?
- What are some simplifications, assumptions or other features of this model with which you don't agree? What are some ways that you can think of improving the structure of the model?
- What important questions about this project are not answered by this CBA? What are some other sources of information or analysis you would like to consider in order to make a decision about which project alternative you should support?

Financial and Economic Analysis of Climate Change Programs on Mitigation and Adaptation

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Juan A. B. Belt

USAID

Introduction

- **Purpose**
  - Show how these courses are components of wider initiatives
- **Outline**
  - Why CBA?
  - Progress in reintroducing CBA at AID: early efforts concentrated in Feed the Future
  - Main priorities going forward:
    - GCC
    - Power, water, roads, education

Why CBA?

CBA can help answer critical questions

- **Is this project beneficial for the economy/society?**
  - Is it financially sustainable? **Sustainability analysis is mandatory as part of project design**
  - Who are the winners and who are the losers?
  - What are the risk factors?
  - Are the benefits to society higher than the costs?
- **CBA is closely linked with Project Design & M&E**
  - CBA can help guide design process alongside LOGFRAME
  - Performance monitoring: CBA defines a without project situation, generates targets & identifies critical variables to monitor
  - Impact evaluation: CBA compares with and without the project scenarios. Ex-post economic rate of return a good summary statistic

Project Design, M&E and CBA in USAID Mid 1990s to 2010

Reintroducing CBA at USAID 2010-13

- 2010: Mary Ott & Gary Linden initiative
  - Arnold (Al) Harberger USAID Chief Economic Advisor
  - 25 USAID officers trained at Duke
  - Supply of USAID CBA analysts exceeded demand: **no CBAs were carried out**
- 2011: June BFS management mandates CBA of Feed the Future programs
- 2012: Getting ready for CBA in other sectors including power, roads, water, GCC
- 2013: Working in other sectors & greater emphasis on CPCs

CBA Training 2010 to 2013

	# of courses	# of participants
Four-week intensive course in CBA	4	90
Online course in CBA	2	130
Feed the Future Workshops	10	200
Project Design & CBA	2	30
GCC Mitigation	1	20
GCC Adaptation	1	30
RDMA: energy, agriculture, GCC	1	25
Pakistan CBA power and agriculture	1	25
Afghanistan CBA for power and agriculture	1	25
CBA for agricultural project design	1	25
Advanced Topics in CBA power, education, & health	1	25
South Africa CBA for government counterparts	1	40
Kenya CBA course for government counterparts	1	40
TOTAL	**27**	**705**

CBA of Feed the Future Programs

- **First Round**: Haiti, Uganda, Ghana, Tanzania, Rwanda, & Bangladesh
- Teams: E3/EP, BFS DLIs, & mission staff
- **E3/EP predominant role with help from G. Jenkins (CRI)**
- **Second Round**: Additional 13 countries
- Teams E3, BFS, & mission staff
- Trainings on CBA of agricultural projects
  - Regional workshops East Africa, West Africa, South Africa (2), Asia, Europe & Central America
  - Country workshops in Haiti and Kosovo
  - 200 USAID officers trained (mostly AG officers)
- **Reduced role for E3/EP in CBAs**

Findings from 14 *Feed the Future* Focus Countries: Radelet Model Validated

	Average	Median	Range
ERR* (%)	30%	22%	14%-64%

- Useful for new and on-going projects – but ***most useful at design stage***
- Important for ensuring sustainability of investments
- Most useful if model "installed" in the mission
- FSN participation critical
- Multidisciplinary effort necessary
- Field visits useful/necessary

* Modified IRR

** Excluding farmer costs

CBA/CEA into the Future

- Continue to support BFS
- New directions:
  1. Carry out CBA early in the project cycle
  2. Strive for impact on resource allocation
  3. Use CBA throughout the project cycle: design, monitoring, and final evaluation
  4. Train partner country officials
  5. Encourage greater use of CBA by partner countries
  6. Work in sectors other than agriculture such as power, water, education, transport, **GCC discussed next slide**

Should CBA be mandatory?

GCC Activities

- **PAST**
  - Eric Postel AA/E3 requested EP include GCC in CBA/CEA plans
  - Courses on Mitigation & Adaptation March 2013 Abt Associates
  - Hiring Bill Ward May 2013
- **PRESENT** Courses on Mitigation & Adaptation 2014
- **FUTURE TRAINING**
  - Mozambique
  - RDMA
  - El Salvador

- Courses based on actual projects
- Include partner government officials

Questions?

Points of Contact for Cost Benefit Analysis

- Juan Belt (jbelt@usaid.gov) (juan.a.b.belt@gmail.com)
- Eric Hyman (ehyman@usaid.gov)
- Sarah Lane (slane@usaid.gov)
- Jerrod Mason (jemason@usaid.gov)
- Kristen Schubert (krschubert@usaid.gov)
- Bill Ward (wward@usaid.gov)

More information on CBA @ AID

http://245elmp01.blackmesh.com/Strengthening_CBA_USAID_Juan_Belt/story_content/external_files/USAID-CBA-STRENGTHENING_CBA-FINAL.pdf

INTRODUCTION TO CLIMATE CHANGE MITIGATION AT USAID

APRIL 29, 2014

MATTHEW OGONOWSKI

E3/GLOBAL CLIMATE CHANGE OFFICE

GREENHOUSE GAS (GHG) TYPES AND SOURCES

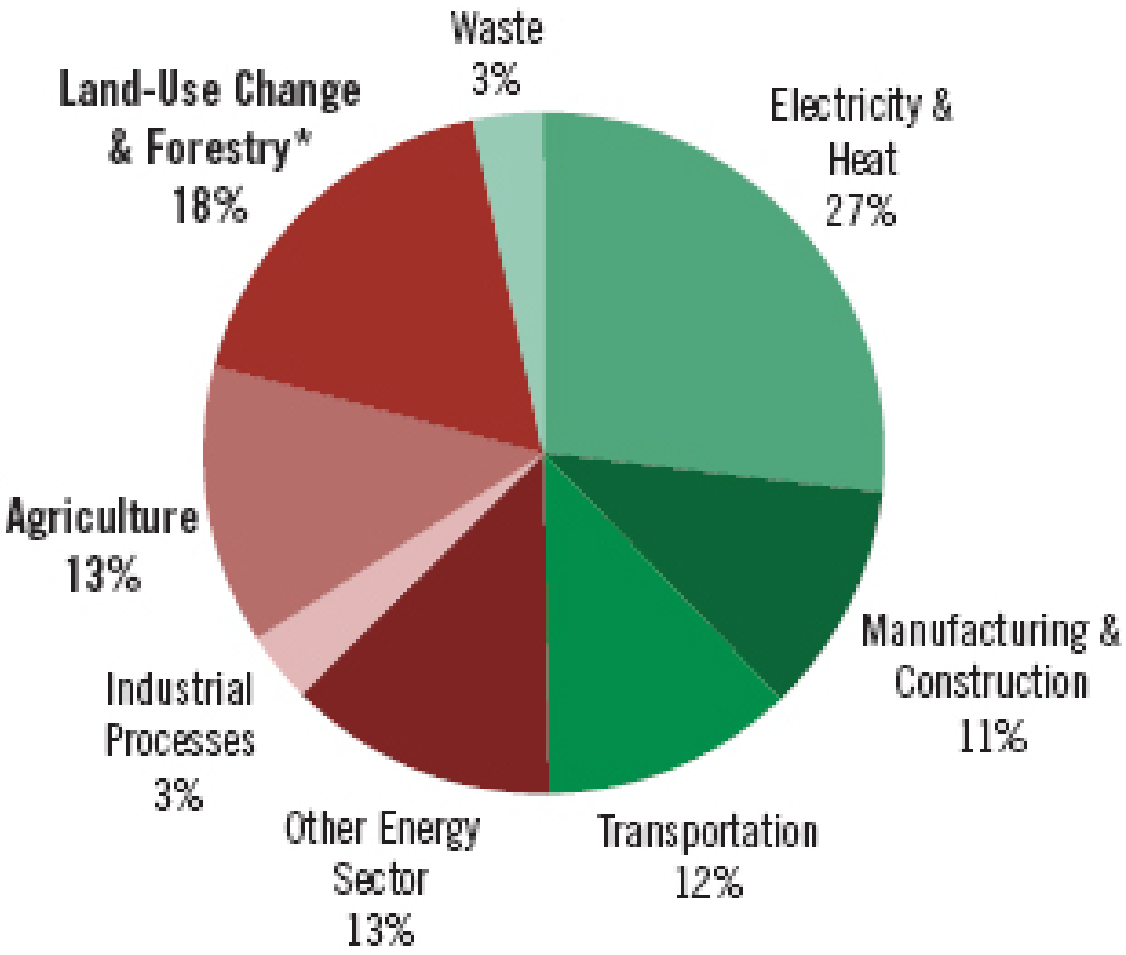
Main GHGs

- Carbon Dioxide (CO_2)
- Methane (CH_4) -- global warming potential 21 X CO_2
- Nitrous Oxide (N_2O) global warming potential 310 X CO_2

Key Sources

- Burning of fossil fuels for electricity, transportation, industrial production, etc.
- Land use change (land clearing, deforestation, forest degradation)
- Land use (agricultural methane and N_2O)

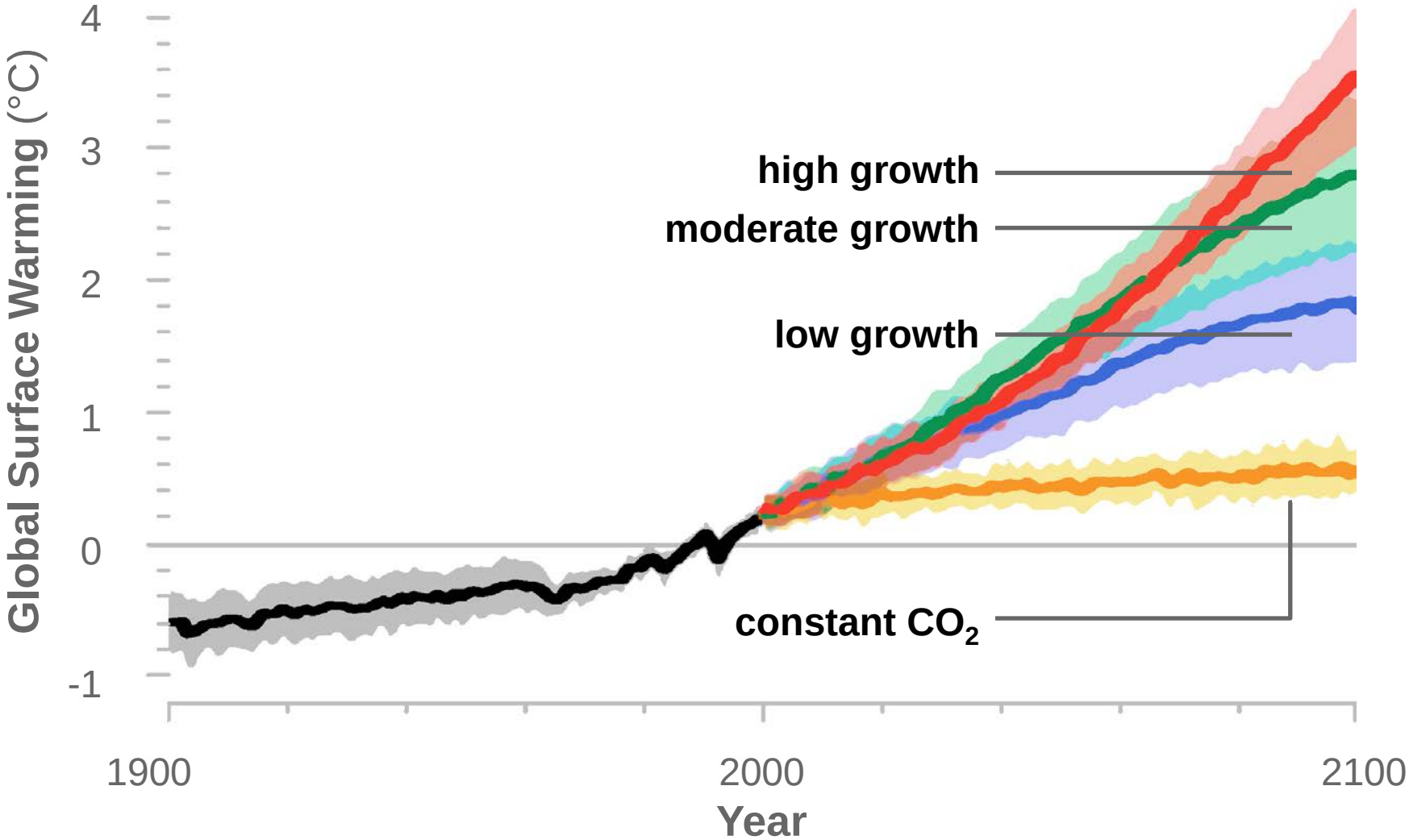
GLOBAL GHG EMISSIONS BY SECTOR



Source: http://earthtrends.wri.org

PROJECTED CLIMATE CHANGE

As emissions increase > average global temperature increases



Source: http://www.epa.gov/climatechange/science/futuretc.html

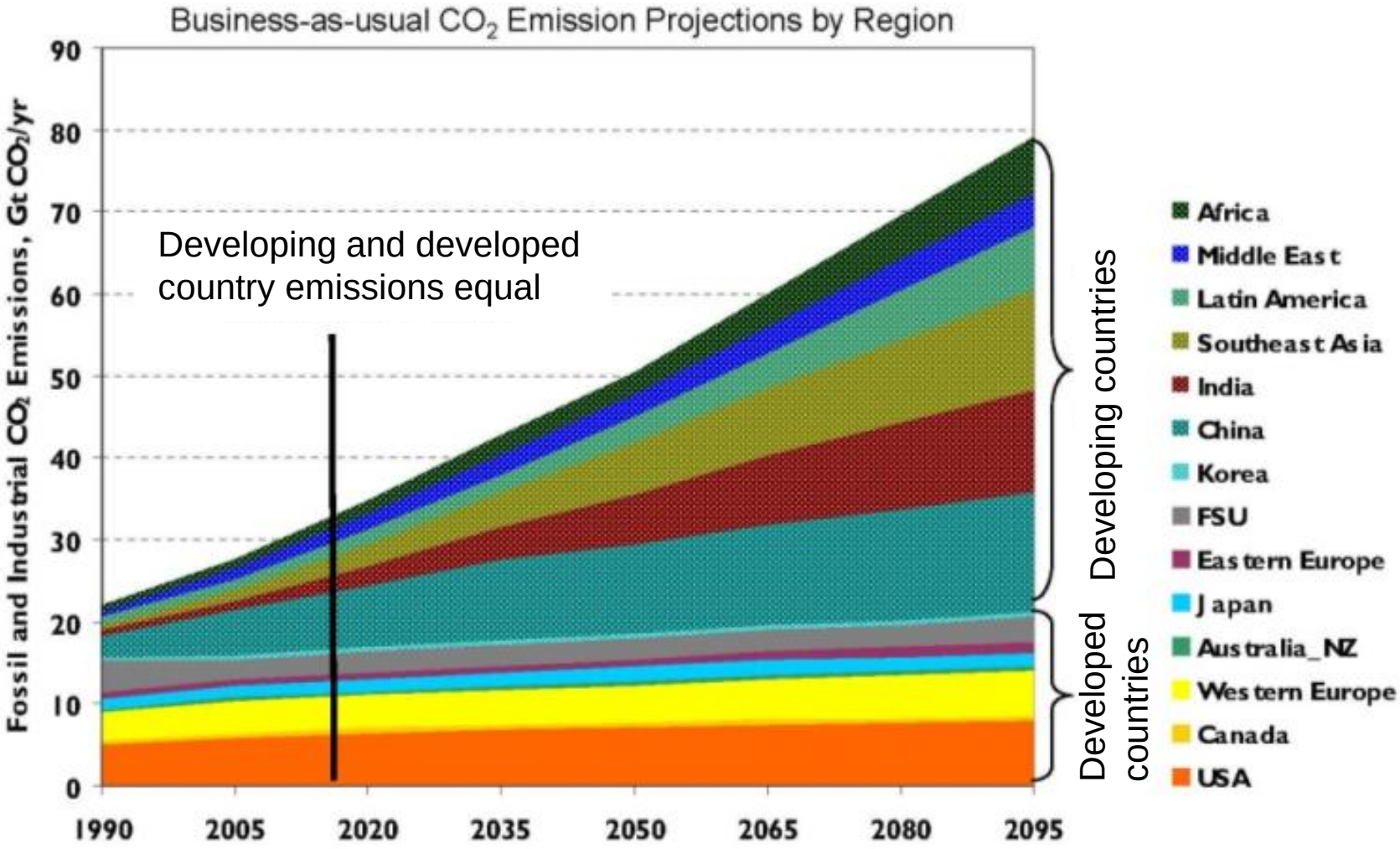
CLIMATE CHANGE IMPACTS

- Increasing average temperatures (with large increases or decreases in some countries, regions)
- More extreme weather events, including stronger storms
- Changing precipitation patterns (droughts, floods more common)
- Rising sea levels (submerges coastal lands, harm to local ecosystems)

Image source: Global Post

- Ocean acidification (leads to coral die-off, disruption of marine food chains
- Melting glaciers (additional sea level rise)

ALL NATIONS CONTRIBUTE TO GHG EMISSIONS



Data derived from *Global Energy Technology Strategy, Addressing Climate Change: Phase 2 Findings from an International Public-Private Sponsored Research Program*, Battelle Memorial Institute, 2007.

ADDRESSING GCC MAKES ECONOMIC SENSE

- Reducing GHG emissions **now** → avoids **future** climate change damages

- Difficult to accurately predict both climate change impacts and associated costs, and costs of mitigation…

- …but investing in climate change mitigation and adaptation NOW is a smart long-term investment.

UN FRAMEWORK CONVENTION ON CLIMATE CHANGE

- Adopted at Rio Earth Summit in 1992
- Sets overall framework for global response to climate change
- Objective:
  - *To stabilize greenhouse gas concentrations in the atmosphere at a level that will prevent dangerous anthropogenic interference with the climate system.*

www.unfccc.int

- *Common but differentiated responsibilities*
- Conference of the Parties (COP): Supreme decision-making body of the Convention. All States that are Parties to it are represented at the COP, at which they review progress and take decisions necessary for the effective implementation of the Convention.

UNFCCC: COPENHAGEN ACCORD

- Agreed in December 2009 in Copenhagen, Denmark at COP 15
- Not legally binding, but meaningful step forward
- Agreed to limit climate change to no more than 2 degrees Celsius by 2100
- $30 billion in climate finance pledged from developed countries (“fast start” finance) by 2012
- Developed countries also agreed to mobilize $100 billion in climate finance per year by 2020

COP15 COPENHAGEN

UNITED NATIONS CLIMATE CHANGE CONFERENCE 2009

UNFCCC: CURRENT STATUS

- In Warsaw last year at COP 19, countries agreed to develop a new international climate agreement
- Agreement to be finalized at COP 21 in Paris in December 2015, implemented starting in 2020
- Agreement will apply to all Parties
- Countries requested to make “nationally determined contributions” to global GHG mitigation

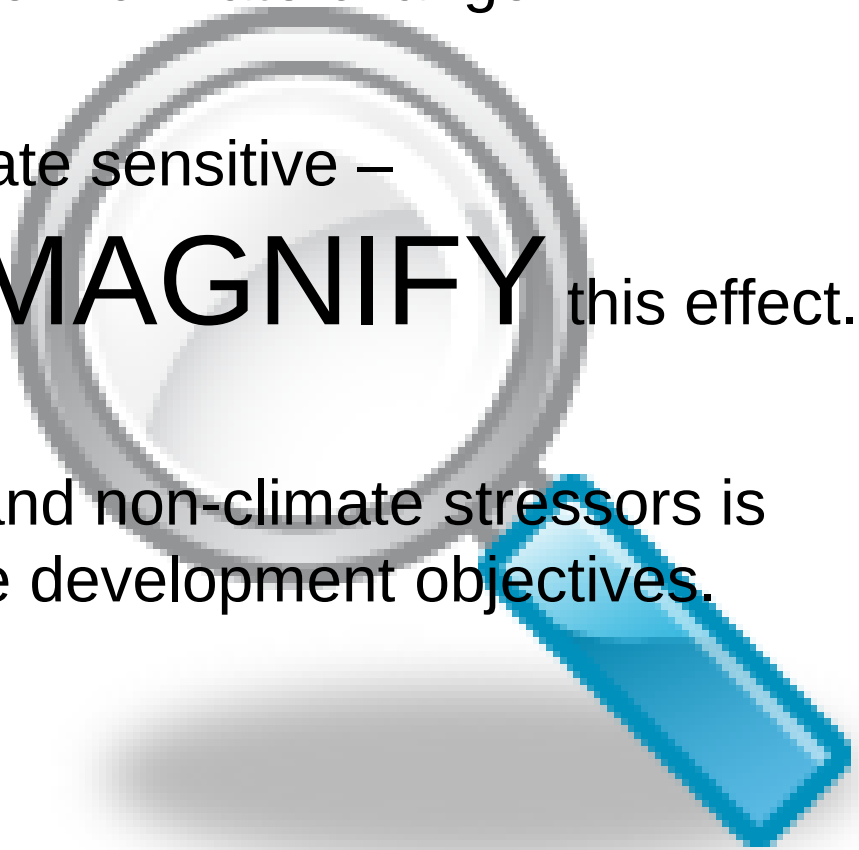
WHY CLIMATE CHANGE MATTERS FOR DEVELOPMENT (1)

- The poorest and most vulnerable people and countries will suffer the most from climate change.

- Development is climate sensitive –

  climate change will MAGNIFY this effect.

- Addressing climate and non-climate stressors is necessary to achieve development objectives.



WHY CLIMATE CHANGE MATTERS FOR DEVELOPMENT (2)

- Altering water availability
- Disrupting food production
- Damaging or destroying infrastructure
- Expanding the range of human and animal diseases
- Exacerbating existing environmental problems
- Contributing to migration
- Disrupting how people earn a living
- Causing conflicts over resources and governance problems

CLIMATE CHANGE: ADMINISTRATION/USAID PRIORITY

- President's Global Development Policy includes **Global Climate Change Initiative (GCCI)** in 2010
- One of USAID's top three priorities along with Feed the Future and Global Health
- Obama's 2013 **Climate Action Plan**: deploying clean energy and improved transportation in the United States to reduce emissions; preparing the country to adapt to climate change; promoting international action

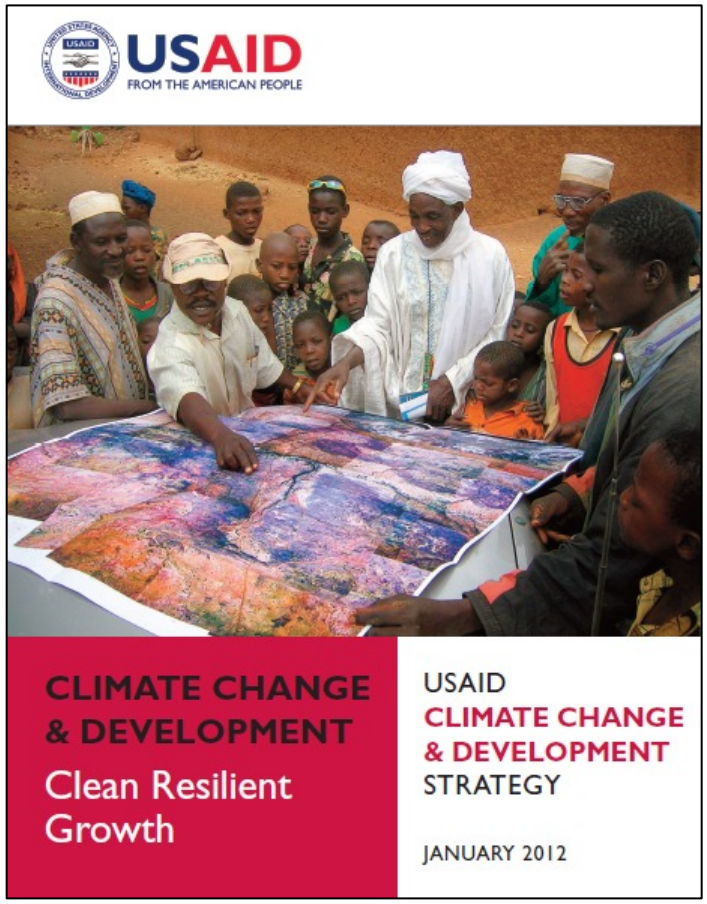
USAID
FROM THE AMERICAN PEOPLE

USAID CLIMATE CHANGE & DEVELOPMENT STRATEGY

USAID's Climate Change & Development Strategy (2012-2016)

Goal: Help countries accelerate their transition to climate resilient, low emission sustainable economic development

Overarching Principle: *Strengthen development outcomes through direct climate change program investments and by integrating climate change throughout USAID programming, learning, policy dialogues, and internal operations*



http://www.usaid.gov/climate/gccs

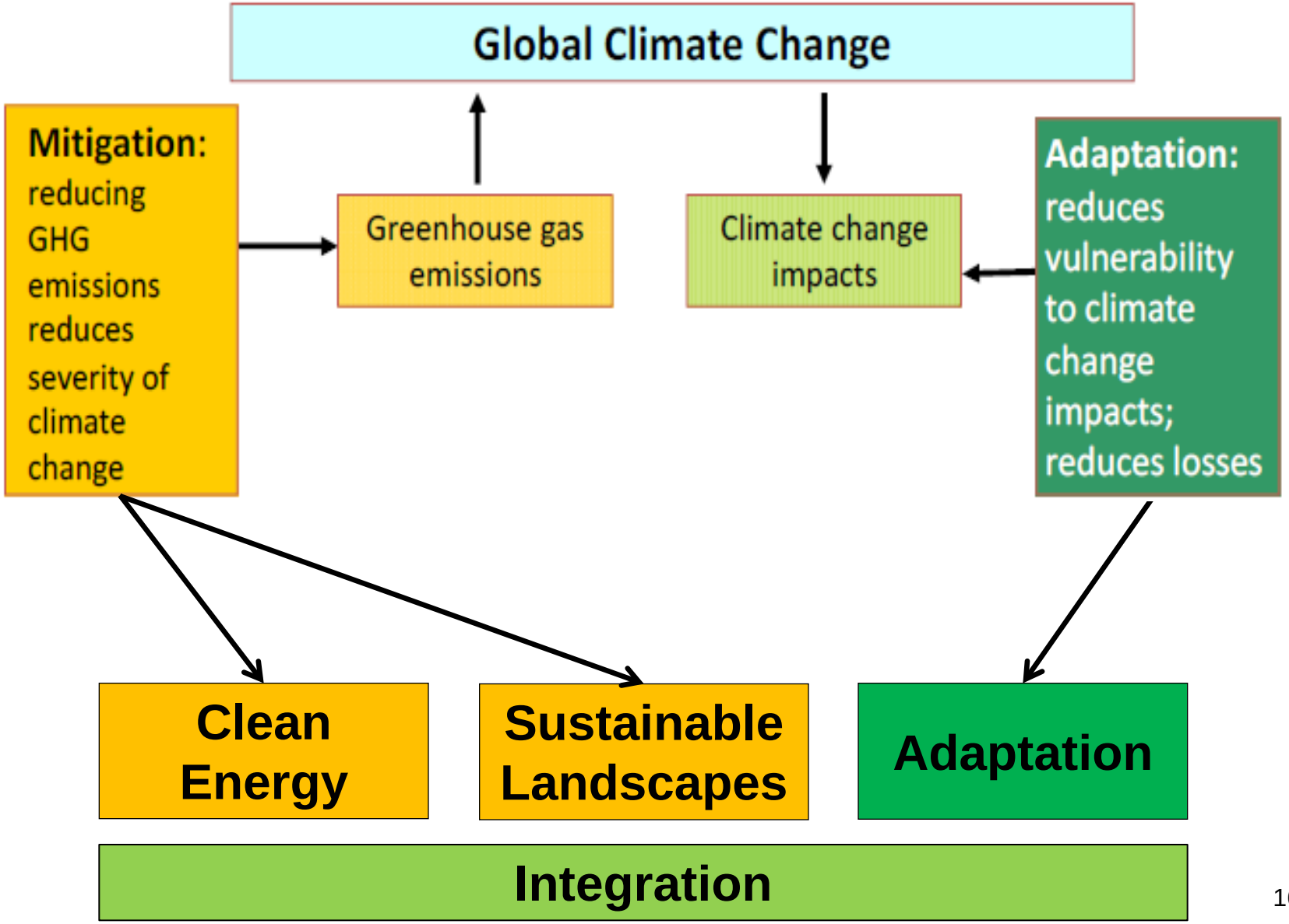
STRATEGIC APPROACH

- Emphasizes seeking **large and systemic impacts** by investing in enabling environments

- Highlights the importance of **mobilizing private sector resources**, which have the potential to be several orders of magnitude greater than foreign aid resources alone

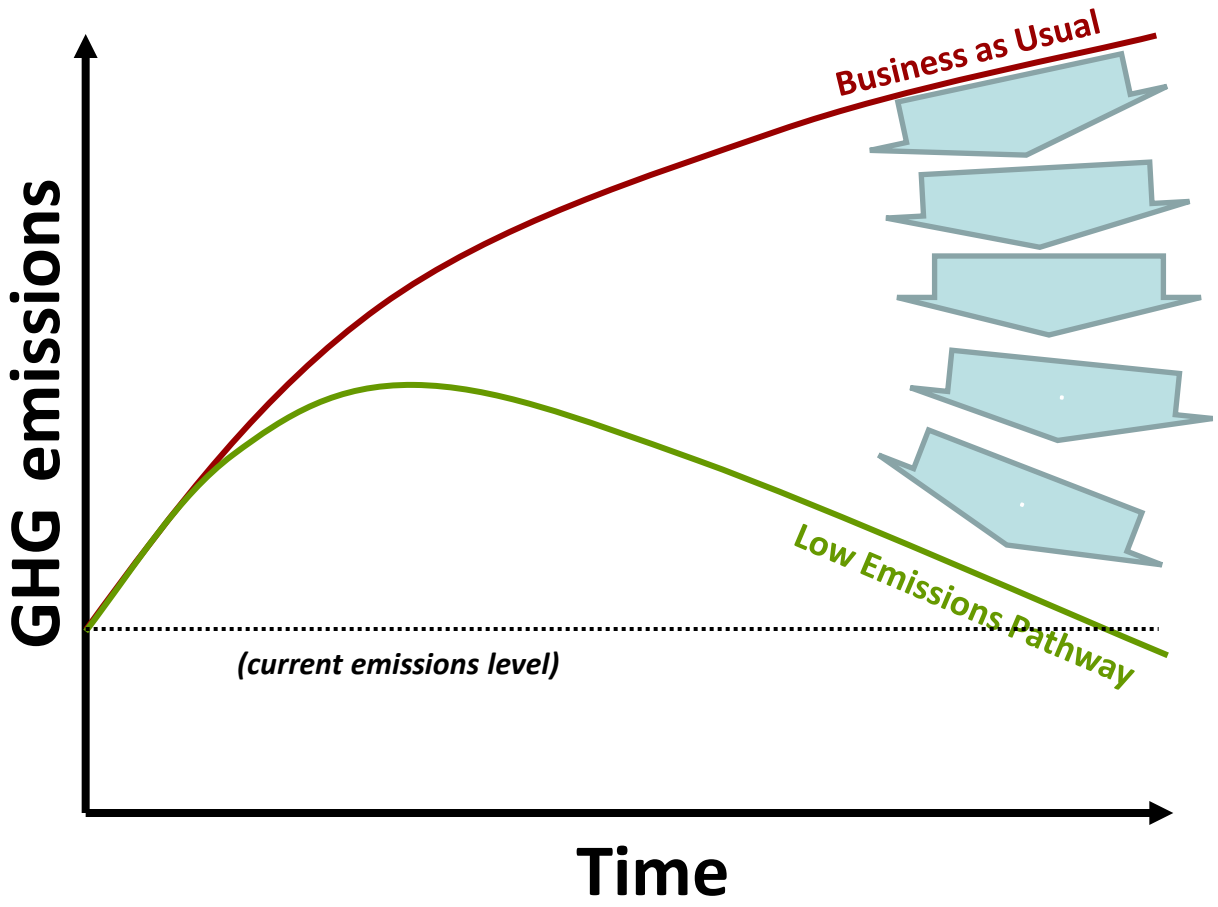
- Instructs that demonstration projects should have clear potential to **catalyze national policy or institutional changes**

USAID CLIMATE CHANGE APPROACH: THREE PILLARS



TO AVOID GOING BEYOND 2 DEGREES WARMING…

… we need to bend emissions curves



CLIMATE CHANGE & DEVELOPMENT STRATEGY: MITIGATION

Anticipated outcomes

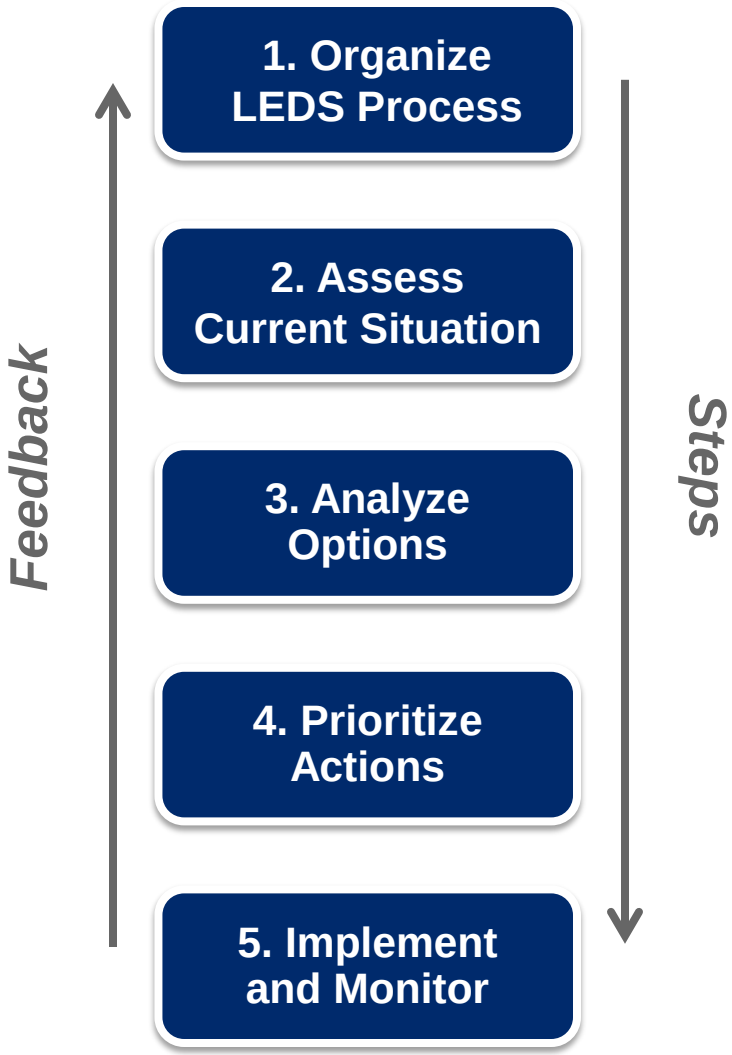
- Greenhouse gas **emissions reduced or sequestered** through expanded use of clean energy or improved ecosystem management
- Partner **countries implement** laws, policies, or regulations addressing climate change mitigation
- Increased number of **institutions with improved capacity** to address climate change mitigation
- **Public or private resources leveraged** for climate change
- **Low Emission Development Strategies** (LEDS) supported in 20 partner countries

WHAT IS A LEDS?

A Low Emission Development Strategy is…

- …a strategic economic development and environmental planning framework
- …that articulates **actionable** programs and policies
- …to put a country on a climate-resilient development path
- …while working toward long-term measurable GHG emission reductions.

ORGANIZING, DEVELOPING AND IMPLEMENTING LEDS



- Each step serves as a foundation for the next
- Feedback loops make the LEDS process iterative

WHAT IS THE ENHANCING CAPACITY FOR LOW EMISSION DEVELOPMENT STRATEGIES (EC-LEDS) PROGRAM?

A whole-of-government U.S. initiative to support partner countries' efforts to pursue long-term, transformative development and accelerate sustainable, climate resilient economic growth while slowing the growth of greenhouse gas (GHG) emissions

Objectives:

1. To provide **targeted technical assistance** for LEDS design and implementation
2. To build **global dialogue** and a shared international **knowledge base** on LEDS

EC-LEDS PRINCIPLES

- Focus on enhancing capacity of partner countries
- Build upon existing climate change-related strategies in partner countries
- Support partner country priorities and national development objectives
- Adopt a whole-of-government approach both for U.S. and partner countries
- Coordinate closely with other donors, existing processes, national programs

EC-LEDS US GOVERNMENT AGENCIES

EC-LEDS is a joint initiative led by USAID and the Department of State.

EC-LEDS brings to bear the resources and expertise of numerous U.S. Government agencies.

These agencies provide support through scoping, assessments, technical assistance, and capacity building activities.

EC-LEDS AND USAID MITIGATION PILLARS

- USAID funding for climate change mitigation includes Clean Energy (CE) and Sustainable Landscapes (SL)

- *In EC-LEDS partner countries, both Clean Energy and Sustainable Landscapes funding must be used for activities that support the improvement or implementation of a partner country's LEDS*

- Promotes large-scale action and long-term sustainability

MISSIONS RECEIVING GCC MITIGATION FUNDS FY2013

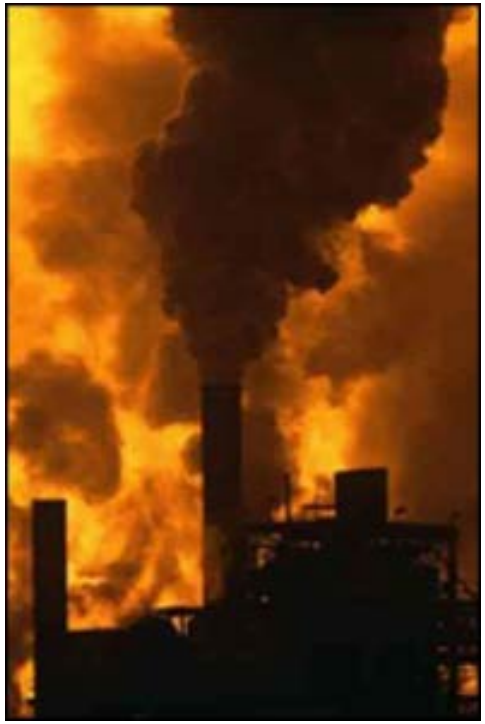
- **Clean Energy**: Bangladesh, Barbados, Ghana, India, Indonesia, Kazakhstan, Philippines, Vietnam, Colombia, Mexico, Kenya, South Africa, Georgia, Ukraine
- Regional missions RDMA, East Africa, Southern Africa, West Africa, ECAM

- **Sustainable Landscapes**: Bangladesh, Cambodia, Ecuador, India, Indonesia, Nepal, Philippines, Vietnam, Colombia, Guatemala, Jamaica, Mexico, Peru, Malawi, Zambia
- Regional missions RDMA, West Africa, Central Africa, ECAM

CLEAN ENERGY: BASICS

The Issue: Energy is crucial for development, but increasing fossil fuel energy use exacerbates climate change

- GHG emissions from developing countries rising
- BUT billions of people in poor countries need modern energy



The Response: Achieve economic growth without significant increases in GHG emissions through **energy efficiency** and **renewable energy** development

CLEAN ENERGY: COMMON OBJECTIVES

Why should developing countries promote CE?

What benefits does it bring to a country/economy?

1. Economic growth and stability
2. Energy security
3. Greenhouse gas (GHG) reductions

CLEAN ENERGY (CE) PILLAR: CONTEXT

- Developing countries making **energy investments** now that will impact **long-term** energy consumption and GHG emissions

- USAID sees energy as a **critical and cross-cutting input** with significant development impacts
  - Ex. Energy sector reform can strengthen democracy and governance

- USAID CE programming addresses **barriers to clean energy** development and deployment in developing countries
  - Ex. National policies and planning frameworks, energy sector reform, and creating and/or strengthening the enabling environment

CLEAN ENERGY (CE) PILLAR: DEFINITION

- **Goal:** enable countries to accelerate their transition to low emission development through investments in clean energy

- Programs work toward one or both of the following results:
  - **National frameworks for low emission development established or improved**
  - **Clean energy use and investment enabled**

- Support activities that **reduce, mitigate and/or sequester greenhouse gases** that contribute to global climate change

- Support and promote the **sustainable use of renewable energy technologies and end-use energy efficiency technologies, carbon sequestration** [in forests and other lands] **and carbon accounting**

ELIGIBLE CLEAN ENERGY PROGRAMMING EXAMPLES (1)

- Assistance to develop and implement **Low Emission Development Strategies (LEDS)**
- **Renewable energy generation** and **demand-side energy efficiency**
- Strengthening **GHG inventory and accounting systems** and promoting **measurement, reporting and verification** (MRV) systems, including carbon market readiness
- Developing or improving the **enabling environment** (policies, laws, regulations and institutions) for sustainable renewable energy and/or end-use energy efficiency programs

LEVERAGING PRIVATE SECTOR INVESTMENT

- Development Credit Authority (DCA) Guarantees
- Global Development Alliance (GDA)
- Private Financing Advisory Network (PFAN)

SUSTAINABLE LANDSCAPES: BASICS

The Issue:

- Landscapes are a significant source of GHG emissions in developing countries, and are the primary source in many

The Response:

- Preserve forests through **Reducing Emissions from Deforestation and Forest Degradation**, and conservation, sustainable management of forests and enhancement of forest carbon stocks **(REDD+)**
- Reduce emissions from **agricultural lands** and other landscapes that are significant sources of emissions through policy and on-the-ground engagement

FOREST AND AGRICULTURE MITIGATION

- **Avoiding losses** of carbon stocks
  - Reducing deforestation and forest degradation

Reducing GHG emissions

- **Increasing** carbon stocks
  - Replanting or creating forests
  - Developing agroforestry
  - Sustainable forest management

Removing GHG emissions

- **Reducing** emissions from **agriculture**

SUSTAINABLE LANDSCAPES (SL) PILLAR: CONTEXT

- Many countries already working with the World Bank Forest Carbon Partnership Facility, and the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD). USAID investments aim to build on these efforts.
- Where national REDD+ planning processes do not exist, USAID investments can lay the groundwork for such processes
- Key aspects of early action will include institutional and human capacity building, as well as creating enabling environments through policy actions

SUSTAINABLE LANDSCAPES (SL) PILLAR: DEFINITION

- **Goal:** Slow, halt, and reverse emissions from land use
  a) National frameworks for low emission development established or improved, and
  b) Capacity in partner countries for national scale implementation of low emission development strategies in the land use sector increased

- SL funds contribute to moving a country to a low emission, high-sequestration development pathway in the land use sector

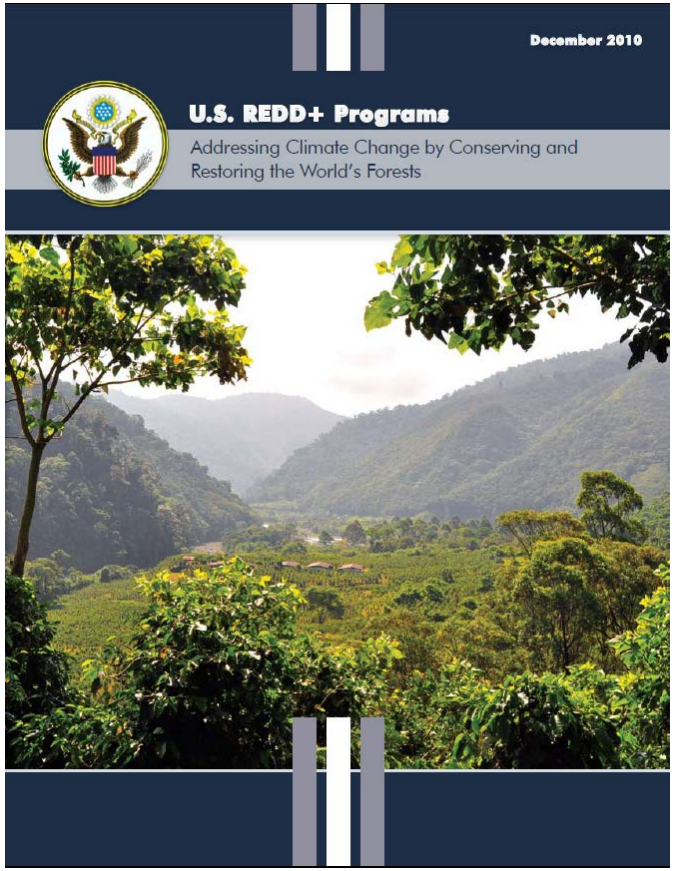
EXAMPLES OF ELIGIBLE FOCUSED SL ACTIVITIES

- Direct/focused SL funded activities: Have primary goal of reducing emissions or building national or sub-national capacity for planning/implementation of low emission development
- Creating or improving national or sub-national **LEDS or REDD+ strategies**
- Implementing or improving **measurement, reporting and verification (MRV)** systems
- Establishing or strengthening **effective institutions** that support low emission development
- **Field-level land use practices** that result in quantified sequestration and are linked to national or sub-national mitigation plans or strategies

EXAMPLES OF ELIGIBLE INDIRECT SL ACTIVITIES

- Indirect activities: Primary purpose not climate change mitigation, but achieve forest conservation/emission reduction benefits
- Supporting a **forest conservation** project that leads to reduced impact logging and less deforestation
- Improving **land tenure systems**, creating incentives for communities to manage and restore forested areas, increasing carbon sequestration
- Supporting an **agricultural activity** that promotes the adoption of no-till systems and incorporation of agricultural residue, leading to **lower use of nitrogen fertilizers**

USG COMMITMENTS: REDD+ STRATEGY



- U.S. pledged $1 billion under Copenhagen Accord
  - FY2010-FY2012 timeframe
  - Part of "fast start financing" of developing country support
  - USG achieved its $1 billion goal
- Goal: Help countries that put forward "ambitious REDD+ plans"
- Objectives:
  - REDD+ Global Architecture
  - **REDD+ Readiness**
  - REDD+ Demonstration

REDD+ READINESS

Common elements of REDD+ Readiness

- **National REDD+ Strategy**
  - ✓ Governance structure / REDD+ implementation plan
  - ✓ Creates plan / road-map for achieving reductions
- **Legal infrastructure**
  - ✓ Carbon rights and ownership
  - ✓ Dispute resolution mechanisms
- **Social and financial infrastructure**
  - ✓ Consultation process and mechanisms
  - ✓ Funding streams and benefits distribution
- **Measurement, reporting and verification (MRV) systems**
  - ✓ Balancing quality and cost, uncertainties and risks

USAID SUPPORT: GHG MITIGATION IN AGRICULTURE

- International Food Policy Research Institute (IFPRI): Modeling impacts of increased agricultural production on GHG emissions in Bangladesh, Colombia, Vietnam
- US Environmental Protection Agency (USEPA): Methodologies for estimating agricultural emissions for national GHG inventories
- Center for International Forestry Research (CIFOR): Understanding and estimating landscape-level emissions
- Development of MRV for GHG emissions from rice in Vietnam
- Participating in various “climate smart” agriculture activities (with Bureau for Food Security)

Integrating Economic and Policy Analysis in Sustainable Landscapes for Low-Emission Development

April 30, 2014

Evan Notman & Matthew Ogonowski

E3/Global Climate Change Office

OUTLINE

- Land-use emissions intro
- Project level approaches to reducing emissions
  - Approaches
  - Challenges
- National or Large Scale approaches
  - Opportunity Costs and Marginal Abatement Cost Curves
  - Other benefits and Costs

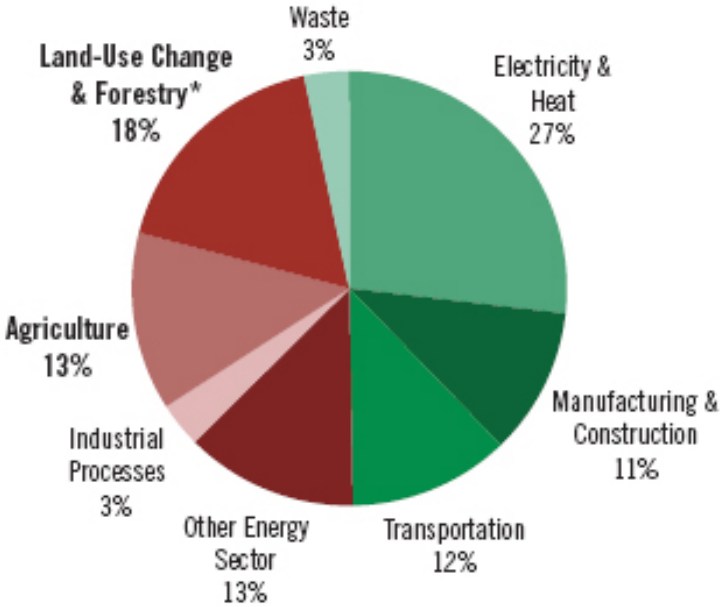
- Low emission development planning and implimentation
- Conclusion

Why do Forests and Land USE Matter for Climate Change?

- GHG Emissions from Agriculture, Forestry and other Land Uses (AFOLU) account for 20-25%* of global emissions
  - *This has declined from 25-30% of total over last 10 years (IPCC 2014 data)

- Huge potential source of future Emissions if deforestation increases.

- Low cost mitigation potential with additional associated benefits



Causes Of Deforestation

- Standing forests are not valued
- Ecosystem services provided by forests are not captured by markets
- Un-occupied lands used as political escape valve – incentivizing or allow migration to low population areas
- Perverse incentives often tying land tenure claims to forest clearing.

Bauxite mining in Suriname

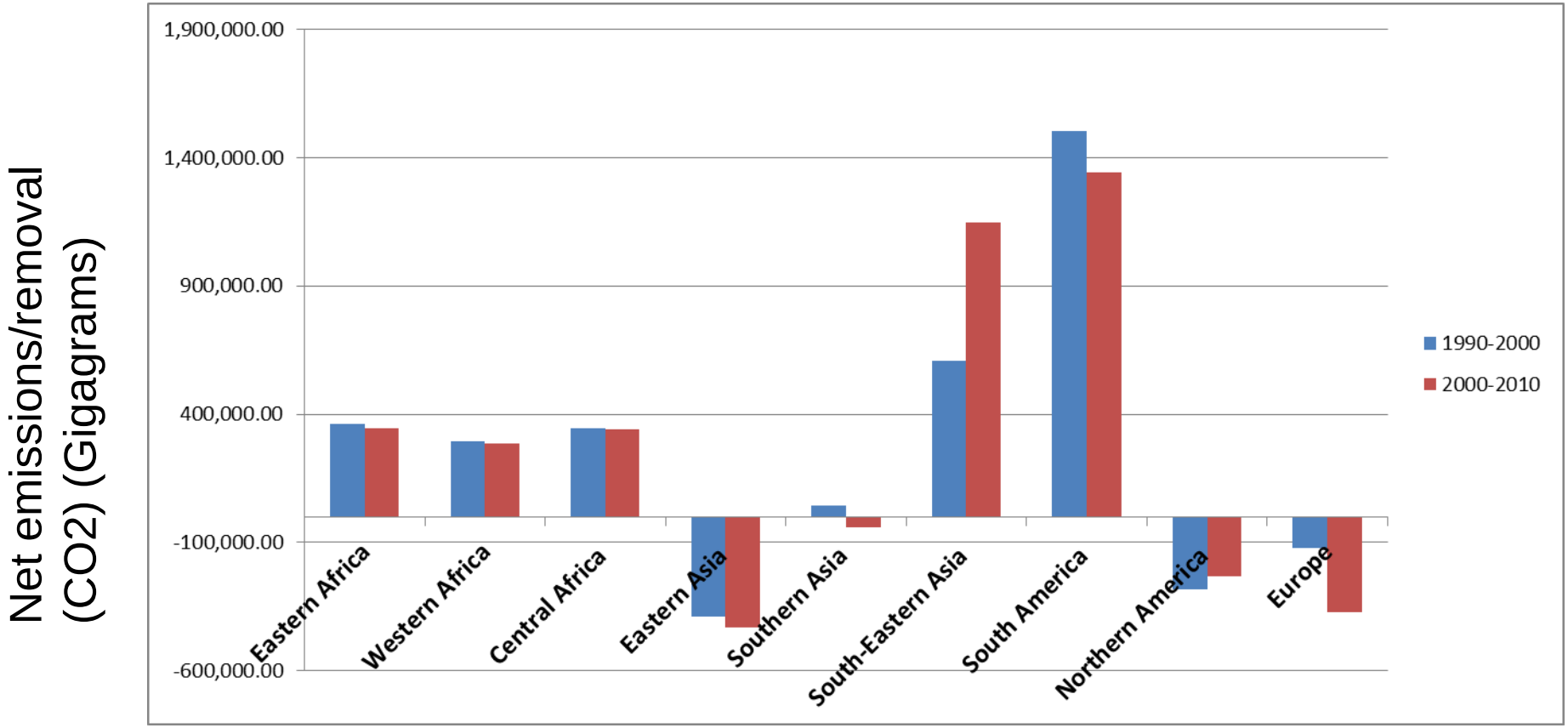
Incomplete market incentives drive forest losses

- **For a private good:** Landholder receives compensation from commodity markets (soy, beef, timber, shrimp,…) for extractive behavior: S/he cannot fully capture the value from other ecosystem benefits

- **For a public good:** Non-monetized forest ecosystem services (e.g., habitat, biodiversity, carbon sequestration) benefit all but there are not easy ways to charge for these services

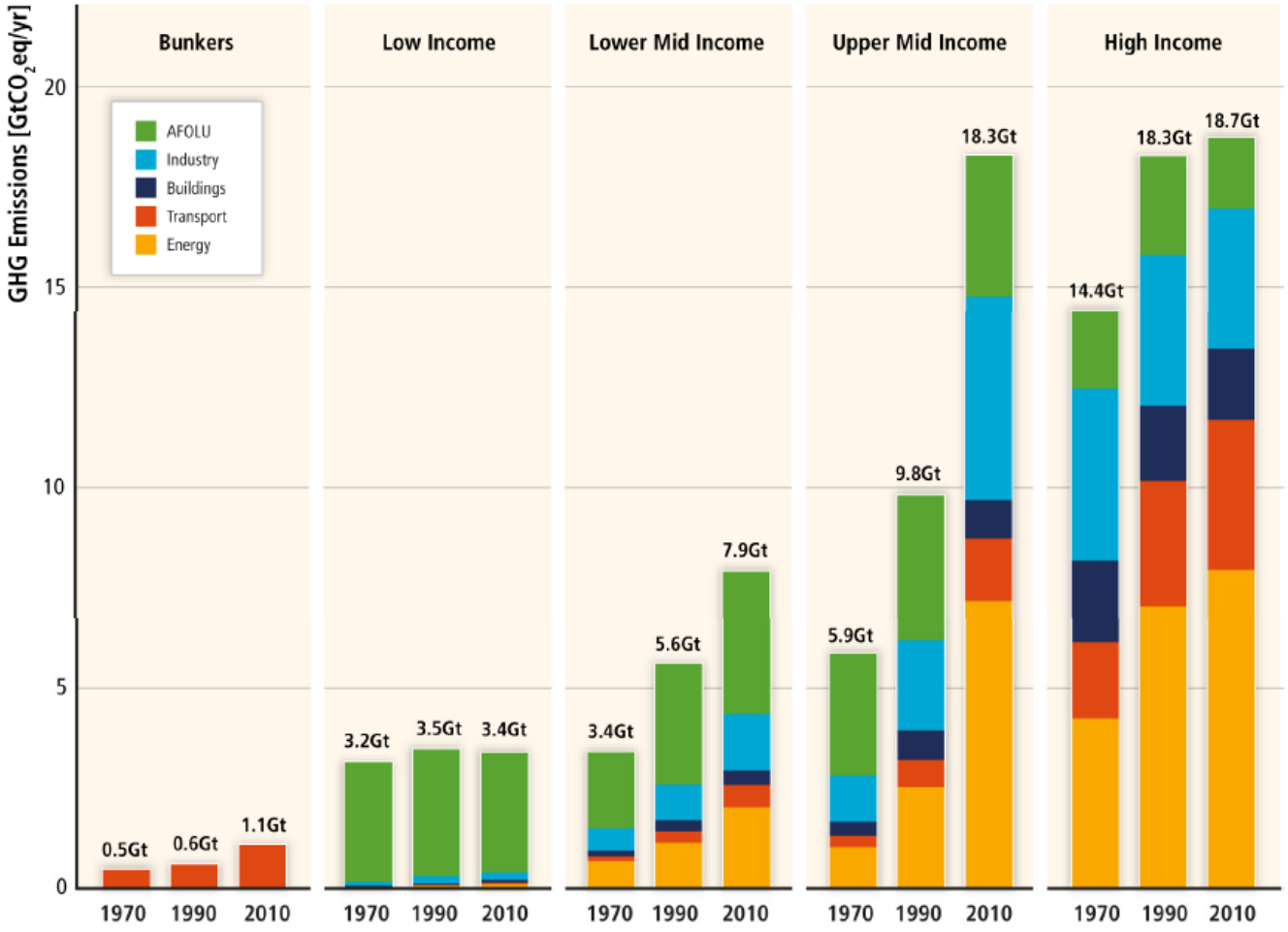
- **Externality:** Extraction negatively affects downstream parties (e.g., water consumers) but this cost remains external to the transaction

Emissions by regions



Source: FAOSTAT data 2013

Emissions From Land Use In Developing Countries



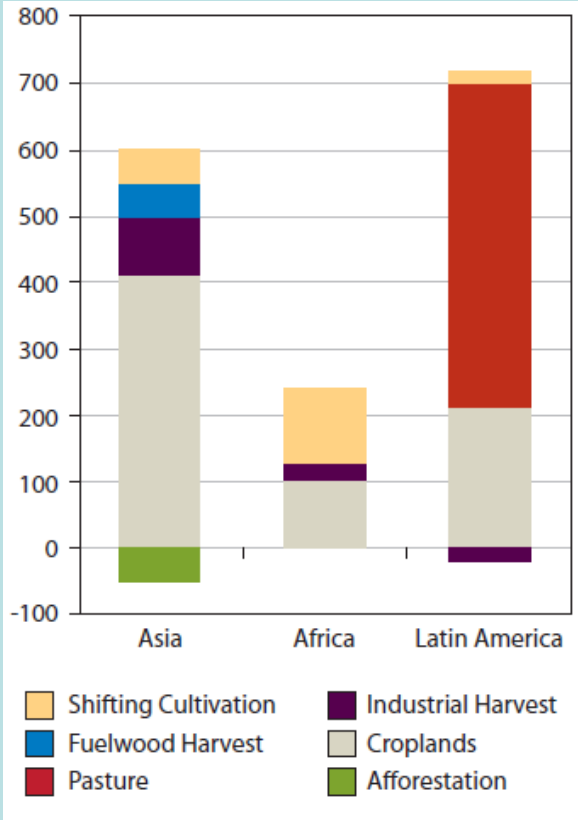
Allocation of GHG emissions across sectors and country income groups

Deforestation/Degradation Drivers By Region

S/SE Asia –
Palm oil, logging, and aquaculture

Congo Basin –
Logging, and subsistence, small-scale agriculture

Amazon –
Large scale agriculture, grazing and Road-building



Sources of Carbon Emissions from Deforestation and Degradation in Tropical Regions

Boucher et al. 2011

Potential fixes

- **Regulate:** Prohibit overuse & protect
  - not easily legislated and enforced in many settings

- **Policy incentives:** Policies not based on direct compensation
  - Change agricultural loan requirements, allow land rights not based on land use conversion

- **Alternative Livelihoods:** **Promoting and implementing alternative economic activities**
  - sustainable forest management, agroforestry, ecotourism, non-timber forest products

- **Compensate:** **change financial/market incentives**
  - Compensate for provision of public goods to retain sustainable landscapes, offer payments for ecosystem services (PES)
  - Payments to reduce CO_2 emissions from Deforestation and forest Degradation and sustainable management of forests, conservation of forest carbon stocks and enhancement of forest carbon stocks (REDD+)

Assessing SL projects benefits and costs (CBA)

- At the project level need to decide if a project should take place.
- Use the best practices to quantify the benefits and costs of sustainable landscape projects.

OVERALL ASSESSMENT APPROACH

- **Financial assessment:** Compare present value of alternative land uses (project versus baseline use, e.g., agriculture)
  - Identify, quantify and monetize all benefits and costs
  - Select time frame for assessment (20 yr+) and discount rate for future benefit/cost flows
    - Financial decision making: opportunity cost of capital
  - Economic: social rate of time preference
- **Environmental assessment**
  - Does the project support/undermine other environmental objectives?
- **Institutional assessment: can this work?**
  - Social assessment/Local buy-in
  - Benefit-sharing
  - Legal: Ability to enforce agreements

SL PROJECT BENEFITS

- **Benefits (monetized and non-monetized)**
  - Carbon
  - Non-carbon: selective logging, multi-cropping options (agro-forestry), watershed management, eco-tourism, non-timber forest products, biodiversity
  - Social

ASSESSING COSTS OF SL PROJECTS

- **Start-up (pre-project) costs:**
  - Project planning
  - Assessment
  - Registration

- **Implementation costs:**
  - Capital costs
  - Ongoing operating and maintenance costs
  - Measurement, reporting and verifying (MRV)

Assessing SL carbon benefits

- **Process:**
  1. **Estimate amount of GHGs saved** (not released to atmosphere) from sustainable land management from avoided deforestation and/or degradation: tCO_2e/yr
     a) Estimate GHG reference baseline w/o project
     b) Estimate GHG absorption w/project

  2. **Know carbon market value** and the social cost of carbon of SL projects: $/$tCO_2e$

- **Potential carbon stock pool categories:**
  - Live biomass: Above and below ground
  - Dead wood, litter, soil
  - Harvested wood products

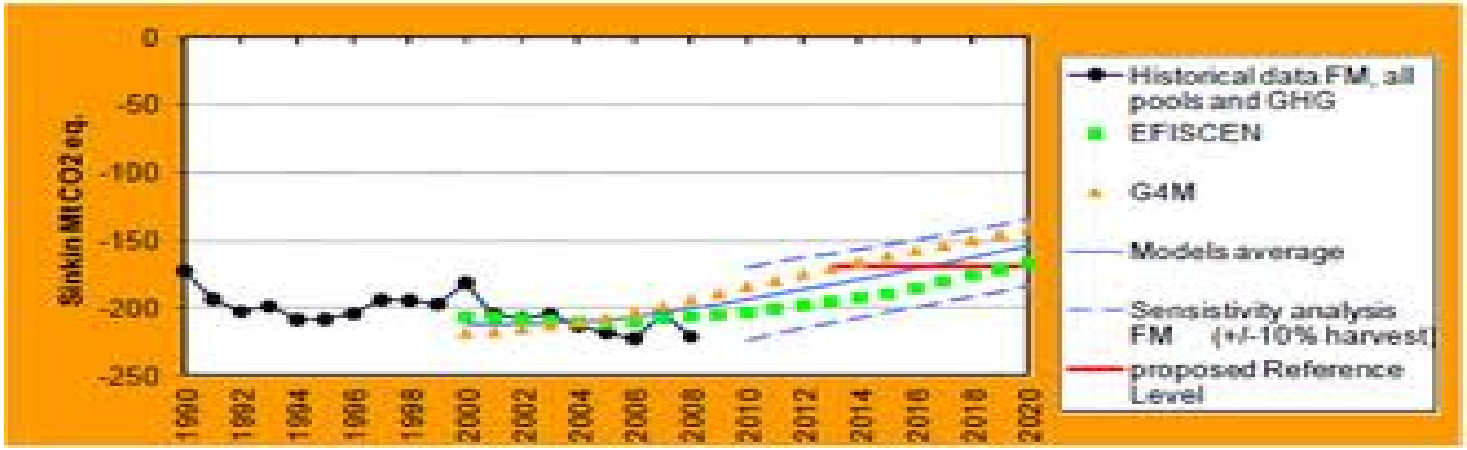
ESTABLISHING SL GHG REFERENCE (BASELINE)

- **Challenge:** estimating the counterfactual Business As Usual (BAU) baseline emissions (without project)

- **Baseline carbon stock:**

  $S^B_t = A^B_t * D^B_t$

  - A^B_t = Forest area in baseline, Year t
  - D^B_t = Carbon density of forest area



GHG RELEASE AVOIDED (EMISSIONS SAVED)

- **Project emissions**
  - An estimate of the carbon trajectory within the project boundaries expected to occur ***if project took place (ex ante), or actual emissions (ex post)***
- **Net GHGs saved/avoided release:** Compare baseline to the actual project emissions to quantify reduction credits

$$C^C_t = [S^P_t - S^P_{t-1}] - [S^B_t - S^B_{t-1}] - \text{adjustments*}$$

Where

- $\mathbf{C^C_t}$ = Credits issued at the end of period t (tCO_2e)
- $\mathbf{S^P_{t\,(t-1)}}$ = Observed carbon stock in place in the project area at the end of period t (t-1)
- $\mathbf{S^B_{t\,(t-1)}}$ = Crediting baseline: estimated carbon stock that would be in the project area at the end of period t (t-1) if the project did not take place

WHAT ARE ISSUES WITH THE BASELINE?

- **Data needs**
  - Forest area:
    - Initial: GIS, inventory,…
    - Area change: Land use model, qualitative estimation
  - Carbon density (tCO2e/ha):
    - Initial: default factors, sampled data
    - Change : forest stand models, observed degradation trends
- **Ex-Post monitoring of project emissions easier:**
  - Quantifying actual carbon stocks as the project proceeds is (somewhat) more straightforward

Carbon market benefits approach

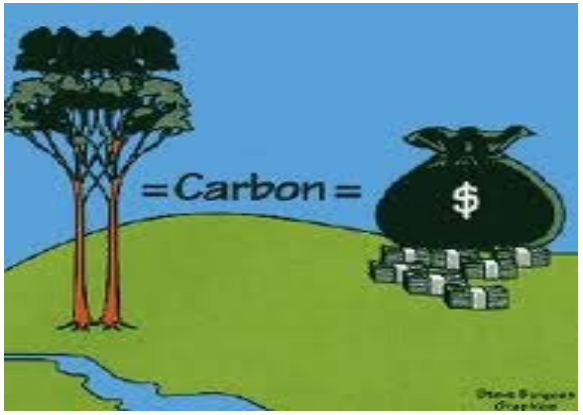
- Developing country carbon buyers (compliance or voluntary regimes) pay carbon benefits over time period (t)

$$\text{Carbon benefits (\$)} = \mathbf{C^C_t * V^C_t}$$

- $\mathbf{C^C_t}$ = Credits issued at the end of period t (tCO_2e)
- $\mathbf{V^C_t}$ = Market value of credits ($/$tCO_2e$)

Current Market Prices:

- USA carbon projects ~ $10/per ton
  - No price discovery yet
- non-USA projects~ $6-10 (Ecosystem Marketplace)
- CDM < $1 (A/R only)



triplepundit.com

WHAT ARE ISSUES WITH CARBON CREDITS AT THE PROJECT LEVEL?

- **Uncertainty**
  - Uncertainty “haircuts”/reserves: Crediting registries have protocols that require projects to take a discount on their credits
  - Provides incentive for better methods
- **Leakage**
  - Shifting land use (deforestation/degradation) to another place
    - Local activity shifting
    - Distant shifting via markets
  - Diminishes net benefits, various methods for estimating leakage using economic models
- **Permanence**
  - Buffers to protect against carbon “reversals” – future loss of credited carbon from natural or human-caused disturbance

MONETIZING NON-CARBON BENEFITS

- Ecosystem services of retained forest (e.g.)
  - Sustainable harvests
  - Non-timber forest products (NTFP)
  - Water quality provision
  - Micro-climate regulation
  - Species habitat (consumption and existence values)
  - Cultural and aesthetic values

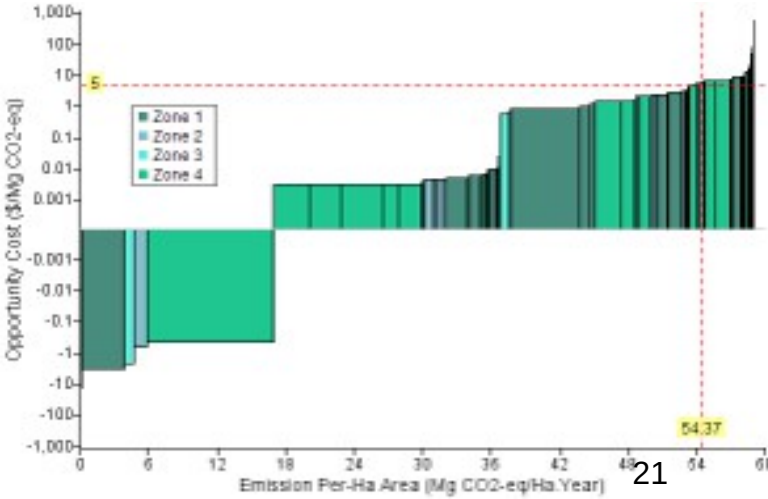
- These can all be valued in principle, using a variety of market and non-market valuation methods
  - **See other presentations in this workshop**

OTHER COSTS OF SL PROJECTS

- **Opportunity costs**
  - What economic opportunities do landholders/resource users forego in order to engage in the project: revenue from timber, agriculture, development,… ?
    - "Land rents" – net returns from alternative land uses
    - Estimation – using budget data, existing land values, econometric models
    - Usually 80% or more of REDD+ costs*

Guardian

Worldforestry.org



- **Q: Will buyers pay each seller their actual costs or will they pay more (price determined on the margin)?**
- **Other social costs**
  - Access to forests for locals
  - Loss in local economic activity?

Working at the National or Jurisdictional scale

OPPORTUNITY COST VS. MARGINAL ABATEMENT COST

- Opportunity cost (OC): Net present value (NPV) of benefits forgone
  - From land-use activities (e.g., timber harvesting, agriculture) not undertaken (to achieve GHG mitigation)
  - Expressed as average dollars per hectare or per ton of emissions avoided over the time period

- Marginal abatement cost (MAC): NPV of difference in opportunity and other costs (implementation, transaction) minus benefits of REDD+ and other actions, expressed in dollars per ton.

- In climate policy related to mitigation from forests and other land use, OC and MAC analysis are **both** important (used interchangeably here)

OCs/MACs: APPLICATIONS (1)

- Estimate costs of REDD+, agricultural mitigation projects

- Identify likely future drivers of deforestation

- Identify forest/land areas most likely to be prioritized for development
  - Can help determine candidate areas for REDD+, improve spatial planning

OCs/MACs: APPLICATIONS (2)

- Estimate potential leakage patterns
- Evaluate impacts of REDD+ programs across different social groups (see World Bank, *Estimating Opportunity Costs of REDD+ at the Country Level*, 2009)
  - Helpful in designing benefit distribution systems
  - But need to account for political decisions as well as economics
- Estimate levels of payment for Payments for Ecosystem Services (PES) programs

OCs/MACs: ANALYTICAL CHALLENGES

- Key data often uncertain, difficult to obtain
  - Historical rates of deforestation can be volatile, disputed
  - Future growth of drivers of deforestation (e.g. commodities)
  - Illegal activities (e.g., logging, mining)
  - Valuation of some ecosystem services

- Whether to discount emissions (tons) avoided when benefits occur far in future >> increases OCs/MACs

OCs/MACs: BASELINES AND ADDITIONALITY

- Baselines: Estimate what would have happened under BAU conditions
  - Smallholder degradation difficult to estimate
  - Whether/what portion of timber in year 1 is assumed to be sold, consumed locally or burned can have major impact on NPV

Additionality: Must demonstrate that mitigation actions to be undertaken would **not** have happened under BAU

- Easiest to do with projects involving businesses holding official permits for forest clearing/land development
- How to address in reducing emissions from “protected” areas
- Conservation also challenging

OCs/MACs: APPLICATION CHALLENGES (1)

- **Diverse expertise needed for accurate OC/MAC analysis often lacking in developing countries**
  - Experience in adapting past forest/land management experience to climate policy limited
- **Ecosystem services**
  Which to include?
  Include potential as well as existing uses?
- **Less helpful for developing incentives to address deforestation driven by production of high value commodities**
  - e.g., mining, palm oil, illegal activities

OCs/MACs: APPLICATION CHALLENGES (2)

- OCs typically understate costs
  - Estimating implementation/transaction costs can be more difficult than OCs
  - OCs/MACs do not account for changes in prices and supplies >> broader economic impacts

- Evaluating the full cross-sectoral impacts of GHG mitigation in forests/other lands requires more detailed economic and policy analysis at the macro level

POTENTIAL MACROECONOMIC IMPACTS OF SL PROJECTS

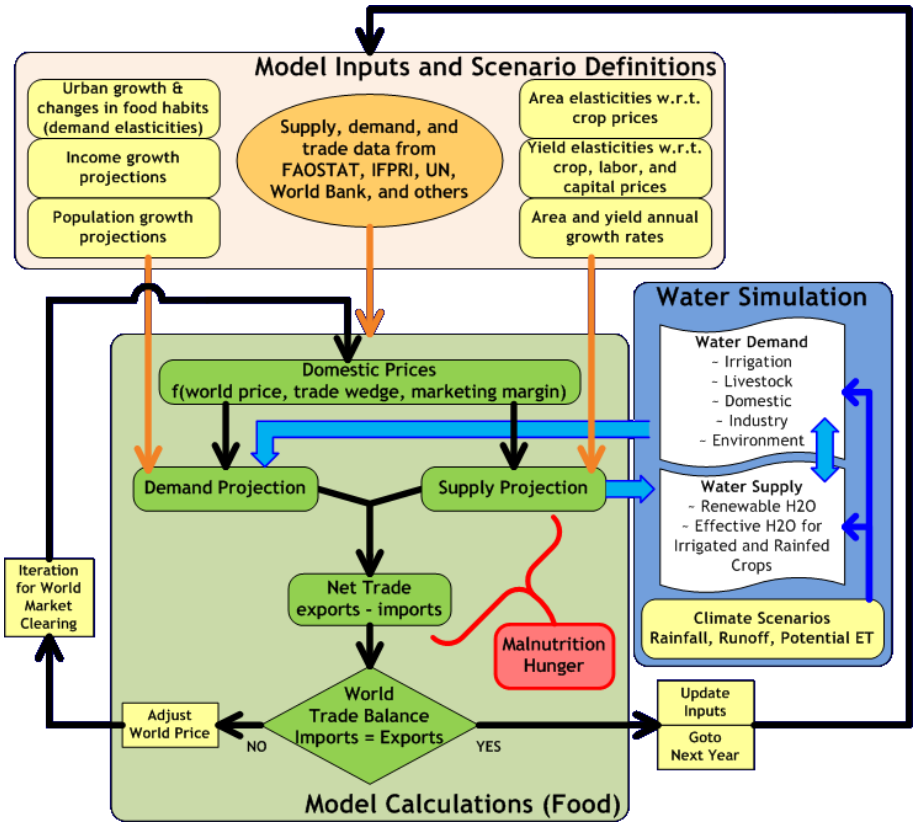
- Decreased production: timber, agricultural commodities, minerals/fuels
- Increased prices of raw materials used as inputs to other sectors, finished goods
  - Potential impacts on **food supplies/prices** very controversial
- Increased imports of raw materials

POTENTIAL MACROECONOMIC IMPACTS OF SL PROJECTS

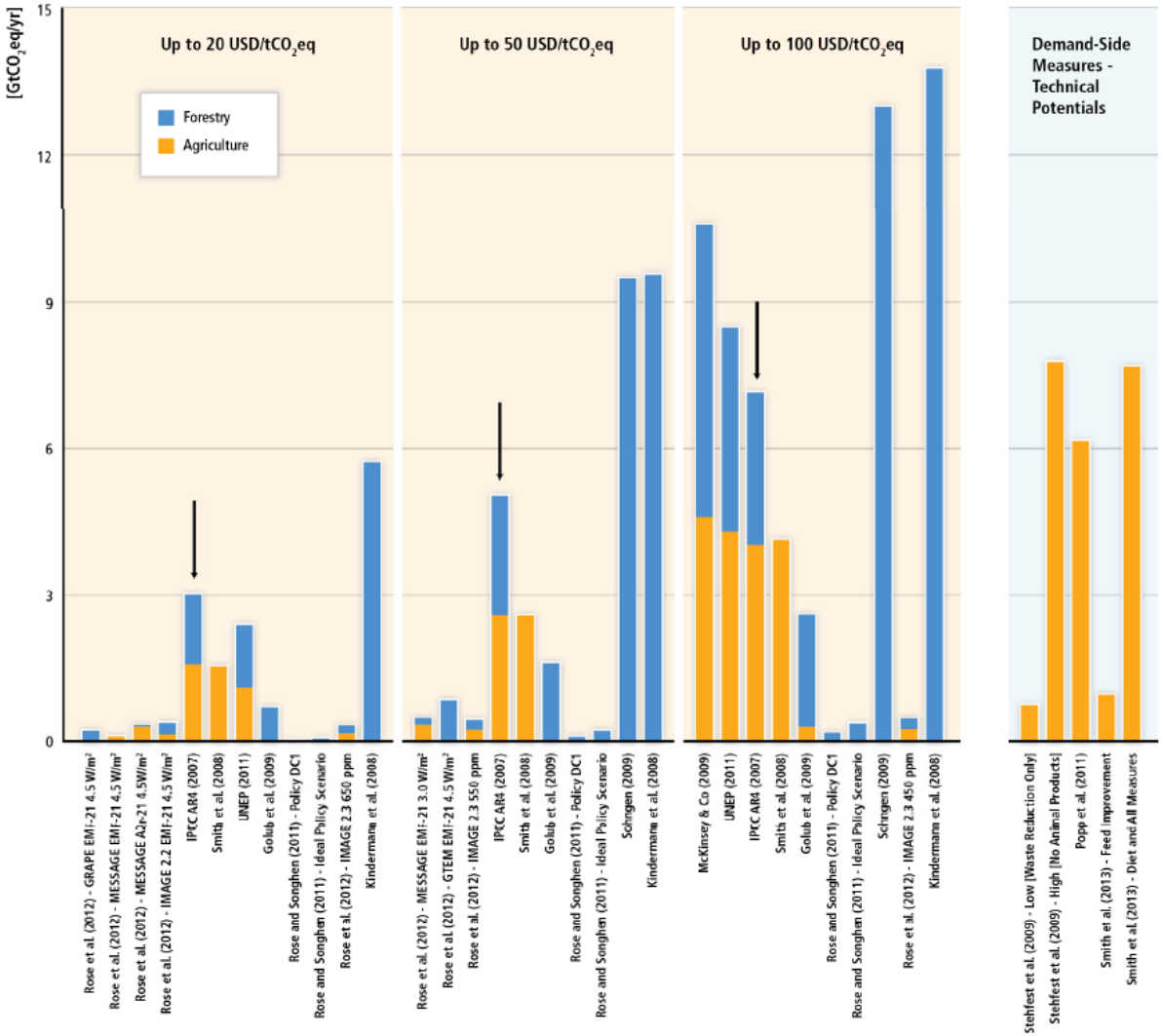
- Production of non-timber forest products (NTFPs)
- Development of ecotourism, agroforestry activities
- Changes in forestry/agricultural employment
- Increased transportation bottlenecks (compared to BAU)
  - Can occur if roads through protected forests/lands not built
- Increased forest degradation
  - Potential in forest areas previously slated for clearing
- Emissions leakage

MACROECONOMIC ANALYSIS: MODELS AND TOOLS

- IFPRI Impact model
- INVEST (Integrated Valuation of Environmental Services and Tradeoffs)
- Millennium Institute's Threshold 21 (T21) dynamic simulation tool



Economic Mitigation Potentials In The AFOLU Sector



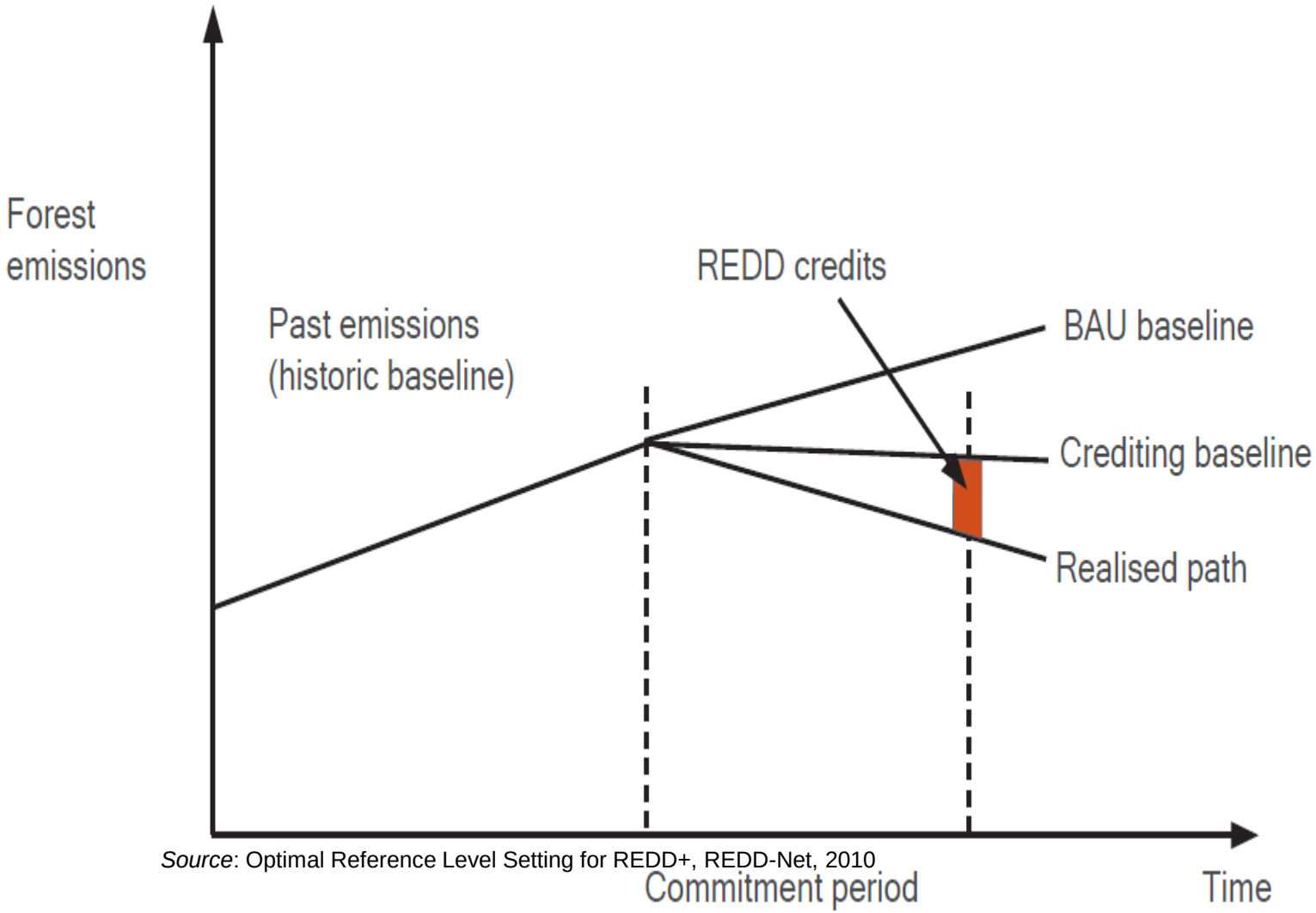
Modeling mitigation potential at global scale

LEDS IMPLEMENTATION: MRV AND CREDITING

- Measurement, Reporting and Verification (MRV):
  - Degradation difficult to measure -- very site-dependent
  - Also challenging with conservation, sustainable management of forests – are no standard, universally accepted methodologies

- Crediting baselines
  - REDD+ projects typically use projected/BAU baselines to estimate credits for sale
  - Historical or hybrid crediting baselines produce greater net reductions globally

REDD+ CREDITING BASELINES



Source: Optimal Reference Level Setting for REDD+, REDD-Net, 2010

LEDS IMPLEMENTATION: LAND AND CARBON RIGHTS

- Defining consistent land and (in programs designed to generate credits for sale) carbon rights is key to effective SL projects
- Tenure rights are frequently unrecognized, overlapping or violated in many countries
  - Makes it difficult to apply economic analysis to design/implementation of real-world policies
  - Can generate mistrust, opposition to mitigation efforts
  - Can reduce incentive effectiveness
- Need transparent, legal arrangements for land/carbon rights and dispute resolution

LEDS IMPLEMENTATION: LEAKAGE AND PERMANENCE (NATIONAL SCALE)

- Leakage
  - Integrated multi-regional, cross-sectoral land use planning, increased monitoring, tailored incentives to local conditions

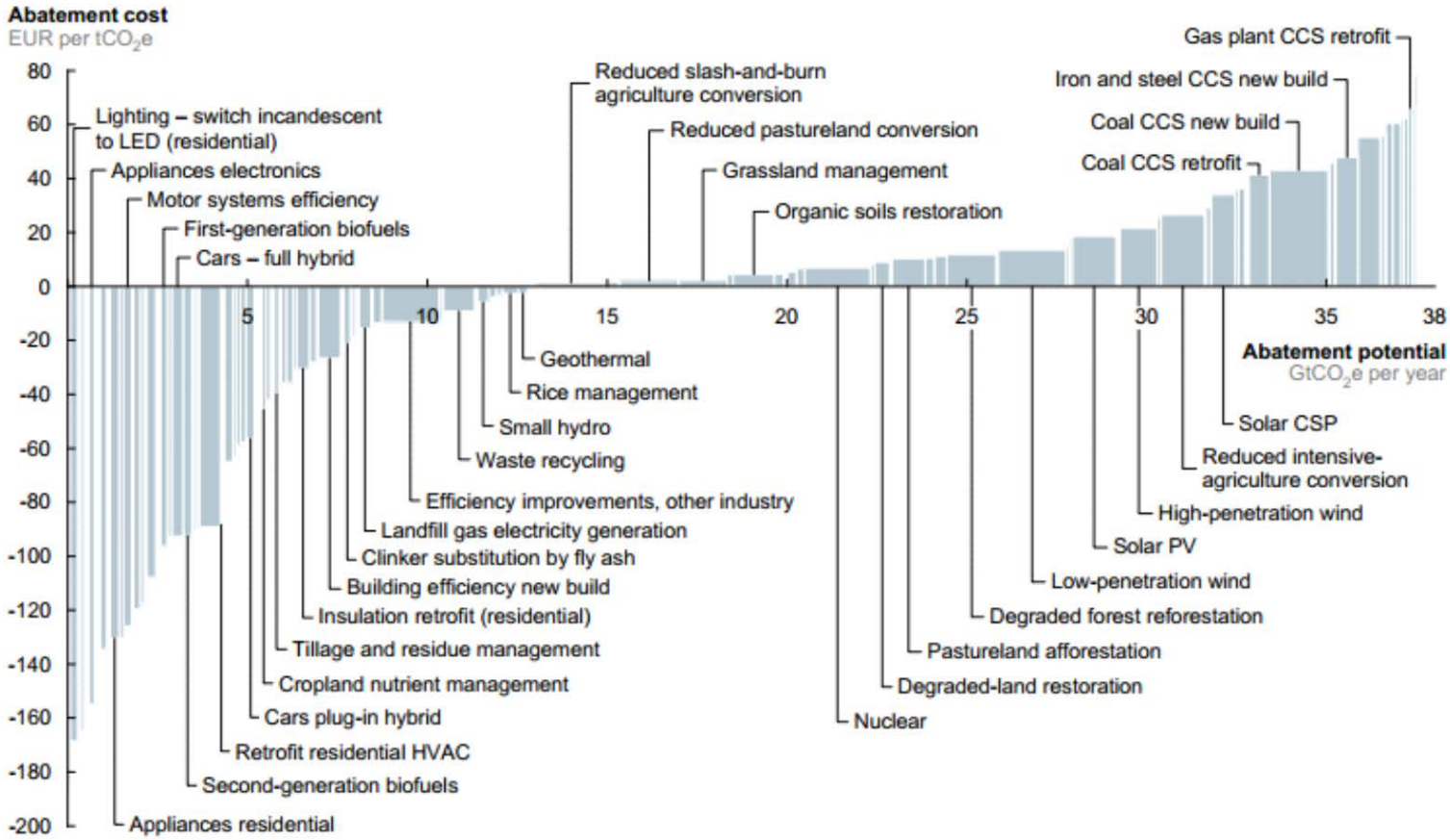
- Permanence: Reversals from end of REDD+ projects, illegal actions, political decisions
  - Long term: Transition away from payments to integrated self-sustaining development activities (e.g., agroforestry, ecotourism, plantations, NTFPs)

LEDS IMPLEMENTATION: OTHER CHALLENGES

- Defining appropriate role of SL projects/sub-national programs in LEDS planning
  - Maximizing reductions/revenues vs. testing policies
  - Need method to integrate into national level REDD+ plan/LEDS
- Cross-sectoral interactions often significant
  - Integrated policy planning and implementation, institutional coordination key
- Sale of GHG reductions as offsets on carbon markets
  - Can generate revenues for communities
  - If sold, low-hanging fruit cannot be used to meet national GHG reduction targets >> attainment more expensive

GLOBAL GREENHOUSE GAS MACC

V2.1 Global GHG abatement cost curve beyond BAU - 2030



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below EUR 80 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play

Source: McKinsey & Company, Global GHG abatement cost curve v2.1

Conclusions

- Emissions from land use a major source of emissions
- Economic value of intact forests and other high carbon ecosystems often low or poorly captured
- Improving management of high-carbon ecosystems can be cost effective means of reducing emissions.
- Modeling of costs and benefits an important element of planning improved management.
- Capturing value of carbon through markets or other policy measures can also be used to incentivize reducing emission reduction and/or increasing sequestration.
- Approaches may be implemented at project or national scale.

AILEG Project Valuing Environmental Benefits from Fragile Ecosystems in Colombia

Dr. Marcia Gowen Trump (Abt Associates)

USAID University E3 Course on Economic Analysis and Planning for Climate Change Mitigation

April 29, 2014

Learning Objectives

Understand:

- Key definitions critical to environmental valuation
- Challenge: Páramo ecosystem losses in Colombia
- Solution: Valuation of the environmental benefits from Páramo de Santurbán ecosystem
- Methodology: Application of environmental valuation and payment for environmental services methods
- Exercises
- Results and recommendations
- Exercises
- Planning decisions

Key Definitions (I)

Ecosystem

- Plant, animal, and micro-organism communities
- Physical (abiotic) environment
- Dynamic interactions

Ecosystem Services

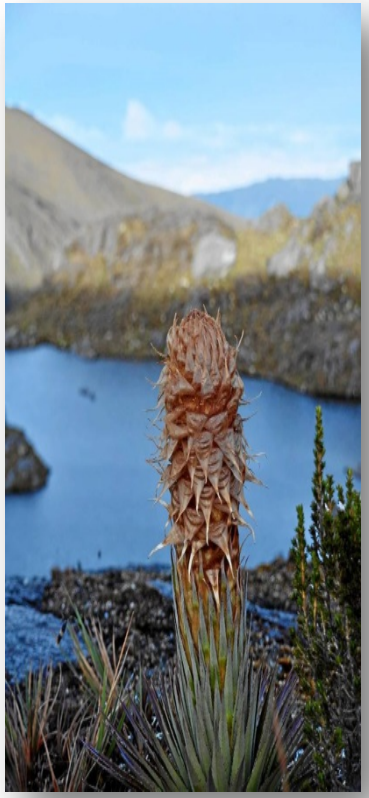
- Benefits people obtain from ecosystems
- Goods and services of nature

Ecosystem Degradation

- Persistent reduction in capacity to provide ecosystem services

Natural Capital

- Extension of economic concept of capital
- (means of production) to environment
- Capital stock = resource base
- Flow = consumptive and non-consumptive uses



Key Definitions (II)

Sustainable Landscapes

- Sustainable landscape management essential to curbing global emissions where there is maintenance of an environmental area for sustainable use
- Includes forest degradation and deforestation, and non-forest landscapes, such as peatlands, wetlands, and agricultural lands.

Environmental Valuation

- Estimating the monetary value of the goods and services provided by the environment

Payments for Environmental Services (PES)

- Monetary compensation paid to owners of an area for the damages or potential loss of environmental services to conserve an ecosystem

Challenge: The Páramo Ecosystems in Colombia

- **Páramos**
  - Unique high altitude alpine tundra ecosystems (e.g., moors)
  - All high, neo-tropical montane ecosystems above the contiguous timberline but below the permanent snowline
  - Northern Andes of South America (mostly in Colombian Andes)
  - Evolutionary “hot spots”
- **Provide:**
  - Fresh water
  - Hydropower
  - Agriculture and livestock grazing
  - Mining (gold)
  - Biodiversity
  - Recreational value & tourism
  - Bequest value

Drivers of Páramo de Santurbán *Ecosystem* Losses

- **Supplying Water Demand:** 48 municipalities (population of 2.3 million people)
- **Hydroelectricity Use**: Tasajero thermoelectric station critical to watershed sustainability
- **Agriculture and Forest losses:** Land degradation and conversion creates biodiversity losses
- **Gold Mining:** Small, illegal mining operations pollute streams and water masses

Key Policy Drivers of Páramo Ecosystems

- **Governance and Policy Responses**
  - *Paramos* are protected areas by law
  - But no clarity on how to draw boundaries
  - Ministry of Environment wants to determine ecosystem benefits of valuing and paying for environmental services (PES) to protect *Páramos*
  - ***Government has other PES systems in place***
    - *Utility owning a hydroelectric plant in Upper Magdelena Watershed pays land owners annually*

AILEG Project Páramo Ecosystem Benefits Valuation and PES Activity

- **USAID Request:**
  - Government of Colombia/ Ministry of Environment and USAID/Colombia requested AILEG focus one of its LEDS activity on environmental valuation of benefits of Páramo de Santurbán

- **AILEG LEDS Solution**
  - AILEG supported an economic analysis to estimate the value of the ecosystem services provided by the Páramo de Santurbán
  - Purpose to inform government on sustainable land use and payment for environmental services options

Exercise 1A: What eco-benefits to measure?

Environmental Benefits	Methodology	Data Collection

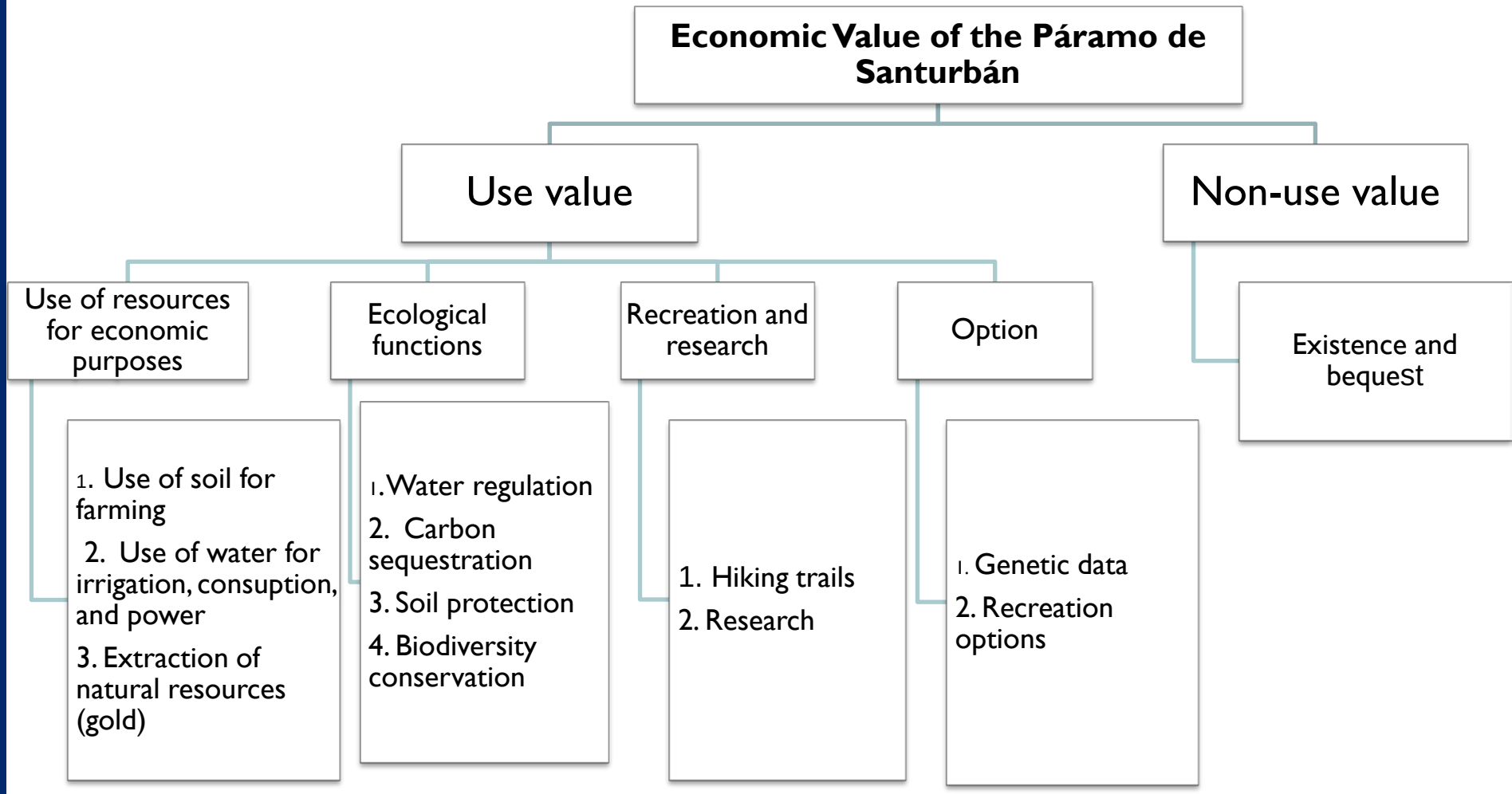
Exercise 1B: What methods are appropriate?

Environmental Benefits	Methodology	Data Collection

Exercise 1C: What data collection process?

Environmental Benefits	Methodology	Data Collection

AILEG: Eco-Benefits Measured



AILEG: Actual Eco-Benefits Measured

Environmental Benefits	Methodology	Data Collection
Existence and Bequest Value	Willingness to pay (WTP) for non-use costs by nearby urban inhabitants	Survey residents of Bogotá and Medellín not to receive direct services
Carbon Sequestration	Benefits transfer analysis using Colombia's carbon price for CO_2 sequestration	Carbon market value of land as CO_2 sink in Colombia
Recreation	Travel cost methodology of visitors to the area	Travel costs and other payments from tourism
Water Provision	Contingent valuation of residential water users	Payments (WTP) by 3 city users (750 HH surveys)

Method: Contingent Valuation of Existence and Bequest Values of Páramo

- **Existence value**
  - Value to conserve natural resources, such as natural parks, regardless of their desire to visit them.
- **Bequest value**
  - Desire to preserve a natural resource for their descendants. e.g., expect their children or grandchildren to enjoy the direct services (water, recreation, biodiversity)
- **Contingent value**
  - Creates a hypothetical market through surveys, asking about individuals' willingness to pay for the conservation of a natural resource.

Results: Bequest Value from Bogotá and Medellín

	Frequency		Willingness to Pay (WTP)	Total
	(Persons)			
	Medellín	Bogotá	(Pesos)	(Million Pesos)
Minimum WTP	2,447,348	5,154,948	31,335	238,217.95
Maximum WTP	2,447,348	5,154,948	102,172	776,741.79

Results: Bequest Value from Bogotá and Medellín

- **WTP Survey Facts:**
  - People from 400 surveys in Bogotá and Medellín, although not directly benefited by the Páramo de Santurbán
  - Estimated WTP as USD 15 or 30,310 pesos (not actual paid) to convert the páramo into a regional natural park to ensure its preservation
  - WTP increases with higher education, greater incomes, gender, and a higher environmental concern

Exercise 2: What issues might change values?

- What are potential WTP Issues/Biases?
- What are Factors that change WTP?

Exercise 2: What issues might change values?

- **WTP Issues/Biases:**
  - Starting point bias
  - Stated versus actual market WTP
  - “Multi-good” versus “single-good” WTP

- **Factors that change WTP**:
  - Information
  - Education
  - Gender
  - Income
  - Response Bias

Method: Benefit Transfer Valuation of Carbon Sequestration of Páramo

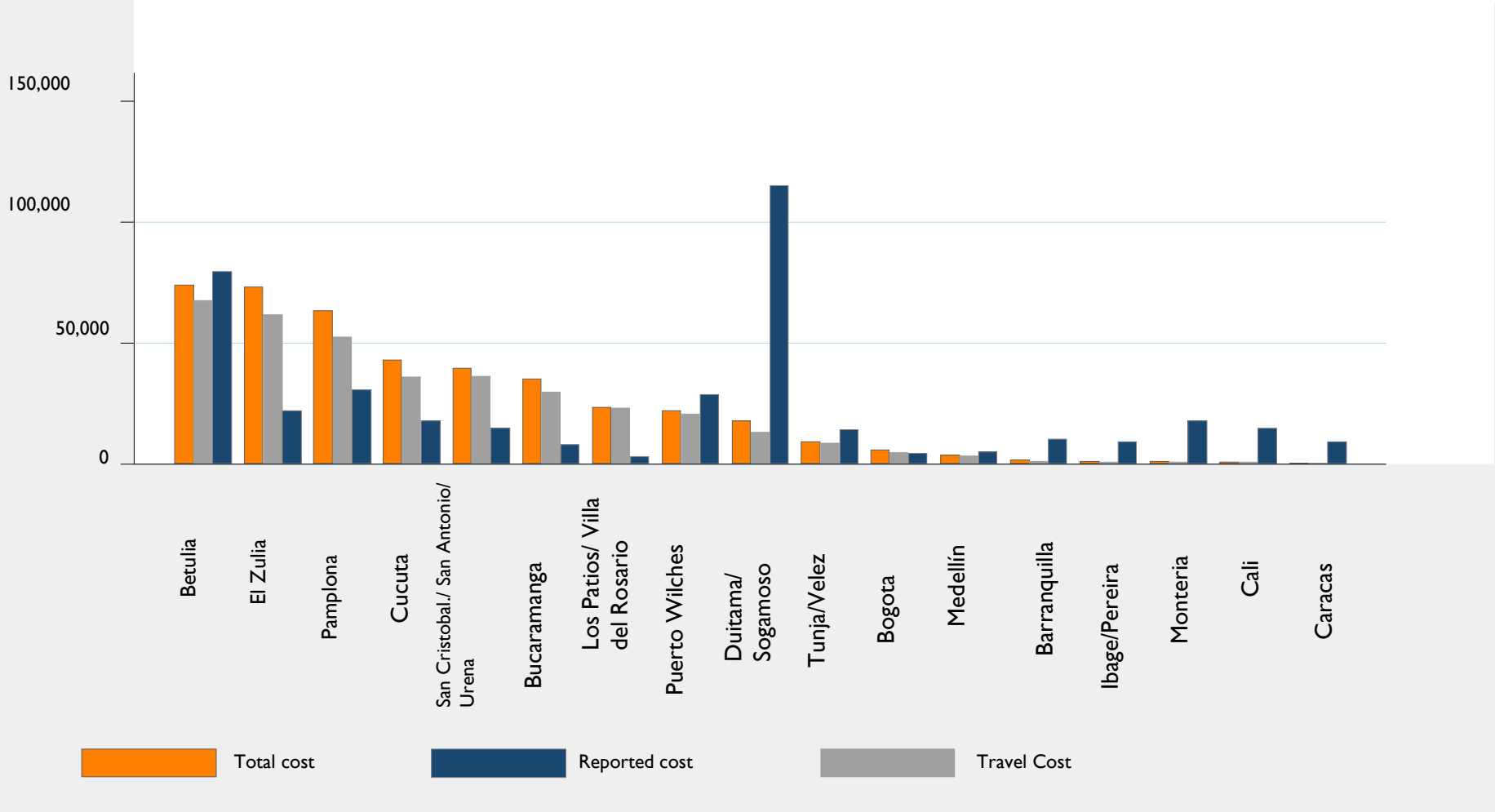
- **Benefit Transfer Method**
  - The benefit transfer method was used to assess carbon sequestration in the Páramo de Santurbán
  - Benefits transfer is an economic valuation technique for environmental goods and services that uses secondary sources of information

- **Objective**
  - To transfer and adapt the monetary value calculated for certain environmental services in a place where primary estimates have been determined

Results: Protecting Carbon Sequestration

- **Carbon Sequestration Results**
  - Total area of Páramo de Santurbán = 80,000 hectares
  - Páramos have 10 percent carbon and over 70 percent water
  - Each acre of protected páramo sequesters 79.8 tons of CO_2 per hectare
  - Protection of the Páramo de Santurbán would avoid the emission of 6.3 million tons of CO_2 currently stored in the soil.
- **Value of Carbon Sequestration: Financial value**
  - Assuming USD 5/tCO_2e, conservation of the páramo for its carbon content gives a value of USD 31.92 million, or 58,340 million pesos.
  - Priced at USD 2 per ton of carbon, the value would be US$12.77 million, or 23,336 million pesos.

Results: Travel Cost Method for Recreation Value



Recommendations: Travel Cost Recreation Value

Annual Surplus per Zone Total Cost	Annual Surplus per Zone Travel Cost	Annual Surplus per Zone Reported Cost
1,363 pesos/yr	1,150 pesos/yr	2,169 pesos/yr

- **Travel Cost Recreation Value:**
  - USD 0.77-100/yr or 1,150 and 2,169 million pesos/yr

- **Payment for Environmental Services:**
  - 92 % visitors agree with declaring area a regional natural park
  - 58 % would agree to pay an entrance fee (PES) if park
  - Average WTP is USD 11/yr or 21,176 pesos/yr

Contingent Valuation of Water Provision and Regulation in Páramo de Santurbán

1. What makes an individual likely to be willing to pay to preserve the quantity and quality of water from the Páramo de Santurbán?

2. How much are they willing to pay?

"To preserve the quantity and quality of the water you receive, it is necessary to protect its sources in the Páramo de Santurbán, which implies increased funding by users. How much more are you willing to pay on each water services bill, in addition to what you currently pay?"

Results: Contingent Valuation of Water Provision and Regulation

Value Assigned to the Protest Votes (Pesos)	Average Willingness to Pay (WTP) (Pesos)	Annual Aggregated WTP (Million Pesos)	WTP Aggregated to Perpetuity (r = 12 percent) (Million Pesos)
1,000	3,066	15,259.90	127,165.87
2,000	6,180	30,758.71	256,322.60
3,000	11,461	57,042.97	475,358.15
4,000	17,686	88,025.66	733,547.18

Results and PES Recommendations: Water Provision and Regulation

- **WTP Estimate:**
  - The average value per person of between 3,066 and 17,686 pesos (minimum values) as considers only residential water users in Bucaramanga, Cúcuta, and Pamplona
- **Factors Affecting WTP:**
  - Variables increasing WTP to protect water quality and quantity are related to individuals' medium-term goals: children, and know the Páramo de Santurbán
- **PES Recommendation:**
  - A payment for environmental services (PES) scheme could be funded through the water bill. A payment of 3,000 pesos, the minimum payment estimated in the analysis, would be acceptable to a large part of the population. An acceptable minimum would be 3 percent of the water bill.

AILEG Páramo de Santurbán Eco-Benefit Analysis Results and Recommendations

Service	Method Used	Minimum Value (Million Pesos/yr)	Maximum Value (Million Pesos/yr)
Water provision and regulation	Contingent valuation	127,165.87	733,547.18
Recreation	Travel cost	9,592.00	18,075.00
Carbon sequestration	Benefit transfer	23,336.00	58,340.00
Existence and bequest	WTP	238,217.95	776,741.79
Total Economic Value		**398,311.82 (USD 206)**	**1,586,703.97 (USD 820)**

Ecosystem-Benefit Analysis Conclusions

- **WTP**
  - a current bimonthly rate of 3,000 pesos can be established for the páramo's conservation, with just Bucaramanga, Cúcuta, and Pamplona, resources would amount to 7,393 million pesos annually.
  - With these resources, it would be possible to establish a PES scheme, under which páramo landowners would be compensated for conserving páramo areas outside the areas declared as regional natural park.
  - Unlike a scheme in which the government buys the land or pays the owners from a budget, studies show that a PES scheme is more successful if there is a direct relationship between the provider and the environmental service user.
- **Ministry Recommendations**
  - Expand values included in analysis and regions of analysis

Exercise 3: Discuss methods and values estimated

Environmental Benefits	Methodology	Data Collection
Existence and Bequest Value	Willingness to pay (WTP) for non-use costs by nearby urban inhabitants	Survey residents of Bogotá and Medellín not to receive direct services
Carbon Sequestration	Benefits transfer analysis using Colombia's carbon price for CO_2 sequestration	Carbon market value of land as CO_2 sink in Colombia
Recreation	Travel cost methodology of visitors to the area	Travel costs and other payments from tourism
Water Provision	Contingent valuation of residential water users	Payments (WTP) by 3 city users (750 HH surveys)

Exercise 4: Suggest Recommendations

- **Advice to and from Government**

- **Advice to USAID**

Reference

- Adapted from “Valuation of the Environmental Goods and Services Provided by the Paramo de Santurban: Final Report” by Fedesarrolo with Santiago Enriquez and Michele Laird (Abt Asociates) for the USAID AILEG Project.

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Millennium Challenge Corporation (MCC) Green Prosperity Project Sustainable Landscapes Valuation in Muaro Jambi, Indonesia

Dr. Marcia Gowen Trump (Abt Associates)

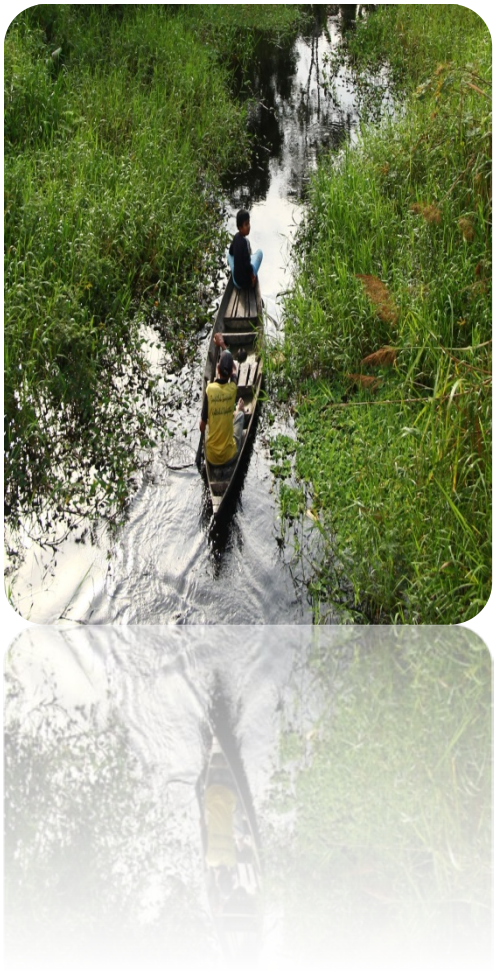
USAID University E3 Course on Economic Analysis and Planning for Climate Change Mitigation

April 29, 2014

Learning Objectives

Understand:

- Key definitions
- Challenge: Land conversion and degradation
- Solution: Government of Indonesia (GoI) is seeking green, low emission investments through valuation of sustainable landscapes
- Methodology: Cost-benefit analysis of alternative land uses
- Exercises
- Results and recommendations
- Planning decisions



Key Definitions

Ecosystem Services

- Benefits people obtain from ecosystems
- Goods and services of nature

Ecosystem Degradation

- Persistent reduction in capacity to provide ecosystem services

Social Cost of Carbon

- The social cost of carbon reflects the true cost of carbon to society

Carbon Market Price

- Price of carbon is what local or international market may be willing to provide for mitigation activities.

MCC Green Prosperity Study: Strategic Environmental Assessment (SEA)

- **Goals**
  - Determine potential low emission investments for areas with serious land degradation and losses occur in strategic assessments
  - Analysis part of a broader Millennium Challenge Corporation (MCC) and Millennium Challenge Account – Indonesia (MCA-I) program, where the country controls and defines the MCA assistance, to identify investment options that protect sustainable land uses

- **MCC Green Prosperity Analysis**
  - Compare the economic value of natural resources not accruing to the community, or accruing but not recognized by the community – are discussed in detail in the context of Muaro Jambi.

Objective: Seek Low Emission Investments

- Assess current land use allocation and potential land use changes in Muaro Jambi.
- Estimate financial and economic returns to land and how distributed by stakeholder groups.
- Evaluate land pressures on forests to aid in formulation of ecosystem management plans.
- Evaluate options to reduce future emissions.
- Assess the demand for renewable energy investments by examining electrification rates
- Assess socio-economic and political landscape that may impede or enhance investments.

Muaro Jambi District, Indonesia

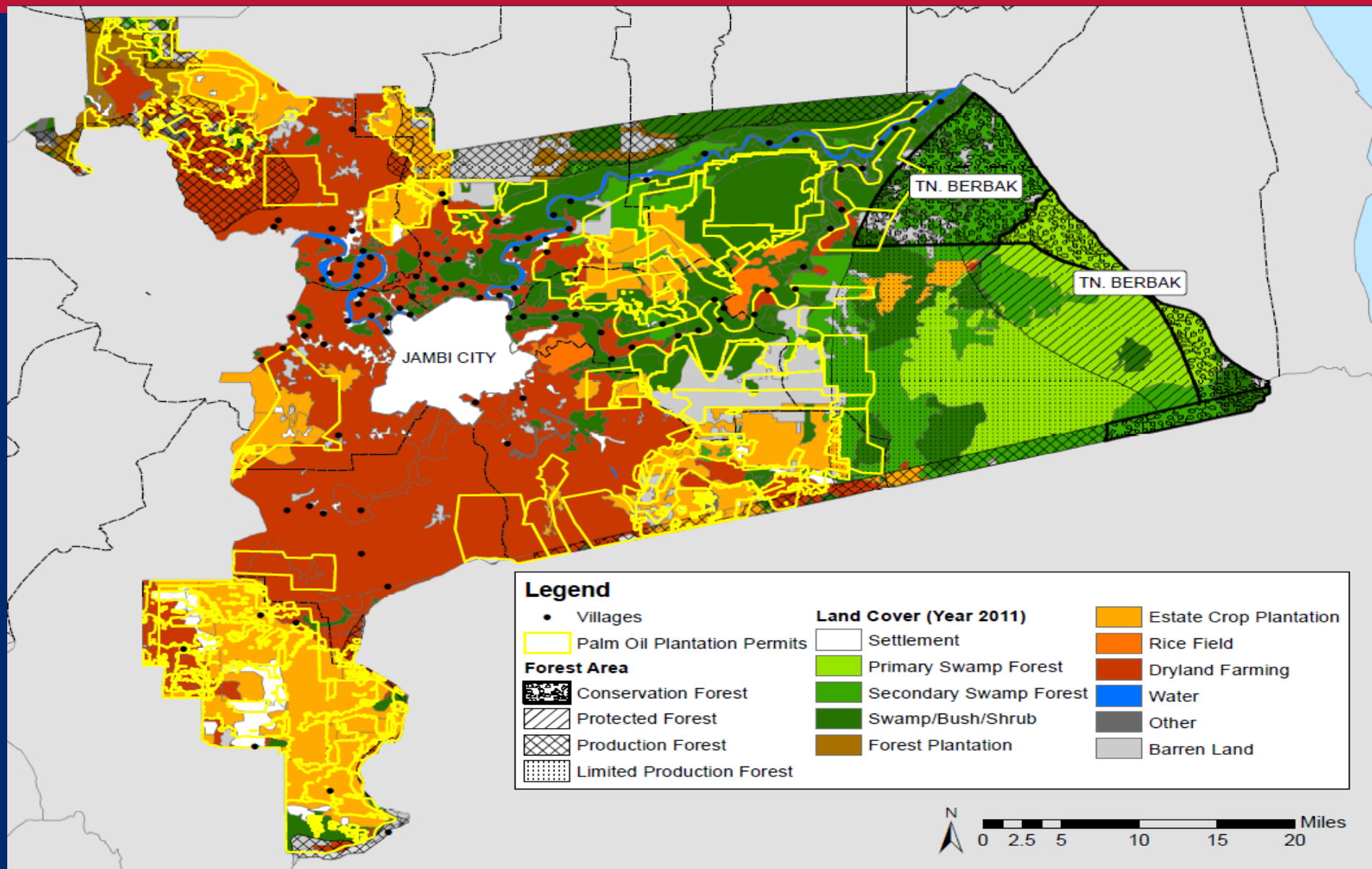
- **Muaro Jambi** district is home to the Berbak National Park, a protected area in Indonesia's Ramsar Site (1971 Convention of Wetlands of International Importance designated area) and an internationally recognized waterfowl habitat

- The Berbak national park has an area of peatlands:
  - 110,000 hectares
  - Forest park (Taman Hutan Raya or Tahura) covers 60,000 hectares

- Land use in the district is dominated by:
  - Dry agricultural land (293,256 hectares)
  - Oil palm plantations (87,992 hectares)
  - Wet agricultural land suitable for rice (17,000 hectares).

Location of Muaro Jambi District, Indonesia

Land Use Map in Muaro Jambi



Challenge: Land Uses in Muaro Jambi

- Agriculture contributing 30% of gross regional economic product
- Mining (petroleum) giving 26% of gross regional economic product
- Smallholder and estate oil palm plantations contribute most to local GDP in the agriculture
- Oil plantations seen by land owners as having the highest financial returns per acre

Challenge: Forest Land Losses in Muaro Jambi

- **Deforestation rates:**
  - Inside Berbak National Park (BNP) 2.44%/yr
  - Outside BNP 4.66%/yr
- **Reasons for losses and economic impacts:**
  - Forest fires from illegal logging and land clearing for plantation agriculture
  - Forest fires lead to loss of timber, plantations, farmland, tourism, commerce, industry, travel, health, and degrade hydrologic functioning to cause soil erosion
- **Peatlands:**
  - Peatlands = 40% of the district, used for heat
  - Peat forest area in Muarjo Jambi has reduced from 68% in 1989, to 25% in 2007

Objectives for Valuing Sustainable Landscapes

- To inform resource management decisions this analysis assesses:

1. Current land uses - based on the current land conversion patterns
2. Future land use changes
3. Financial and economic returns to land from various uses
4. Distribution of impacts by groups
5. **Low emission investments – protected forestlands, electricity production from palm oil (?)**

Exercise 1: What and how to measure values?

- What landscape values could be measured?

- What methodologies to measure ecosystem benefits?

Sustainable Landscape Benefits

- **Carbon sequestration**
  - Carbon market value (financial value)
  - Social cost of carbon (economic value)
- **Critical habitats** (tigers, orangutans)
  - Berbak National Park also provides habitat for critically endangered Sumatran tigers and other flora and fauna.
- **Climate regulation and hydrological value**
- **Direct uses**
  - Productive (timber, non-timber forest products)
  - Oil palm, other crops
  - Tourism
- **Non-use values** (option, bequest, existence)

Financial Returns to the Land Stakeholders

- **Direct-use financial returns** from protected and production forests include:
  - Visitor entry fees
  - Logging (only legal logging was estimable)
  - Non-timber forest products(only legal extraction estimated)
  - Oil palm plantation, rubber plantation, and crops such as rice and corn each have higher financial returns than forest
  - Returns from crops vs forests compared
  - Forest areas that are not national parks are under particular threat from the pressure exerted by agricultural use.

- Used annualized values (using a 10% discount rate) of private, financial returns to land in its various uses in Muaro Jambi

Economic Returns to Land

Ecosystem services are economic returns to land including:

- **Indirect use values**: Benefits from ecosystems' regulation of climate, carbon sequestration, hydrological, and other processes.
- **Option values**: Having the option to use a resource in the future.
- **Non-use values**:
  - Inherent attributes of an ecosystem
  - existence value
  - bequest value (future benefits to a person's descendants)
  - altruistic value (knowing that someone else benefits).

Results: Valuing Peat Forests

- **Peat forest economic returns**
  - Protected peat forests are **USD 83 or 968,604 rupiah/hectare/year**
  - Carbon sequestration value of the forests (an indirect use value) equals the net carbon emissions resulting from land use changes valued at the social price of carbon.
- **Social cost of carbon**
  - The carbon emissions from peat conversion accounts for positive emission from drainage, net of carbon sequestration provided by alternative land use
  - USG Interagency Working Group (2013) midpoint value : **USD 52/ton or 636,481 Rp/ton**

Valuing Benefits from Production Forests

- **Production forests carbon value**
  - Since production forests less dense than protected forest, carbon sequestration from production forests are 40% of the sequestration from protected forests, valued at **USD 32 or** 370,450 rupiah/hectare/year.
- **Production value of forests**
  - The total economic return from production forest is **USD 112 or 1.3 million rupiah/hectare/year**
  - Production value of forests is higher than economic returns from protected forests because of the financial returns they provide.

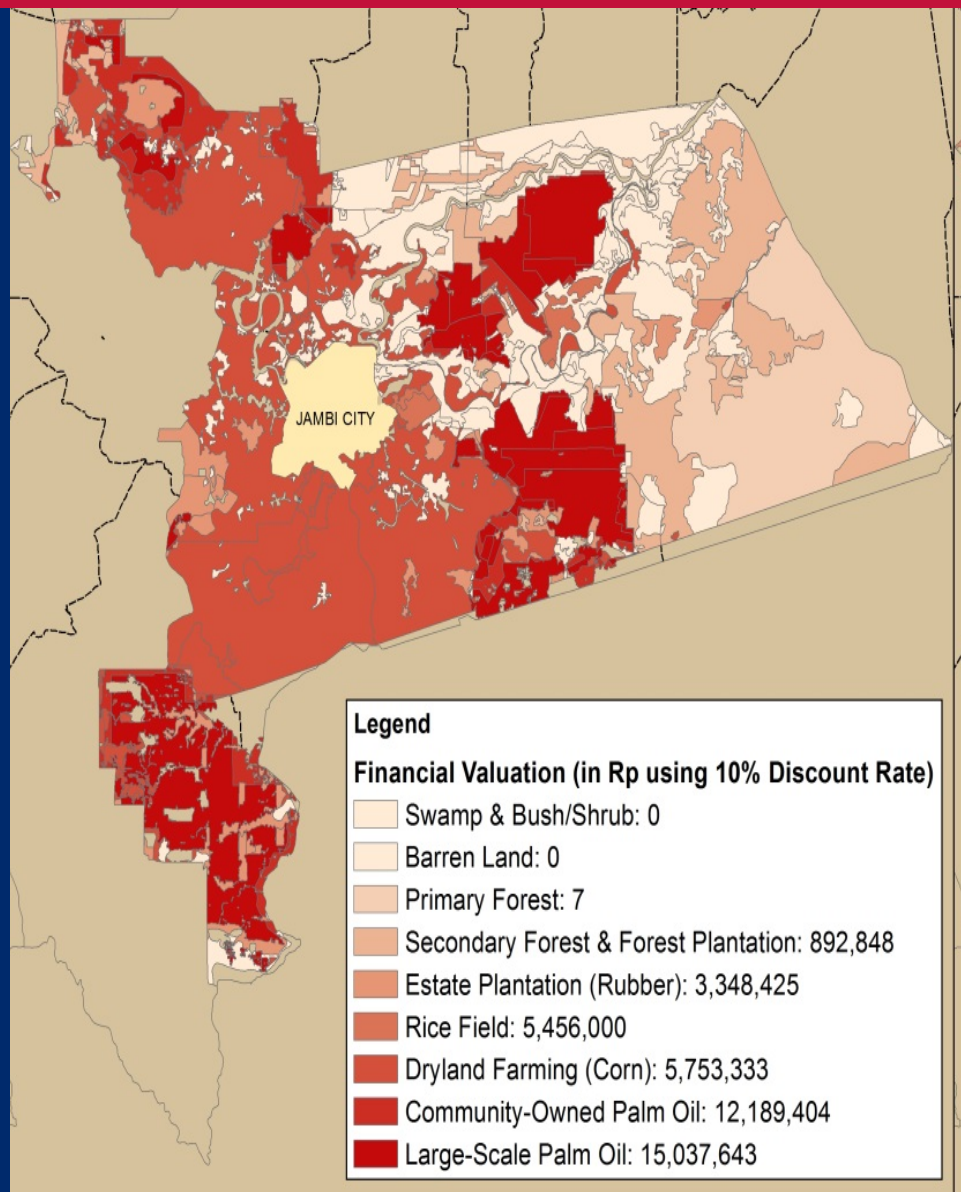
Results: Valuing Critical Habitats

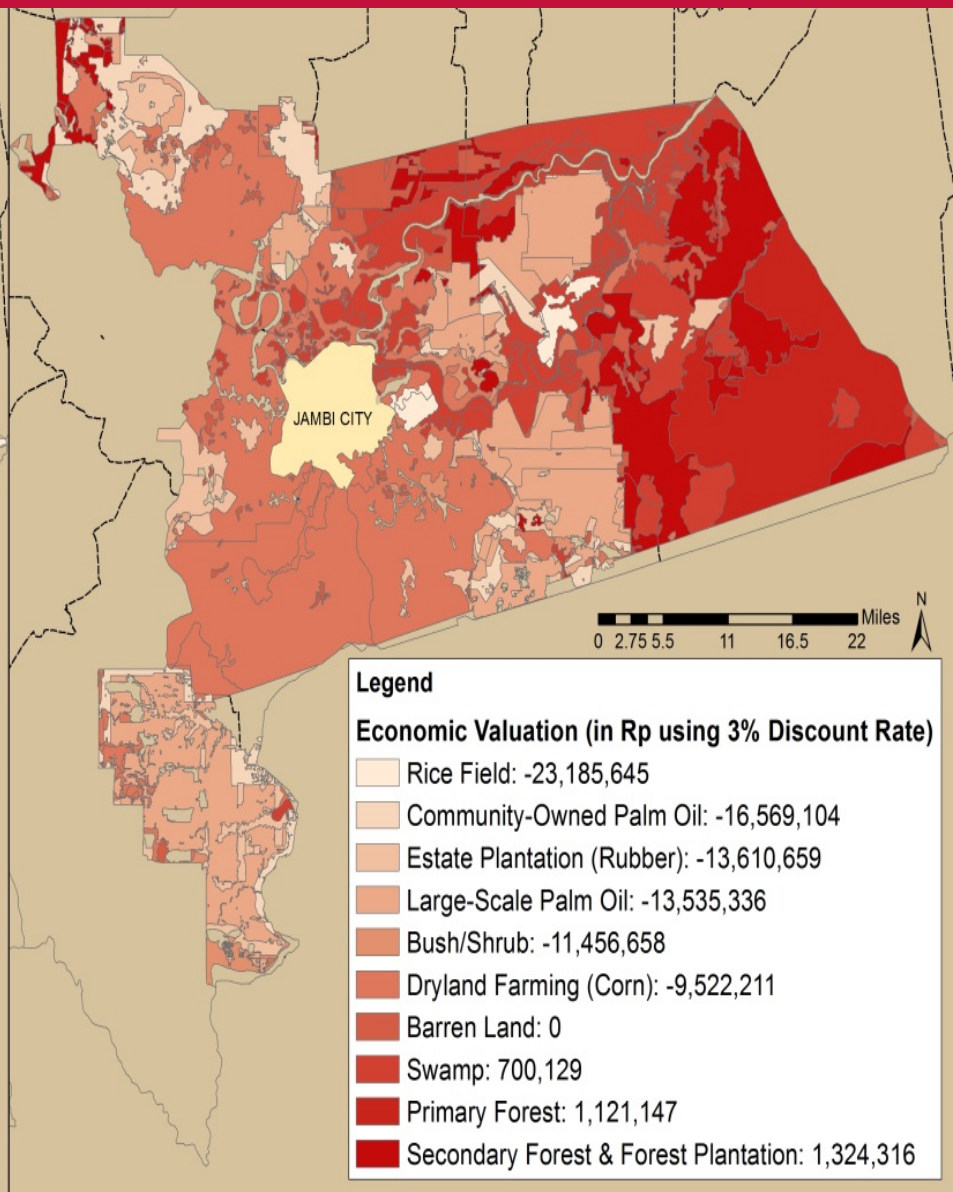
- **Net present value for forest habitat conservation**
  - In the Leuser Ecosystem (in Northern Sumatra) is USD 171-828 million (2.1-10.1 trillion Rp) using a 4% discount rate and a 30-year time period) based on WTP by Indonesians and foreigners for Sumatran rhinoceros, tigers, primates, mammals, and birds.
  - Separate tiger-only WTP analysis Extrapolated supporting the population of tigers is USD 158 or 1,836 billion Rp.
  - Estimated the annualized value of **USD 9.15 million or 106 billion Rp for conservation of tigers' habitat USD 3.67 or 42,470 Rp/hectare/year**, which is an upper bound,
- Willingness-to-pay for tiger habitat in Muaro Jambi was not calculated directly

Valuing Social Costs from Agricultural Use

- ***Emissions Net of Sequestration***
  - Economic values for palm oil, rubber, corn, and rice production include the net social value of carbon sequestration and carbon (CO_2) dioxide emissions.
  - For three agricultural uses, emissions are greater than sequestration, resulting in net social costs
  - Used: 64 tons/hectare on palm oil plantations; 41 for rubber plantations tons/hectare; and 45 tons/hectare for paddy farming.
  - Used an estimate of **USD 54.8 or 636,481 Rp/ton of carbon dioxide equivalents** as the social cost of these agriculture emissions.

Financial and Economic Returns from Land Uses

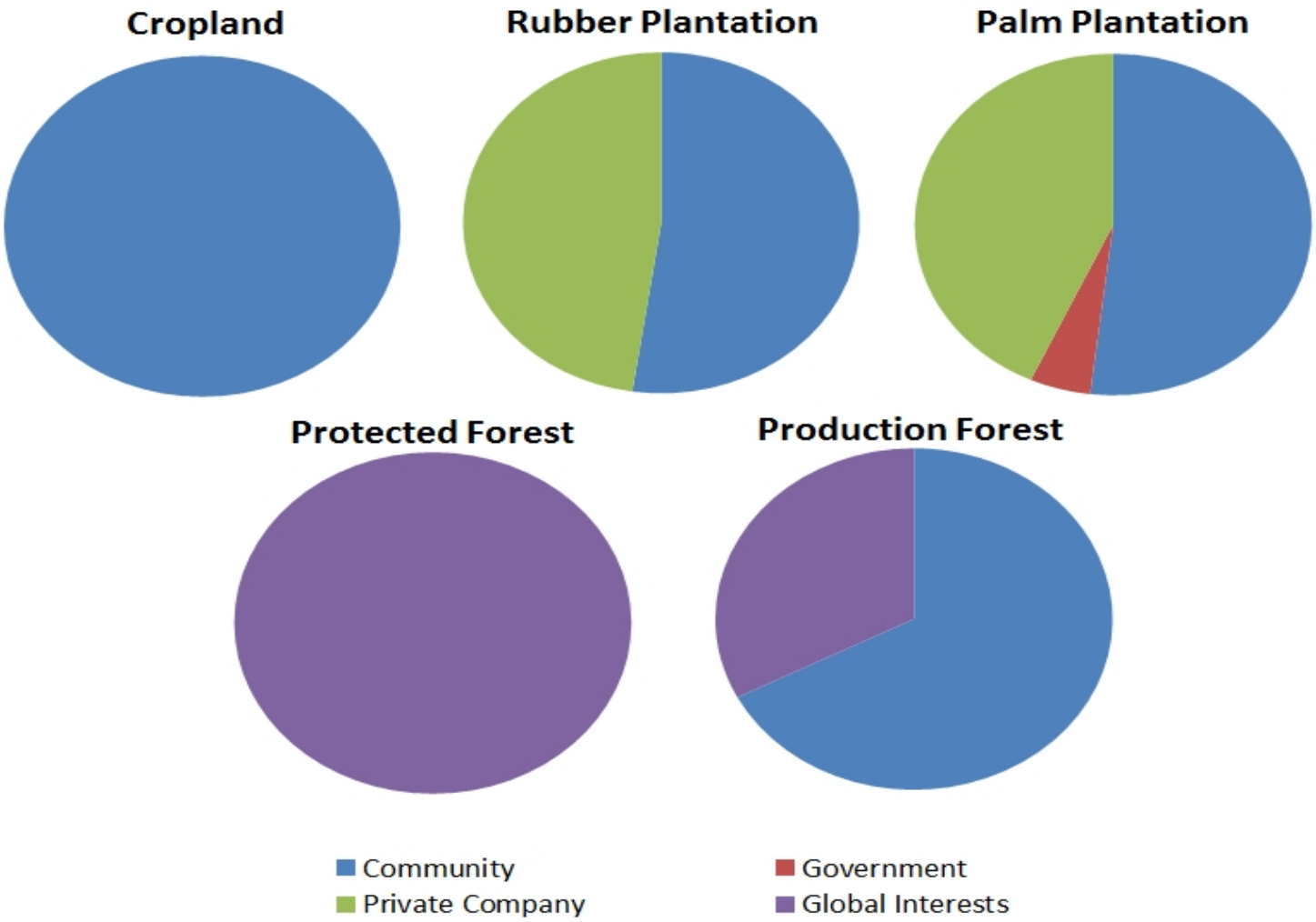




Exercise 2: Interpretation of Results

- Financial results point towards?
- Economic results point towards?
- How to reconcile with sustainable landscape perspective for green growth?

Distributions of Financial and Economic Returns to Landowners



Exercise 3: Recommendations to Locals and GoI

- What economic preferences and guidance do you recommend to different stakeholders?
  - Locals
  - District
  - GoI
  - MCC/MCA-I
  - USAID

Government and MCC Recommendations (I)

- **Awareness Campaigns**: Protecting forest and peat land communities in Muaro Jambi need information and incentives to maintain sustainable landscapes.
- **Information needed on:**
  - Protecting the biodiversity and peat forests
  - Maintaining water resource flows
  - Reducing fires and soil subsidence
  - Providing increased agricultural productivity

Government and MCC Recommendations (II)

- **Low Emission Investments**:
  - Conversion of forests to oil palm plantations has the highest impact on cumulative carbon emissions.
  - Incentives for conversion are high because the benefits of keeping land in forests do not accrue to the entities engaged in conversion.
  - Incentives schemes such as payment for environmental services (PES) may be needed to align the private incentives with the social incentive.

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Sustainable Landscape Projects and Economic Analysis

Dr. Gordon Smith (CEADIR Project)

October 21, 2014

Learning Objectives

- Identify potential terrestrial emission reductions (ERs)
- Assess available resources and synergies
- Assess constraints on achieving ERs
- Assess what constraints can be addressed, and to what degree
- Set terrestrial ER goals
- Develop terrestrial ER implementation strategy

Terrestrial GHG Emission Sources

- Globally, deforestation is the largest terrestrial source, 4.4 billion tCO2e/year (van der Werf et al. 2009); ¾ is to get land for agriculture; higher proportion in tropics
- Livestock enteric fermentation, about 2.1 billion tCO2e/year
- Nitrogen fertilizer and manure on lands: 1.5 billion tCO2e/yr
- Rice paddies: 0.5 billion tCO2e/yr

Amounts from FAO 2014 unless otherwise cited

Other Potentially Large Sources

- Forest degradation estimates are uncertain
  - Wood products, primarily commercial, including charcoal
  - Fuel wood, primarily subsistence and local markets
  - Fire
- Often degradation is counted within later deforestation, or trees grow back
- Peat decomposition or burning, greater than 1.7 billion tCO2e/yr, including methane from burning (Wetlands International 2010)
- Manure management, 2.2 billion tCO2e/yr (FAO 2013), (this double counts some land application emissions counted with fertilizer)

Which Potential Reductions are Large?

Source	Emissions	Fraction Reduction
Deforestation	**High**	**High**
Enteric	Moderately High	Low
Fertilizer Nitrogen	Moderately High	Low*
Rice Methane	Moderate	Moderate
Forest Degradation	Moderately High?	Moderate?
Peat	**Moderately High**	**High**
Manure Management	Moderately High	Moderate

Potential Deforestation Reductions

- Increase agricultural yields, or crop harvest/processing efficiency on non-forest lands so new land from forests is not needed
- Secure land tenure and improve capacity of forest communities to exclude squatters and accrue economic returns from forest
- Increase non-subsistence livelihood opportunities so rural population growth does not require new farms
- Zone lands and require forest conservation

Potential Enteric Emission Reductions

- Change livestock types from ruminant (cattle, sheep, goats) to non-ruminants (pigs, poultry)
- Change feed to more digestible with more grain and oil (must count emission from producing grain or oil) & supplements
- Livestock breeding for lower emissions
- For meat production, change management to shorten growth periods
- Develop Tier 2 or Tier 3 emission factors (accounting reduction only, not emission reduction)

Potential Nitrogen Fertilizer Reductions

- Fertilizer use and emissions are low on subsistence farms
- Emissions mainly on commercial farms
- Change form of fertilizer from more volatile or soluble to slower releasing
- Timing fertilizer application to be at the time and place where crop plants absorb more
- Limit amounts of fertilizer to amounts crops can take up
- Improve soil tilth: carbon, structure & microbial communities

Potential Rice Emission Reductions

- Reduce duration and/or depth of flooding
  - Additional benefit: reduces water use
  - Mid season drainage may decrease CH4 but increase N2O; consider entire system
- Change varieties to reduce transmission of methane from roots, through stems
- Change from paddy rice to upland rice
  - Yields are often lower, requiring more land per unit of production

Potential Forest Degradation Reductions

- Change forest management to maintain timber stocks
  - Increase rotation lengths (may displace harvest to new locations during transition period)
  - Decrease harvest intensity (may displace harvest to new locations)
  - Increase tree growth rates
  - Increase wood utilization rates (including charcoal production efficiency) provides same amount of product with less harvest
- Reduce shifting agriculture
- Fuel wood: establish woodlots or expand agroforestry

Potential Peat Emission Reductions

- Stop new clearing of forest on peat
- Stop new drainage
- Stop tillage
- Rewet drained peat

Potential Manure Emission Reductions

- Reduce wet storage of manure
  - Generally confined animal feeding operations, not subsistence farms
- Capture methane from stored manure and burn it
  - May generate power
- Change animal feed
- Watch for displacement between CH_4 and N_2O emissions

Which Potential Reductions are Large? (1)

- Deforestation is a large source and potentially most or all can be eliminated
- Enteric emissions are moderately large, but probably only a small fraction can be eliminated
- Nitrogen fertilizer emissions are moderately large, but only a modest fraction can be eliminated
- Rice emissions are moderate; potentially a moderate fraction can be eliminated

Which Potential Reductions are Large? (2)

- Forest degradation may be a moderately large source but understanding is limited and many emissions are in areas with increasing population pressure
- Peat emissions are moderately high and can be stopped by stopping new deforestation and draining on peat, and rewetting drained peat
- Manure management has high emission mitigation potential in developed countries but limited potential in developing countries

Every Country is Different

- Global sectors with biggest mitigation potential:
  - Deforestation
  - Peat: very large emissions per hectare
  - Forest degradation?
- Identify large emissions and reduction potential in your country/target area and address those
- But work to mitigate all emissions

Carbon Sequestration

- Increase soil organic matter:
  - Improves soil nutrient exchange capacity and water holding capacity
  - Achieved by increasing carbon inputs and/or decreasing soil disturbance
  - Practices: Retain residue in the field; increase residue by changing variety or increasing growth with fertilizer; switch from plowing to conservation tillage
- Agroforestry
- Forest management: Increase timber/carbon stock
- Convert non-forest to forest
  - Can produce timber or other wood products or fuel

Identify Actions

- What policies or actions would be implemented to achieve desired outcome?

SL project benefits and costs

- Analyze from perspectives of farmer/land manager, banker, government
- Benefits (monetized and non-monetized)
  - Market products: Crops, wood products
  - Non-consumptive products: Eco-tourism
  - Non-market products: Food consumed by household, medicines
  - Ecological products: Carbon, watershed services, ecosystem services
  - Social and cultural benefits
- Costs
  - Capital
  - Operating and Maintenance costs
  - Opportunity cost of land in another use

More on Benefits

- Can increase net revenue by increasing productivity or decreasing costs
  - Example: Improving roads decreases cost of getting goods to market
- Increase value by moving up the value chain
  - Example: Sell dried lumber instead of logs

Valuing Environmental Benefits

- Requires baseline land use projection
  - Baseline is counterfactual and requires assumptions about future behavior
  - Selections of comparison areas and time matter
  - One REDD project may capture much of a province's baseline
- Observed payments are more reliable than stated preferences
- Land user may not be able to monetize environmental benefits
  - May not have rights
  - May not be able to quantify effects
  - Transaction costs may be greater than benefits

Financial Assessments

- Analyze from perspectives of farmer/land manager, investor, government
- Social discount rate lower than investor discount rate
  - Reducing risk can lower investor & land manager discount rates
- Shorter time horizon for investor NPV
- Land user may not be able to monetize environmental benefits

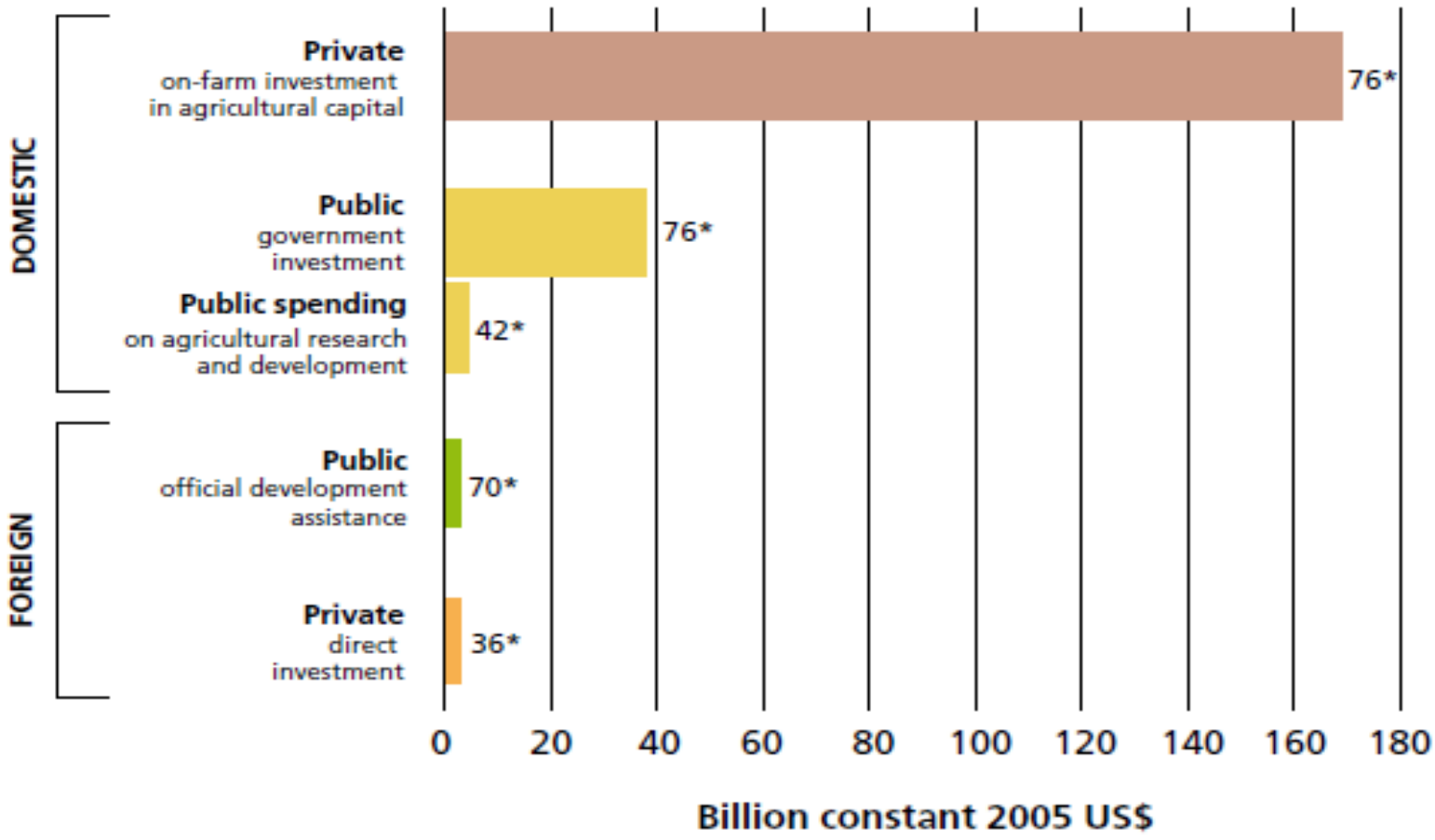
Long Term Sustainability

- Land user revenues > costs, forever
  - Crops or wood products are often largest revenue source
- Can have loss periods but must cover cash flow
- Donor funds and carbon revenues are short term; good for startup costs
  - Setting up systems
  - Initial implementation of new practices
  - Training
  - Capital investments, infrastructure

Assess Available Resources

- Largest resource is land users
  - Commercial
  - Smallholder
- 1.5 billion ha global arable land, including permanent crops (FAOSTAT 2014)
- Private investment
- Development funds
- Climate funds
  - Green Climate Fund supposed to be $100bn/yr; so far $2.5bn, all sectors

Annual Investment in Agriculture
Selected Low & Middle Income Countries



Source: FAO "The State of Food and Agriculture 2012" Figure 5.

Who Pays?

- If policies change where private investment is made, large investments might be achieved with small public cost
- Strategic investment in public goods can generate large social benefit
- Input subsidies may transfer wealth with net loss of welfare

Synergy Examples

- Reduce farmer costs or increase net income
  - 40% of crops are wasted in harvest or processing; increasing efficiency can give significant gain to farmer for same cropping inputs while reducing demand for new land
- Support other government goals
  - Forest management that maintains harvest and productivity over time (and maintains operator cash flow) can avoid further degradation and maintains many forest dependent species (but may not maintain key species of interest)
- Practices that sequester soil carbon often increase crop yields, especially in drought years

Assess Constraints on Achieving ERs

- Poor access to capital
- Poor access to information
- Poor access to inputs or equipment
- Timing or amount of labor
- Food insecurity (producing less than annual household consumption)
- Poor access to markets
- Insecure tenure
- Perceived risk of new practices
- Cultural preferences

Barrier: Value of Emitting Activities

- Returns from land uses causing emission may be larger than non-emitting uses
- Deforestation pays: returns from agriculture generally greater than from forestry
- Development pays: returns from development generally greater than from agriculture
- Corollary: Facilitating access to developed uses elsewhere can spare forest
- Corollary: Increasing value of agriculture increases demand for agricultural land; zoning is required to maintain forest

Addressing Constraints (1)

- Gender affects access
- Access to capital
  - Commercial: Develop lending programs
  - Smallholder: Recruit microfinance programs
- Access to information
  - Partner with influential farmers
  - NGO technical transfer programs
  - Mobile text information systems
- Access to inputs and equipment
  - Farmer cooperative saving groups
  - Cooperative buying programs
  - Facilitate seed production and distribution
  - Facilitate development of agricultural service providers

Addressing Constraints (2)

- Timing or amount of labor
  - Can practice changes or equipment reduce demand for labor, or change time when labor is needed? Weeding consumes a lot of smallholder labor
  - Increasing production beyond household needs can generate revenue to pay to hire labor
- Food insecurity (producing less than annual household consumption)
  - Increase yields or farm size
- Access to markets
  - Transportation infrastructure
  - Cooperative pooling and marketing
  - Mobile information services

Addressing Constraints (3)

- Insecure tenure
  - Biases against conservation
  - Blocks commercial investment
  - High risk = high discount rate
- Demonstrate new practices/varieties locally with respected farmers to mitigate perceived risk of new things
- Cultural preferences
  - Articulate values served by new practices, such as food security, risk reduction, income increase
  - Proposed activities may not be socially acceptable

Value Barriers

- Returns from land uses causing emission may be larger than non-emitting uses
- Deforestation pays: returns from agriculture generally greater than from forestry
- Development pays: returns from development generally greater than from agriculture
- Carbon values are small
- Ecosystem service values are usually unpriced

Addressing Value Barriers (1)

- Requiring conservation keeps forest but landowners forgo development value
  - Seek compatible uses, especially wood products and agricultural practices that build soil
  - Product certification and lending criteria are tools
  - Frequent, comprehensive monitoring is required
  - Conservation: Map forest or require retention of a % of each ownership
  - Facilitating access to cleared lands or developed uses elsewhere can spare forest
  - But: Increasing the value of agriculture increases demand for agricultural land

Addressing Value Barriers (2)

- Payments for ecosystem services
  - Values are often very small per hectare
  - Hard to show that change in land management changes ecosystem service
  - Hard to get beneficiaries to pay unless benefit is concentrated
  - Urban use of water can be valuable
  - In remote areas with poor links to markets, development values are low and carbon values might exceed development values

Scale

- Monitoring and verification costs are relatively insensitive to project size
- Pooling carbon revenues
  - Carbon payments to individual landowners are trivially small
  - A share to communities can pay for community benefits like water systems and schools
  - A share to governments can pay for tech transfer, infrastructure, or law enforcement
- Landscapes: identify high emission localities and sites with high value for protection
- Nested carbon projects can claim much of a region’s baseline

Setting Goals: Strategies

- Look for synergies, especially changes that increase value to landowners
- Look for emissions that can be changed
- Larger scale gives more resources
- Policy approaches tend to address national or sub national scale
- Service delivery amenable to project scale
- What adoption rate is required to make activity successful?

Setting Goals: Other Factors

- Resources needed
  - Financial
  - Institutional
- Partners

Pay for Performance?

- Increasing population and need to improve nutrition requires significant increase in agricultural production in Africa
- May not be absolute decrease in emissions even with large decrease in emission per unit of production
- Might have rising baseline
- Might target specific locations or sectors for reductions

Developing an ER Strategy

- State goal, and metric(s) of success
  - Metrics should be measureable
  - Requires a monitoring system
- Specify all necessary activities and changes required to achieve goal
- Identify who controls achievement of each activity and how to get them to act
- Identify resources needed and source of each
- Make a realistic timeline
  - Show when later steps are dependent on earlier steps

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Experiences with Sustainable Landscape Projects in Africa: Agriculture, Livestock, and Forestry

Dr. Gordon Smith (CEADIR Project)

October 21, 2014

Learning Objectives

- Understand actions taken in example agriculture, livestock and forestry projects
- Understand expected costs and benefits of projects
- To the extent information exists, understand outcomes of projects
- See economic similarities across sectors

Example Projects and Activities

- Agriculture: Vi Agroforestry
- Livestock: Kaptumpo Dairy Project
- Forestry, REDD: Kasigau Corridor
- Forest management: Wijma Cameroun S.A.

Vi Agroforestry

- Targets smallholder farmers; works with farmer groups
- Integrated program: Tech transfer for integrated cropping systems, crop seeds, tree seeds, economic analysis, saving groups, social support
- Projected 200,000 ha, 133,000 farmers
- Paid for by grants, carbon credits; intend that farmers continue adopted practices without support

Vi Agroforestry

- Scenarios analyzed (Tennigkeit et al. 2011):
- Management only: Tillage, residue and nutrient management, no new seed or fertilizer inputs
- Seed: Management changes plus high yield seed
- Management plus seed and fertilizer: Seed scenario plus fertilizer
- Agroforestry: Management plus seed, plus trees and low fertilizer inputs

Vi Agroforestry

Scenario	Manage-ment	Seed	Seed & Fertilize	Agro-forestry
NPV $/ha	-$91	$140	$397	$107
Yield increase, kg/ha-yr	225	1500	3000	1500
Labor increase, days/ha-yr	30	45	60	50

Baseline maize yield 1000kg/ha-yr
Discount rate 10%/yr; NPV over 20 years
Source: Tennigkeit et al. 2011

Kaptumo Dairy Project

- Targets smallholder farmers; works through farmer groups
  - Average farm size 1.15 ha; 3 cows
  - Increasing population; decreasing farm size
- Funded by Gates Foundation, to East Africa Dairy Development program, implemented by Heifer International
- GHGs estimated using FAO Ex-Ante Carbon-balance Tool (EX-ACT)
- Needed GHG quantitative data not available (Jonsson 2012); used IPCC Tier 1 factors

Kaptumo Dairy Project

Actions

- Livestock management changes
  - Improve feed quality: Napier & Rhodes grasses, lucerne and dismodium fodder for protein; increase dry fodder
  - Improve pasture; 30% fertilized
  - Improved breeds
  - Veterinary care & vaccines
- Shift some maize production to cash crops
- Interplant cash crop trees: Tea, passionfruit
- Reduce forest clearing (small percent of area)
- Milk chilling and marketing centers
- Adoption rates vary by practice

Modeled GHG Outcomes

- “Realistic” adoption rate scenario
- Reduce average emission from 3 tCO_2e/ha-yr to 1 tCO_2e/ha-yr sink, averaged over 20 years
- Most of benefit is biomass sequestration in crop trees
- Large soil carbon sink
- Livestock emissions reduced 24%
- Modest reduction in deforestation emissions (little forest present at start)

Surveyed Financial Outcomes

- Average income increase from dairy is 6% of median farmer income
  - Higher milk yield per cow
  - Healthier cows
- No data on income increase from crops
- Project participants had 2.5 times crop income of non-participants; suspect much of this difference is because higher earners enrolled in the project, not income gain from the project

Program Cost

- Phase II: $25.5 million grant from Gates Foundation
- Goal to assist 200,000 farmers
- Cost would be $127.50/farmer
- Activities expected to continue after grant funding ends

Kasigau Corridor REDD+ Project

- 200,000 ha in southeast Kenya
- Avoid conversion of woodland to cropland
- Large private land ownerships, including group ranches
- Project developer: Wildlife Works, for-profit
  - Does monitoring & verification and some project activities
- Paid for by carbon credit sales into the voluntary market (VCS)
  - Requires private capital to initiate projects

Kasigau Corridor REDD+ Project

Kasigau Corridor REDD+ Project

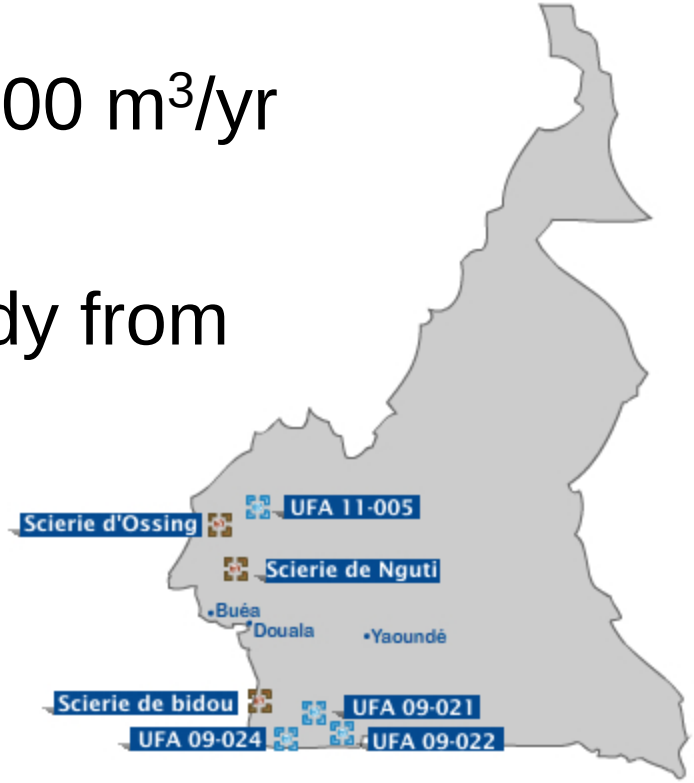
- Baseline deforestation rate 3%/year
- Little deforestation occurred after project start
- Revenue split: 1/3 communities, 1/3 landowners (may be community ownership), 1/3 project developer
- 2011: Gross avoided deforestation 1.54 million tCO_2e; 1.2 million tCO_2e sellable credits
- More avoided emissions from soil than trees

Kasigau Outcomes

- Little deforestation since project start
- Communities use revenues for general benefit
  - School fees
  - Water systems
  - School construction
- Where the landowner is a community, landowner share of revenues also goes to community benefit
- Over $100,000/year monitoring & verification costs

Wijma Cameroun S.A.

- Forest Stewardship Council certified since 2006, gets access to European market
- 251,083 ha forest in four forest management units in Cameroon
- Harvest more than 90,000 m^3/yr
- 3 sawmills
- Certified chain of custody from forest to consumer
- Dutch owned, for profit



Wijma Cameroun S.A.

Wijma Observations

- 0.36 m^3/ha-yr is very low harvest rate
- High value products: 2013 Cameroon non-coniferous roundwood export: \$378/m^3 (ITTO online database)
- \$136/ha-yr export value of logs
- Concession rates to Cameroon government tend to be low
- Challenging operational environment

General Observations: Revenues

- Competitive returns to land users
- Long term revenues from commodities
- Start up revenues from grants or carbon credits
  - tech transfer, social or physical infrastructure, community benefits
- Front-loading payments encourages smallholder participation

General Observations: Carbon Payments

- Carbon benefits in these examples are mostly soil, less biomass
- Globally, few carbon projects have generated many credits
- Large percent of verified credits are unsold (VCS Mai Ndombe)
  - Kasigau credit sale to Althelia took 3 years: 2012 credits not issued until October 2014
  - No other known terrestrial offset large sales
- Project developers waiting for sales to start projects

General Observations: Projects vs Programs

- Few locations support projects; selection bias
- Lower opportunity costs make modest project revenues more attractive
- Programs and policies can address all lands
  - Mandates applying to all avoid selection bias
  - See: Nationally Appropriate Mitigation Actions (NAMAs), Low Emission Development Strategies (LEDS), Intended Nationally Determined Contributions (INDCs)
- Monitoring required to measure outcomes
- Real time monitoring assists law enforcement (Brazil, Indonesia)

Scale

- Monitoring and verification costs are relatively insensitive to project size; >$100k/yr
- Pooling carbon revenues
  - Communities payments for community benefits like water systems and schools, need community group to decide and operational actor to implement (can be NGO)
  - A share to governments can pay for tech transfer, infrastructure, or law enforcement
- Landscapes: identify high emission localities
  - Estimate adoption rates for voluntary programs
- Nested carbon projects can claim much of a region's baseline

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- Wijma reports

Cost Effectiveness Analysis: Principles and Application

Wu Zeng, MD, MS, PhD
Brandeis University
Gary Gaumer, PhD
Simmons College
A.K. Nandakumar, PhD
USAID

A few slides are adapted from Goldharber-Fiebert J, Chan K, and Forsythe S

What is a cost-effectiveness analysis

- In the context of health and medicine, a cost-effectiveness analysis (CEA) is a method for evaluating tradeoffs between health benefits and costs resulting from alternative courses of action
- CEA supports decision makers; it is not a complete resource allocation procedure

Different Types of Analysis

- Cost Effective Analysis: The costs of the intervention relative to some outcome.
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Numerator / Denominator

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- Cost/HIV Infection Averted

Cost-Utility Analysis

- Cost/QALY (or DALY or HYE)

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- Cost/(Direct+ Indirect Benefits of Intervention)
- Cost/(Willingness to Pay for Intervention)

Why CEA

- Resources are limited
- The need for health interventions is vast
- Donors and implementers want the greatest possible improvement

Steps in Cost-Effectiveness Analysis

1. Define The Program
2. Compute Net Costs
3. Compute Net Health Effects
4. Apply Decision Rules
5. Perform Sensitivity Analysis

Define Program, Perspective and Costs

- Develop alternative approaches to the problem
- Define precisely programs to be analyzed (who, what, where, when, and how)
- Decide from whose perspective the analysis is being conducted: donor, households, society
- Counts all resources used by a health program, regardless of their source.

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- Costs
  - Compute gross program costs
  - Compute monetary savings
  - Discount costs and savings to present value
  - Compute net costs (gross costs less savings)

- Benefits (In health one option is)
  - Additional years with full health
  - Additional years of disease
  - Improvement in health (no extension of life)
  - Negative effects (inconveniences and morbidity)

Compute cost-effectiveness ratio

CE =	Net costs (in monetary terms, e.g., dollars)
	Net health effects (in utility terms, e.g., DALYs or QALYs)

One can compare the CER of different approaches

One should vary parameters and conduct sensitivity analysis

Models for decision analysis and CEAs

- **Decision model:** a *schematic* representation of all of the clinically and policy relevant features of the decision problem
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    - Decision alternatives
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- Two alternatives:
  - Statue quo
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- To simplify the analysis, here we focus on maternal outcomes only
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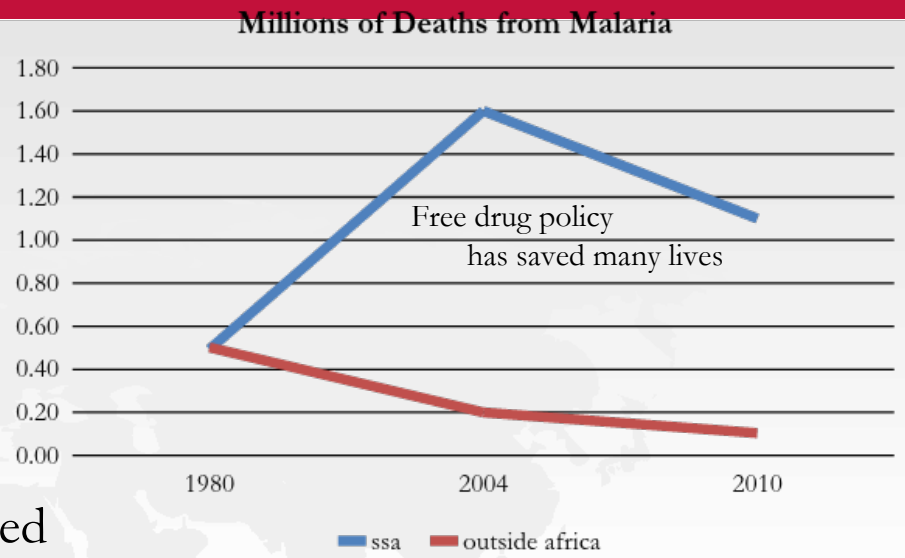

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A few explanations

- Poor diagnosis of malaria and pneumonia
- Wastage of anti-malaria drugs
- Lack of antibiotics
- Hard to access health facilities

Scale up strategies

- Scenario I: Assuming that availability of antibiotic increases from 70% to 95%.
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- Built a decision-analytic model that triages children with febrile illness through decision points relating to
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Simplified Scenario Impact Model

Driving Issues in the CEA

- Current policy is to see only about 16% of the kids in facilities, where free malaria drugs (ACT) are available
- Free Malaria drugs (ACT) have been excessively used due to donor's support
- Presenting febrile illness of unknown cause slow confirmatory testing for malaria and for other infections (only 40% of facilities have RDT for malaria)
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Unbundled scale ups would add RDTs
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	Expanded CHW delivery system	Delivery thru Health Facilities
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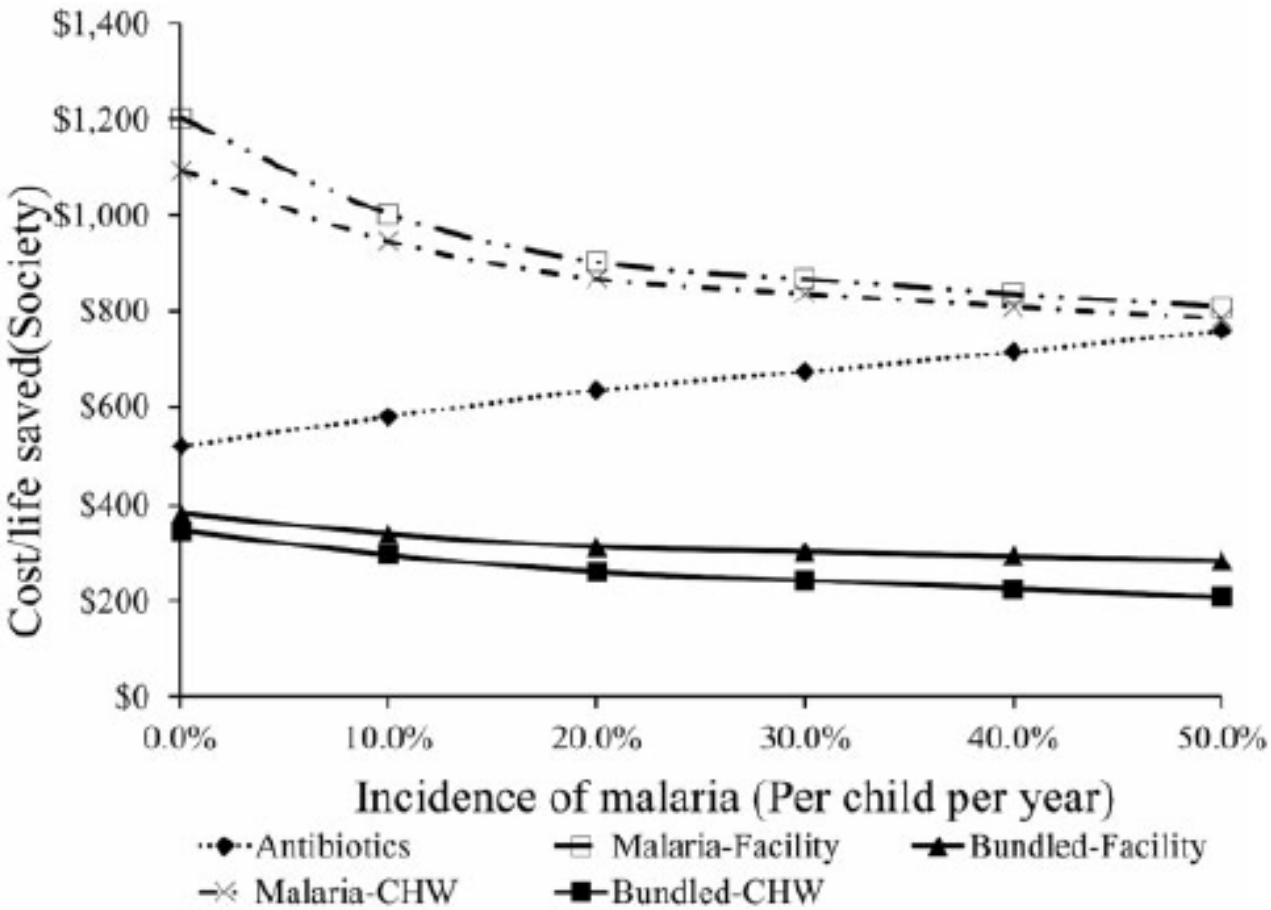
Scale up cost per life saved sensitive to baseline malaria incidence



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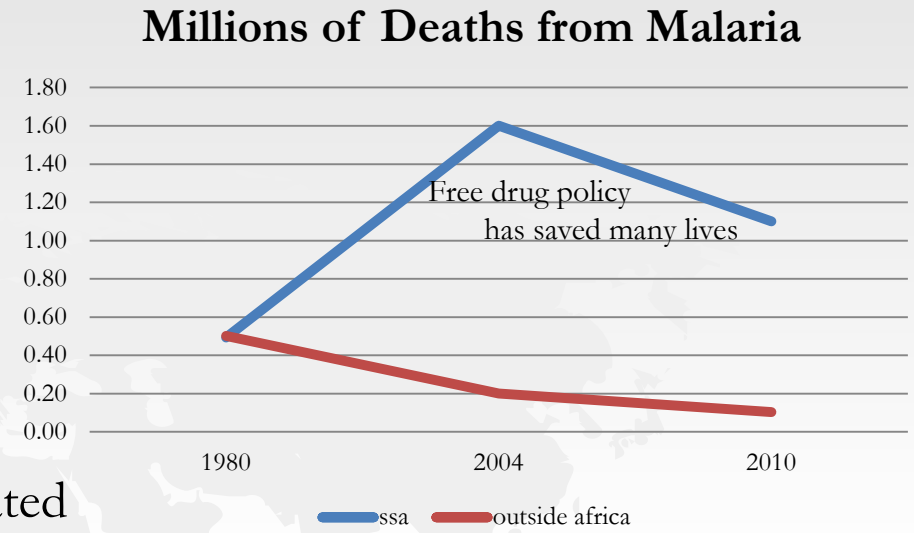

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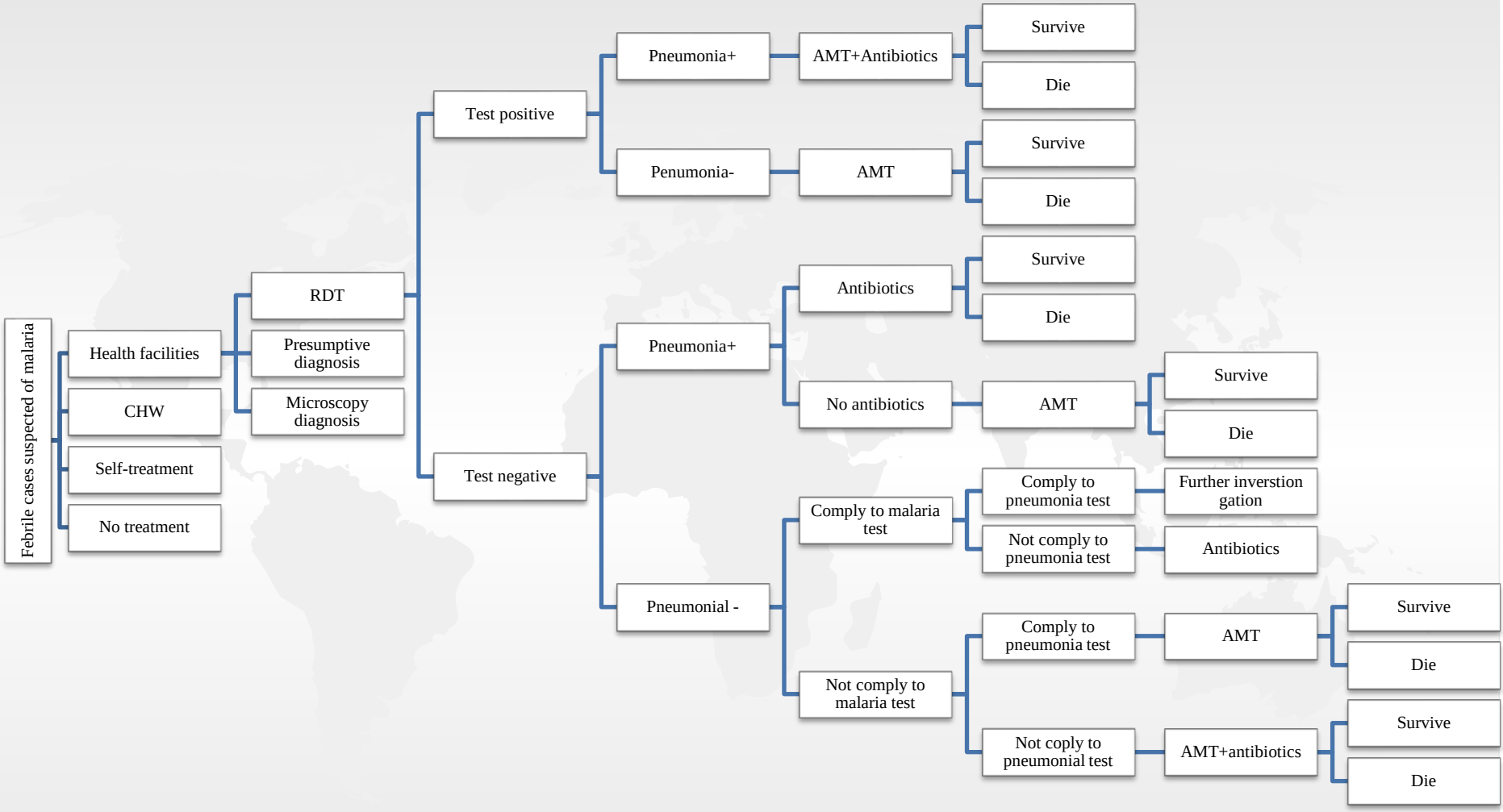

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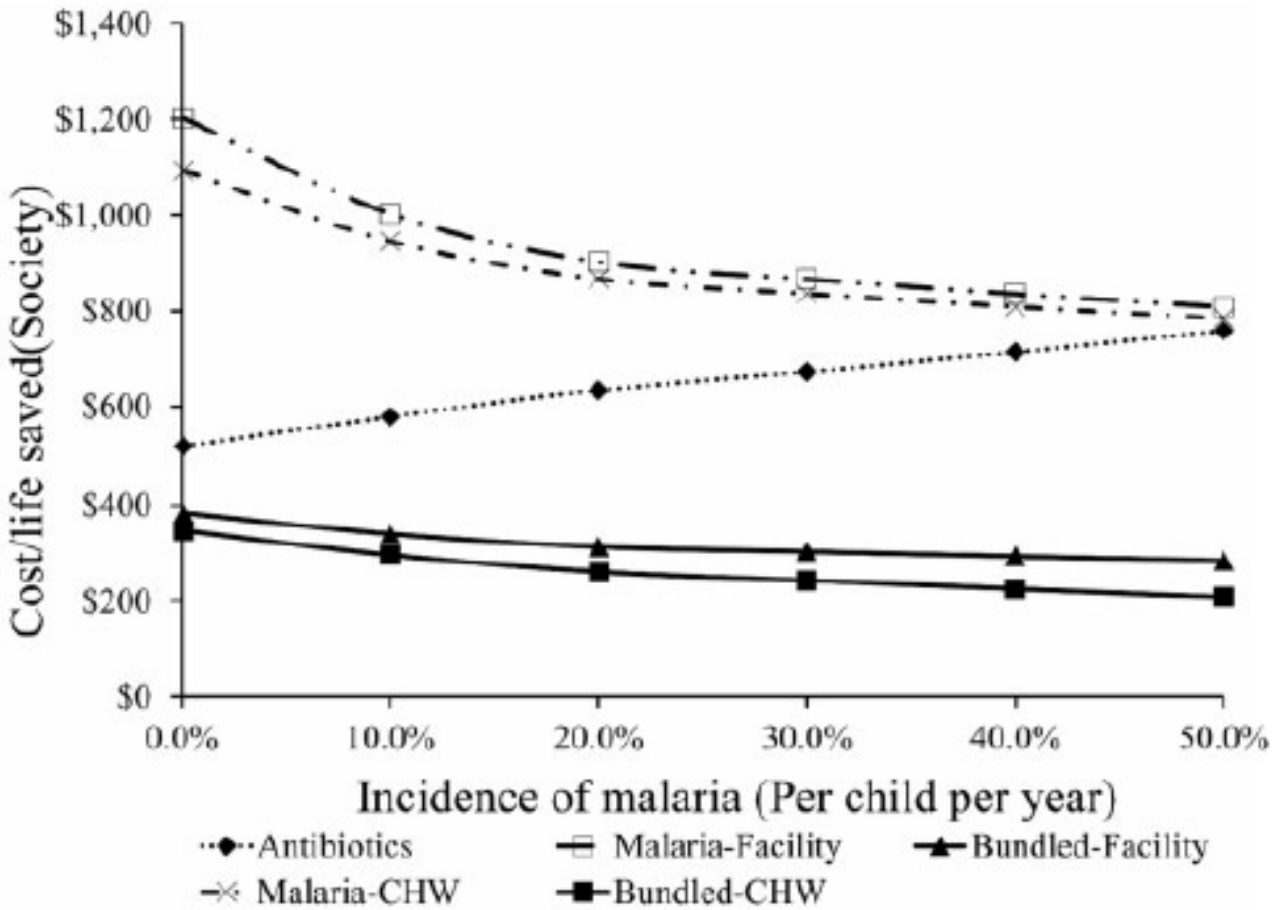

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Modelling the returns on options for improving malaria case management in Ethiopia†

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Background Diverse opinions have emerged about the best way to scale up malaria interventions. Three controversies seem most important: (1) should the scale-up focus on a broader target of febrile illness (including infectious disease and pneumonia)? (2) should the scale-up feature a single intervention or be targeted to the situation? (3) should scale-up have a preference for one kind of delivery mechanism or another?

Methods A decision model of 576 nodes describes the patterns of access, treatment and outcomes of an episode of febrile illness for a child below 5 years. Incremental costs and outcomes relative to baseline (2010) are computed for particular scenarios for Ethiopia using data from the literature. Two perspectives define the relevant costs: society at large and financiers (government and donors) where the costs borne by households are not included.

Findings Scaling up malaria interventions by one means or another is a very inexpensive way of saving young lives in poor countries. The low cost per life saved stems from two main reasons: the excessive baseline costs of presumptive use of antimalarial drugs for non-malaria cases, and the excessive costs of delayed treatment of pneumonia. A very limited policy of supplying antibiotics to facilities to eliminate stockouts would save 2100 lives, at a cost of only $615 a life. A much broader programme option, bundling malaria and pneumonia together for patients presenting with febrile illness [including rapid diagnostic test (RDT) for malaria, respiratory rate timers (RRTs) and free antibiotics], would save tens of thousands of young lives at and still cost society less than child fever management in the baseline situation! It is not clear that scale-up via community health workers (CHWs) is to be preferred to a facility-based intervention. The delivery through CHWs allows for a broader coverage of using RDT and RRT, but with limited effectiveness due to limited skills of CHWs in treating and managing patients.

Keywords: Malaria, scale-up, decision analytic model, cost effectiveness, Ethiopia

Introduction

After $1.5 billion in international funding for malaria in 2009 and much success (World Health Organization 2010), the prospects of further scale-up of the malaria treatment programme has begun to expose diverse opinions about the best way forward. Accompanying the shortage of financing have been concerns about issues such as high costs, diminished pay off, drug wastage, provider compliance rigidities, how best to access rural and isolated groups, and others (Reyburn *et al.* 2004; Bell *et al.* 2006; d'Acremont *et al.* 2010; Cohen *et al.* 2011). Proposals for scaling up need to cope with these issues, and experts have come to see the way forward in quite different ways. The programme of Affordable Medicines Facility—malaria (AMFm) starts addressing some of these issues with

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promising results (Littrell *et al.* 2011; ICF International and London School of Hygiene & Tropical Medicine 2012; Tougher *et al.* 2012; Malm *et al.* 2013).

One area about the scale-up reacts to concerns about the high levels of inappropriate use of antimalarial drugs (AMDs), including artemisinin-based combination therapies (ACTs), and the shortage of essential drugs (i.e. antibiotics) in resource-limited settings. One possible scale-up strategy to address the concerns would be to amend the 'malaria model' by adding antibiotics (e.g. commodities) to eliminate antibiotic stockouts. Alternatively, we could consider a broader strategy aimed at all febrile illness in order to better accommodate to provider practice realities. This kind of intervention might capture benefits from more appropriate (compliant) patterns of treatment (Hildenwall 2009). Broader interventions of febrile illness would combine pneumonia, malaria and even other diagnoses, along with new rapid testing technologies, making appropriate drugs widely available, and using training to support appropriate provider behaviours (World Health Organization 2010). This kind of solution might reduce widespread waste of ACTs and get antibiotics to patients who need them more quickly.

Beyond scale-up solutions that would bundle diagnoses and better integrate treatment decisions, other lines of thinking are beginning to suggest that further scale-up must move beyond the idea of 'one type of universal malaria or bundled solution with multiple interventions'. This thinking is beginning to consider more nuanced, or tailored, or targeted programmes, where different kinds of interventions and delivery mechanisms could be implemented in different situations (Sabot *et al.* 2011; Tren *et al.* 2012).

The third important dimension on which opinion seems to be fracturing relates to how the delivery system needs to be structured to support scale-up (Steketee and Eisele 2009). Both kinds of alternate thinking about scale-up noted earlier (bundling or not, and targeted or not) are suggestive of a broader integration of the programme with extant health services delivery structures and policy. Some see the need to emphasize the role of trained community health workers (CHWs) to eliminate distance and knowledge barriers and allow scale-up to reach the vast majority of the population (Chanda *et al.* 2011). Others see the scale-up differently, emphasizing health facilities including private facilities (Chinkhumba *et al.* 2010), reasoning that training costs for CHWs are high and that some countries have not chosen the CHW as an important form of service delivery.

Methods

A decision model is used to examine the consequences of alternative ways of scaling up the malaria intervention for children below 5 years. The impacts of intervention changes are computed by differencing baseline outcomes (costs, mortality) with the modelling results obtained for a particular intervention scenario. Both health system and societal perspectives are used for defining the relevant costs (and cost savings).

The modelling is based on Ethiopia, using data for a baseline of 2010, the most recent time for which the data on some key epidemiological parameters were available. We chose Ethiopia because it has a mid-range incidence of malaria, a mixed delivery system (CHWs and facilities) and three successful grants from the Global Fund for Malaria programming (The Global Fund 2013). In 2010, Ethiopia had nearly 14 million people below age 5 (United Nations Statistics Division 2012). Incidences of malaria and pneumonia in this population are estimated at 0.15 and 0.30 per person year, respectively (Salomon *et al.* 2011). Deaths from malaria and pneumonia are about 16 200 and 88 000, respectively. Febrile illness is treated in facilities (16%), by access to a CHW (1%) and by self-treatment (83%) (Salomon *et al.* 2011). In the country, there are 412 government health facilities with 1806 physicians and 35 000 CHWs (World Health Organization 2010). For persons treated in government facilities, we assume that about 40% of the febrile cases now get rapid diagnostic tests (RDTs) (Nankabirwa *et al.* 2009; Ndofor *et al.* 2013) and 30% of the time when antibiotics are prescribed, they are not available (Ministry of Health of Ethiopia and WHO 2003; Carasso *et al.* 2009).

Five scenarios are used to understand likely impacts of scaling up the current activities to fight malaria. The determination of scenarios of interest was based on initial discussions with programme officials in the Global Fund and the Bill and Melinda Gates Foundation, followed up with a review of policy discussions found in the literature. The five scenarios include a limited intervention scenario wherein antibiotics would be provided to health facilities in amounts that would eliminate stockouts, which occur about 30% of the time at baseline, and four scenarios defined by interacting the disease scope of the scale-up (two approaches) with the way service delivery are done (two approaches). In all four of these scale-up scenarios, we made no changes in the way the private sector functioned, other than the way scale-up alters the numbers of patients seeking care in that sector.

All scale-up options assume that there will be increases in the number of children with febrile illness who are seen by providers. Now, only about 16% are seen in Ethiopia (Salomon *et al.* 2011). In two of the scenarios, we assumed expansion to 50% (these scale-up scenarios utilize a service delivery model featuring facility-based care). Two other scenarios expand care seeking to 80% of children with febrile illness (these scale-up scenarios utilize service delivery centred around CHWs).

We defined two scale-up approaches regarding disease scope; one scale-up possibility is to continue the current intervention of focusing on malaria alone, but enhanced by adding universal access to RDT; the other scope option is to broaden the malaria programme to include helping providers identify and treat pneumonia. This would be done with added interventions including provision of antibiotics, and by making respiratory rate timers (RRTs) available. The 'bundled' scenarios referenced in the tables and figures refer to scaling up interventions to manage both malaria and pneumonia.

The model is illustrated in Supplementary Figure S1. For an episode of febrile illness, the model captures sequence of choices and results in 576 nodes. The sequence includes

- family decisions about whether and where to seek care (facility, CHW, self-treatment);
- provider approach to diagnosing the underlying condition (microscopy, RDT, RDT+RRT, presumptive);

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Table 1 Parameters that differentiate the baseline and five intervention scenarios

	Baseline	1 Antibiotics[a]	2 Malaria-Facility[b]	3 Bundled-Facility[c]	4 Malaria-CHW[d]	5 Bundled-CHW[e]
Facility access rate (%)	16	16	40	40	10	10
CHW access rate (%)	1	1	10	10	70	70
Self-treat rate (%)	83	83	50	50	20	20
Facility antibiotics availability (%)	70	95	70	70	95	95
Use rate of RDT-facilities (%)	40	40	100	100	100	100
Use rate of RDT-CHW (%)	0	0	100	100	100	100
Use rate of RRT in facilities (%)	0	0	0	100	0	100
Use rate of RRT in CHW (%)	0	0	0	100	0	100
RDT negative compliance (%)	60	60	100	100	100	100
RRT negative compliance (%)				90		90

[a]Assuming that availability of antibiotic increases from 70% to 95%.

[b]Assuming that 40% of febrile cases seek case at health facilities, increased from 16% at the baseline, RDT scales up from 40% to 100% in health facilities, use of RDT among CHW increases from 0% to 100%, the adherence to malaria test results increases from 60% to 100%.

[c]In addition to changes in Scenario 2, it assumes that RRTs are fully used by both health facilities and CHWs to diagnose pneumonia, with RRT compliance rate of 90%.

[d]In addition to changes in Scenario 2 except few cases seeking care at health facilities, it assumes that CHWs took major role in diagnosing and managing 70% febrile cases, self-treatment cases reduced from 83% to 20%, and availability of antibiotics increase from 70% to 100%.

[e]In addition to changes in Scenario 4, it assumes that RRTs are fully used by both health facilities and CHWs to diagnose pneumonia, with RRT compliance rate of 90%.

- given the diagnosis result, provider decision about test compliance and decisions about treatment;
- course of the condition and subsequent care needs (hospital stay, follow-up outpatient care, nothing);
- outcomes in terms of total costs and mortality.

Scenarios are created by positing changes in one or more baseline parameters. In the case of parameters like adherence (compliance) rates and disease incidence rates, we also examine the sensitivity of scenario outcomes to a range of plausible values for the parameter in question. The characteristics for each scenario are shown in Table 1.

The scenarios differ not only in terms of the access to care assumption but also in terms of the practice patterns, or choices, of providers. Overall compliance with RDT negative test results (not giving ACTs when RDT test results are negative) is assumed to be improved in all the scale-up scenarios since the initial introduction of RDT, RRT and antibiotics at least will appropriately treat those who are given ACT due to lack of antibiotics.

The data for modelling the baseline situation in such a complex model are not fully available for any country. Parameters are taken to the extent possible from the 2010 values for Ethiopia available from the World Health Organization, CHOosing Interventions that are Cost Effective (WHO-CHOICE). Other important data sources include extensive African malaria modelling efforts by Salomon *et al.* (2011) and Shillcutt *et al.* (2008). Other data sources used are also identified in the data and assumption tables provided in the Supplementary data. If data were not available from these sources or the literature, assumptions were made to perform the simulation. The baseline model assumptions were also adjusted to conform to known child death rates for malaria and pneumonia.[1] Due to the lack of data on the case fatality rate (CFR) of malaria and pneumonia, we did not distinguish the CFRs by treatment settings. The key epidemiological and cost parameters are showed in Tables 2 and 3.

Results

The baseline situation is shown in the first column of Table 4. Using the model, we estimate the baseline 2010 level of total spending on febrile illness at about $50 million a year in Ethiopia, about 44% of which is financed directly by households, mainly on purchases of drugs from retail private sources. Government/donor cost on febrile illness (66% of $50 million) is mainly on hospital and health facility follow-up care (85%) and both AMDs and antibiotics (14%). The level of government cost on antibiotics is not much different than the amount costed by households. Nearly 113 000 children died from febrile illness at baseline, over 75% of them from pneumonia.

Question 1: Does eliminating the antibiotic stockouts in government facilities save lives and create efficiencies relative to baseline? We created an intervention scenario wherein sufficient antibiotics were purchased and distributed to government facilities to eliminate stockouts, which at baseline are assumed to be 30% (in 3 of 10 patients where the clinician would administer antibiotics, such drugs are not available at the facility). No other changes from the baseline were made in this scenario, including no changes in the use of the private sector delivery system. The cost of the programme is limited to the costs of the antibiotics (the supply systems are not altered in the scenario). The benefits will be the reductions in deaths for persons who did not promptly receive antibiotics (pneumonia deaths) and cost savings achieved by not wasting the free AMDs that are often administered by clinicians who are often pressured to 'do something' when faced with stockouts for the drug of choice.

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Table 2 Key epidemiological parameters among children below 5 years

Parameters	Estimate (%)	Source
Epidemiology		
Incidence of febrile illness (per person year)	56	Salomon *et al.* (2011)
Incidence of malaria (per person year)	15	Salomon *et al.* (2011)
Incidence of pneumonia (per person year)	30	Salomon *et al.* (2011)
Incidence of co-infection of malaria and pneumonia (per person year)	2	d'Acremont *et al.* (2010)
Care seeking behaviour		
Receiving care at health facilities	16	Salomon *et al.* (2011)
Receiving care at community health workers	1	Salomon *et al.* (2011)
Self-treatment	83	Salomon *et al.* (2011)
Sensitivity and specificity of diagnostic approaches		
Sensitivity of RDT	93	Meena *et al.* (2009)
Specificity of RDT	98	Meena *et al.* (2009)
Sensitivity of microscopy	79	Uzochukwu *et al.* (2009)
Specificity of microscopy	82	Uzochukwu *et al.* (2009)
Sensitivity of presumptive diagnosis for malaria	85–90	Ajayi *et al.* (2009)
Specificity of presumptive diagnosis for malaria	20–42	Ajayi *et al.* (2009)
Sensitivity of RRT	80	Assumption
Specificity of RRT	75	Assumption
Sensitivity of presumptive diagnosis for pneumonia	40–80	Assumption
Specificity of presumptive diagnosis for pneumonia	35–63	Assumption
Case fatality rate		
Malaria CHWs treated with initial proper treatment	3	Assumption + calibration
Malaria treated without initial proper treatment	1	Assumption + calibration
Pneumonia without initial proper treatment	6	Gwer *et al.* (2007) + calibration
Pneumonia with initial proper treatment	2	Assumption + calibration

Table 3 Key cost estimates used in the model

Parameters	Estimate($)	Sources or assumptions
Diagnostics		
RDT	0.80	Lemma *et al.* (2011); Uzochukwu *et al.* (2009)
Microscopy	1.30	Chanda *et al.* (2009); Uzochukwu *et al.* (2009)
RRT	3.50	Assumption
Drugs (per treatment course)		
ACT for uncomplicated plasmodium falciparum (p.f.) cases	1.59	Tougher *et al.* (2012) + assumption
Choloquine for uncomplicated plasmodium vivax (p.v.) cases	0.90	$0.3 per day for 3 days
Intravenous quinine for severe malaria cases	5.47	Uzochukwu *et al.* (2009)
Antibiotics for uncomplicated pneumonia	2.52	Banja (2010)
Antibiotics for complicated pneumonia	15.54	Banja (2010)
Health care cost		
Inpatient health care cost (per bed day)	3.56	WHO-CHOICE
Outpatient health care cost (per visit)	0.98	WHO-CHOICE
Lab cost for inpatients		
Lab cost for malaria inpatients	36	Kone *et al.* (2010)
Lab cost for pneumonia inpatients	36	Kone *et al.* (2010) + assumption
Cost of training		
Cost of training/CHW (bundled)	50	$5 for material cost + half day of training and per diem
Cost of training/CHW (unbundled)	100	$10 for material cost + 1 day of training and per diem

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Table 4 Annual costs and deaths for febrile cases <5 in Ethiopia for baseline and five intervention scenarios[a]

	Baseline	1 Antibiotics	2 Malaria-Facility	3 Bundled-Facility	4 Malaria-CHW	5 Bundled-CHW
Health outcomes						
Number of death due to co-infection	9351	9331	8139	7697	7078	6371
Number of malaria death	16 226	16 311	15 608	15 760	15 158	15 461
Number of pneumonia death	87 771	85 607	83 551	71 698	79 114	60 150
Total death	113 348	111 250	107 298	95 155	101 350	81 982
Death rate (per 1000 population)	19.61	19.46	19.17	18.29	18.74	17.34
Costs of government/donors ($)						
Cost of RDT	435 192	435 192	3 473 242	3 473 242	5 953 043	5 953 043
Cost of RRT	0	0	0	128 821	0	128 821
Cost of antibiotics	2 501 487	3 170 917	8 115 278	9 276 373	14 637 600	15 012 134
Cost of AMD	1 325 864	1 149 023	2 483 594	1 824 247	4 200 546	2 995 063
Cost of training	0	0	3 500 000	1 750 000	3 500 000	1 750 000
Other health care cost[b]	23 930 748	24 729 494	23 629 947	24 960 762	26 992 063	27 324 514
Subtotal	28 193 291	29 484 626	41 202 060	41 413 445	55 283 252	53 163 575
Costs of household (HH) ($)						
HH transportation cost	888 601	888 601	2 221 503	2 221 503	555 376	555 376
HH cost of AMD	7 834 026	7 834 026	4 337 430	4 337 430	1 734 972	1 734 972
HH cost of antibiotics	13 245 491	13 245 491	7 979 211	7 979 211	3 191 685	3 191 685
Subtotal	21 968 118	21 968 118	14 538 145	14 538 145	5 482 032	5 482 032
Total ($)	50 161 409	51 452 744	55 740 205	55 951 589	60 765 284	58 645 607
Cost/life saved (programme)		615	2150	727	2258	796
Cost/life saved (society)		615	922	318	884	270

AMD, anti-malaria drug, including ACT, chloroquine and quinine.

[a]Same note for the five intervention scenarios as Table 1.

[b]Other health care costs include the labour costs of medical staff, facility capital costs and costs of laboratory tests other than RDT and RRT.

The results for this scenario are shown in the second column of Table 4. The programme would cost about $670 000 a year for the additional antibiotics, another $800 000 in other health care costs that include labour costs of medical staff, facility capital costs, and costs of laboratory tests other than RDT and RRT, and result in saving 2100 pneumonia deaths in children. The cost per life saved is only $615. One reason this is so inexpensive is that the added costs of testing and other health care are offset by the reduced costs of presumptive use of AMDs including ACTs. A weakness of this very limited intervention is that (without supplementary provision of RDT) only about 40% of suspected malaria cases treated in health facilities are able to be tested with RDT. This commodity strategy for antibiotics is a better payoff (for society and for governments/donors) when pneumonia incidence rates are higher. As Figures 5 and 6 indicate, as incidence rates for pneumonia rise, the costs per life saved become even lower.

Question 2: Does scale-up using a bundled approach to febrile illness yield more programme efficiencies and saved lives than a malaria-only approach? Bundling directly addresses the clinical distortions created by better clinician access to AMDs than to other treatments for conditions that also present as a febrile illness. These distortions manifest as excessive use of the least expensive/more accessible treatment alternative when clinicians face a situation of uncertainty about the underlying condition. The bundled programme would improve access to RDT for malaria, would provide universal access to RRTs (to better discriminate the condition of pneumonia and compromised pulmonary function) and would offer required supplies of both AMDs, including ACTs, and antibiotics (e.g. no stockouts at facilities). We would expect an increase in lives saved (particularly for pneumonia) and modest increments in cost because the costs of the programme of interventions would be largely offset by the reduction in wastage of AMDs. Results are shown on Table 4. In that table, the bundled programme results are shown in column 3 (emphasizing facility-delivered mechanism) and column 5 (emphasizing CHW-delivered mechanism). The scale-up is evident in assumptions made about access to government providers in all scenarios. Now about 83% of febrile patients are self-treated (Salomon *et al.* 2011), with or without privately purchased pharmaceuticals. In the roll out scenarios, we alternatively assume that this is reduced to 50% (in the case where facility delivery is emphasized) and to 20% (where the intervention emphasizes the CHW strategy, where there are much more widely dispersed points of testing and treatment services).

As a scale up alternative, the bundling alternatives (Scenarios 3 and 5) save more lives saved than the malaria-only intervention (Scenarios 2 and 4). In terms of net cost outlays by government/donors, the bundled programme roll out that

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emphasizes the facility delivery mechanism (Scenario 3) would cost about $13 million each year more than current intervention (Baseline). The malaria-only programme under the same assumptions (Scenario 2) would cost $13 million over baseline. The scale-up that emphasizes CHWs would have a net incremental cost increase over baseline of $25 million for the bundled programme (Scenario 5) and $27 million for the malaria-only programme (Scenario 4). While costing more to implement (RRTs and antibiotics), the net costs of bundling are lower or similar relative to the malaria-only programme primarily because of savings that accrue by reducing the wasted AMDs (partly by reducing stockouts for antibiotics and by improving the accuracy of diagnosis). There is no real differential in the household costs between the bundled scale-up with the scale-up that continues to emphasize malaria only.

Scale-up of a bundling alternative improves febrile care outcomes for the population under 5 more than a malaria-only intervention. The savings in lives are primarily due to fewer deaths from pneumonia. Using a facility-focused delivery model, the bundled intervention saves about 18 000 lives each year relative to baseline. The malaria-only intervention would save only about 6000 lives. With the CHW delivery emphasis the mortality benefits of bundling are even more pronounced: with bundling about 31 000 lives would be saved a year, and for a malaria-only roll out, only about 12 000 lives would be saved. Consequently, cost per life saved is far lower for bundled scale-up than for malaria-only scale up. When considering the costs borne by donors/government and households, the bundled intervention scale up more than pays for itself from society's perspective. The cost reductions of the scale-up for the households are not relevant for the government/donor perspective, so the cost per life saved from this perspective is much greater, though they still favour a bundled intervention.

Question 3: Does it matter how scale-up is delivered? Does the emphasis on one or the other service delivery modality influence intervention efficiency and mortality? The intervention options we tested here are defined by a CHW dominant one (80% overall coverage, with 70% going to CHWs and only 10% to facilities) and a facility dominant model (only 50% coverage, of which 40% seek care in facilities and only 10% to CHWs). These results are shown in Table 4, columns 2 and 4, respectively. CHWs require lots of expensive training, but more people can be reached because distance and ignorance barriers to care-seeking are lower.

The overall costs for scaling up via CHW are higher mainly because of the further reach of the programme to more people. The added net costs to the government/donors for the facility centred model of scale-up will be around $13 million, whereas the CHW approach will cost twice that much ($25–27M). The delivery model emphasizing facilities saves far fewer lives (6000–18 000 lives) than the CHW model (12 000–31 000). Overall, from the vantage point of payers or from the vantage point of society at large, the cost per life saved is somewhat lower for a facility-based roll out (for both a bundled and unbundled service approach).

Sensitivity tests

To better understand the impact of delivery system options on outcomes, we performed sensitivity tests. Table 5 shows some sensitivity tests on the mix of the two delivery systems, holding overall scale-up access constant at 50% (e.g. 50% of the population are self-treated). For example, when 20% of the families seek care in facilities, it means that 30% seek care with CHWs. When 50% seek care in facilities, it means that 0% seek care with CHWs. Whether the intervention is bundled or not, from the perspective of the donor/government, it is more cost effective to make maximum use of facilities in delivering the scaled up intervention. As the care seeking choices emphasize more and more use of facilities, the cost per life saved falls. However, from the societal perspective, the story is mixed: the cost per life saved drops when using more and more health facilities to deliver the service for the unbundled intervention, but the cost per life saved increases for the bundled intervention. This is due to the higher facility costs in comparison with the unbundled facility-delivered option, for treating pneumonia, which is part of the bundled intervention.

Table 5 Sensitivity of cost per life saved to mix of delivery system models

Seeking care in health facility (%)	Cost/life saved ($)			
	Government/donors		Society	
	Malaria-Facility	Bundled-Facility	Malaria-Facility	Bundled-Facility
0	2701	777	1118	246
10	2564	764	1069	264
20	2427	752	1020	282
30	2289	739	971	300
40	2150	727	922	318
50	2011	714	873	336

How important is provider compliance with diagnostic testing in scale-up effectiveness? Compliance rates with RDT negative findings for malaria in facilities were assumed to be 60% in the baseline and 100% in the scale-up options. In the case of CHW, we assume that this compliance rate is also 100%. Figures 1 and 2 examine the effect of varying these compliance assumptions for RDT tests. As expected, better compliance rates, other things the same, reduce the cost per life saved for all approaches to scale up and from the perspective of the financiers or society at large. Improving compliance is one key to improving the efficiency of these interventions.

Do scale-up options perform equally well across places with different disease patterns? Keeping the incidence of pneumonia at the baseline level of 0.30 per child per year, when the incidence of malaria is increasing between 0% and about 15% per child per year, the cost per life saved from scaling up the RDT intervention in both facilities and CHW settings decreases from the government/donors perspective. Beyond the incidence of malaria of about 15%, higher malaria incidence is associated with higher cost per life saved for all four of the scale-up strategies from donor/government perspective. Figures 3 and 4 show these results. In the latter case, with moderate malaria burden, and without considering the savings from households, this pattern is largely the result of less wastage from presumptive use of ACTs when malaria incidence gets higher. More intuitively, as malaria incidence increases, the presumptive diagnosis of malaria by default becomes more rational.

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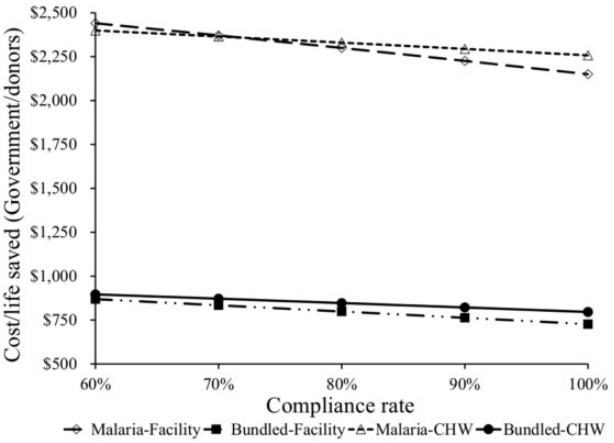

Figure 1 Sensitivity of outcomes to compliance with RDT results for donors/government

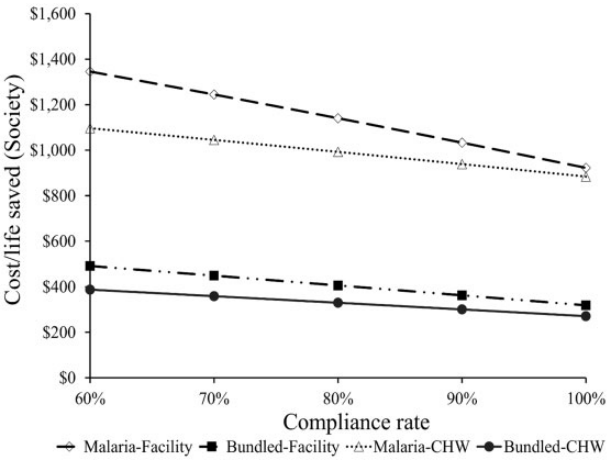

Figure 2 Sensitivity of outcomes to compliance with RDT results for society

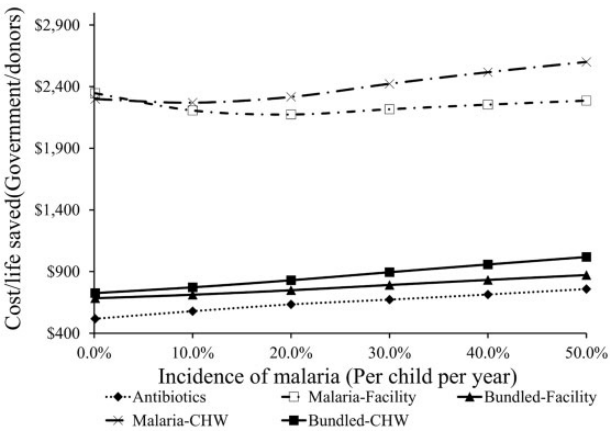

Figure 3 Sensitivity of outcomes to incidence of malaria for government/donors

Investment in RDT becomes less attractive as more febrile cases are malaria cases. This wastage is a large component of financing for scale-up, hence the positive correlation between malaria incidence and cost per life saved. However, from the

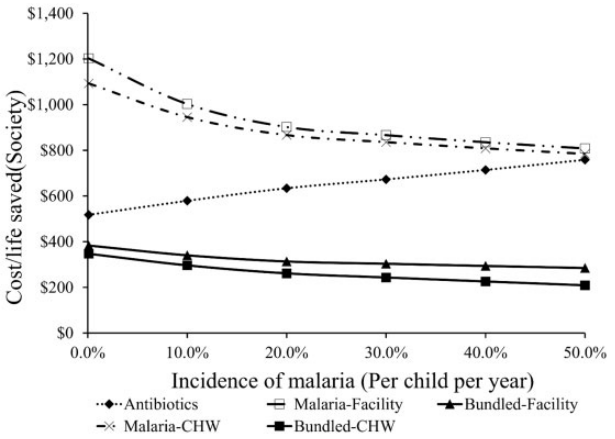

Figure 4 Sensitivity of outcomes to incidence of malaria for society

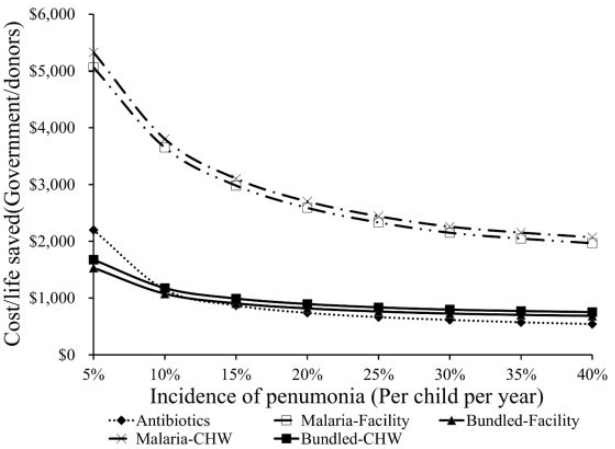

Figure 5 Sensitivity of outcomes to incidence of pneumonia for government/donors

society's perspective, the cost per life saved declines as the incidence of malaria increases.

Holding the incidence of malaria at 15%, sensitivity to pneumonia incidence is more complex (see Figures 5 and 6). For donors/governments, all scale-up strategies have better payoffs as pneumonia incidence rates climb. For society as a whole, the scale-up featuring a malaria-only intervention also shows better payoffs as pneumonia rates climb, *cet par*. But, in the bundled approaches to scale up the cost per life saved become higher as pneumonia incidence rises. Essentially, the bundled intervention (of better diagnostics and commodities allows clinicians to find and treat pneumonia better) becomes less valuable as pneumonia incidence soars, largely because the savings per live saved from households declines (due to reduced costs for transportation, AMDs and antibiotics).

Discussion

Although great efforts have been made towards malaria prevention such as the use of long-lasting insecticidal nets

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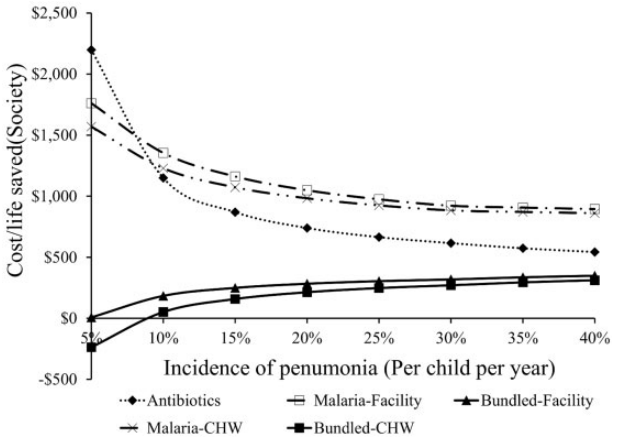

Figure 6 Sensitivity of outcomes to incidence of pneumonia for society

and indoor residual spraying (Otten *et al.* 2009), the malaria burden remains high and threatens population health. And, the economic burden is high on governments and on households. The case management of malaria cases becomes critical in saving lives and doing it in as economical a fashion as is possible. Improving quality and coverage of child fever case management programmes by one means or another seems to be a sensible and inexpensive way of saving young lives in poor countries. The benefits of the scale-up to households can be considerable, shifting the cost of care for febrile illness from their own pockets (mainly purchasing drugs from private pharmacies) to the scaled up public programme. From the vantage point of the financier, on the other hand, the scaling up costs are higher, ranging from $1000 to $3600 per life saved across the options we studied. This large disparity of interests reminds us of the huge financial burdens of out-of-pocket spending for health care in poor countries and how it influences policy discussions.

Would it save money and lives to pursue a policy limited to supplying antibiotics to facilities, reducing stockout problems? The answer to this question is affirmative. This tactic would save around 2100 young lives lost to pneumonia each year, at a cost of about $615 a life. But, this is not a scale-up strategy. Further low cost benefits could be achieved by investing more in scaling up other life-saving interventions associated with febrile illness and malaria in children.

Should the scale-up prefer a bundled intervention focusing on both malaria and pneumonia? The answer is yes. The bundled intervention has a lower cost per life saved in all cases: from the vantage point of the society and from the vantage point of the financier, and whether delivery emphasizes facilities or whether delivery emphasizes CHWs. This seems true because modelling shows that the vast majority of lives being saved in the scale-up are preventable pneumonia deaths, and the bundled intervention provides clinicians tools for doing a better job of identifying and treating pneumonia.

Should the scale-up prefer facility delivery or the use of CHWs? This is not clear from the modelling solution for the scenarios we studied. The accessibility advantages of CHWs may offer more upside total benefits, because the approach can likely reach more people. Getting high access rates is important since the benefits to households can be considerable as they (and their spending) can be shifted from the private to public sectors for their febrile illness care. But the facility-based scale-up is somewhat more efficient per life saved (than the CHW solution) when overall access rate is controlled in the comparison (Table 5). This advantage is due to a number of cost-related advantages of the facility model such as more accurate diagnosis of pneumonia and malaria, which significantly reduces the wastage of both ACTs and antibiotics. Facility-based rollout makes economic sense as far as it can go, but this strategy probably does not offer very high scale-up potential. Using CHWs or some other outreach approach is going to be required to reach remote and thinly populated areas.

We have no evidence that one scale-up intervention is to be preferred at low incidence rates, and another configuration at higher incidence rates. We find that from the government and donor perspective, cost per life saved is $100–200 (about 30–50% higher) across scale up scenarios when comparing a site with malaria incidence of 0.50 with a situation where incidence is only 0.20. In a setting with moderate malaria burden, the primary reason why high incidence populations cost more is that with high incidence, less of the presumptive usage of ACTs in the baseline is wasted, offering less potential as a course of financing for the scale-up. Whatever the intervention included, the scale-up is simply going to cost more per life saved when malaria incidence is high. This inverse relationship is consistent with literature showing an inverse relationship between the cost-effectiveness of a diagnostic test and incidence rate of the associated illness (Shillcutt *et al.* 2008). If one disease is dominant, investment in diagnostic tests to accurately diagnose the dominant disease will result in high cost/life saved.

There are some other implications of the modelling work. The modelling of impacts of the scale-up strategy for malaria tells an unusual story. From the perspective of donors and governments, the scale-up alternatives each save thousands of preventable pneumonia deaths, and are all largely financed by reduced spending on AMDs! For society at large, the story is the same, plus large benefits to households as the scale-up moves health care for febrile illness away from the out-of-pocket spending to the public sector. Why are the benefits of malaria intervention scale-up found in fewer pneumonia deaths? Why are cost impacts driven by the baseline levels of waste in the use of anti-malaria drugs? What has been happening in the malaria programme to date? This appears to be a story of distorted incentives facing clinicians. Pneumonia and malaria and other diseases usually present as fever in children. Rather than consider the interdependencies of the triage situation, the silo (vertical) programme for malaria distorted the incentives by making available copious supplies of free drugs for malaria (the Global Fund and other international donors have promoted ACTs by subsidizing private-sector ACT distribution) (Tozan *et al.* 2013). The lack of parasitological testing, the unreliability of tests when they are available, subjective clinical interpretations, and the pressures from experience and parents all contribute to the excessive use of the free and available ACTs. That is the bad news. The good news is that efforts to scale up RDT have been observed (Zhao *et al.* 2012) and the scale-up of

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RDT can use this waste (the product of the distortion) to partially finance the scale-up. Have the high level of the (preventable) pneumonia deaths at baseline been the result of the distortion? Probably, as the models confirm that compliance rates with RDT negative results are inversely correlated with pneumonia deaths. This is not a positive story about clinical decision-making incentives for the malaria-only intervention to date. It certainly suggests that co-dependent clinical problems are prone to distortion if one disease or treatment approach is singled out over the others. Such distortions should be larger the more co-dependent the diseases and the more important is subjectivity in the provider's behaviour.

How quickly will the results predicted by the models actually occur even if RDTs and RRTs, free antibiotics and other interventions could be made to happen tomorrow? Changes in practice patterns will not happen quickly in the face of longstanding practices, family pressures and known levels (however modest) of unreliability of the tests. The model cannot help us here beyond sensitivity tests (Figures 1 and 2), but it is a very important problem. In the model, the effectiveness of training is not studied directly, but we do examine the sensitivity of outcomes to the rates of compliance (high, low, etc.). And, we find that compliance is a consistent and important predictor of cost effectiveness for these programmes.

Improvement of adherence to malaria or fever case management guidelines will take time to realize. Merely investing in the supply of diagnostic tests and free drugs does not necessarily bring about positive behaviour changes and compliance (Smith *et al.* 2009; Chandler *et al.* 2011, 2012). One approach to achieve compliance could be through additional training, and this would be slow and expensive. Some successful stories of using training to improve clinician adherence to testing results have been reported (Bastiaens *et al.* 2011; Chanda *et al.* 2011; Mukanga *et al.* 2011; Cohen *et al.* 2012). Another potential approach would be through provision of financial incentives for providers, possibly involving explicit criteria, a financial pool and some kind of ex post audit of records. Although the effectiveness of pay for performance in developing countries remains in dispute (Witter *et al.* 2012), in Rwanda and Haiti, for example, pay for performance to health providers and CHWs has shown great impact on maternal health services (Basinga *et al.* 2011; Zeng *et al.* 2012). A similar approach, in conjunction with strong implementation, could be considered in the malaria field to shape provider behaviour in a more direct and faster way.

The generalizability of these cost and mortality findings to the situation in other countries is not known. The sensitivity testing for baseline incidence rates and compliance parameters offers some guidance as to what to expect in countries with baseline febrile illness and care delivery situations different from Ethiopia. The model could be fit to baseline data from other countries.

Supplementary data

Supplementary data are available at *Health Policy and Planning* online.

Acknowledgements

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Endnote

[1] All data, assumptions, modelling details and sensitivity testing results are available directly from the authors.

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Economic Analysis and Planning for Global Climate Change Mitigation

Health Co-Benefits in China, Mexico & Colombia MACCs

William A. Ward

E3/EP, USAID-Washington

Health Co-Benefit Analysis in China (1992-1993)

- Focus was Industrial Energy Efficiency
- NO cutting edge – ‘old’ technologies compared to advanced market economies (1-3 technologies behind the cutting edge)
- Point-source polluters

25 Technology Options

- Metallurgy
- Chemicals
- Building Materials
- Cement
- Textiles
- Pulp & paper
- Electric motors
- Coal
- Electric power
- Residential construction

What we did…

- Localized pollution analysis (Todd Johnson & Gary Wells)
- Analyzed in parallel with remainder of EE CBA
- Worked with leading scholars in academia in analyzing plume models and epidemiological studies
- Focused on health impacts only from
  - Particulates
  - Sulfur compounds
- Did not include corrosion damages, etc.

Why we did not include health co-benefits in final C/E calculations…

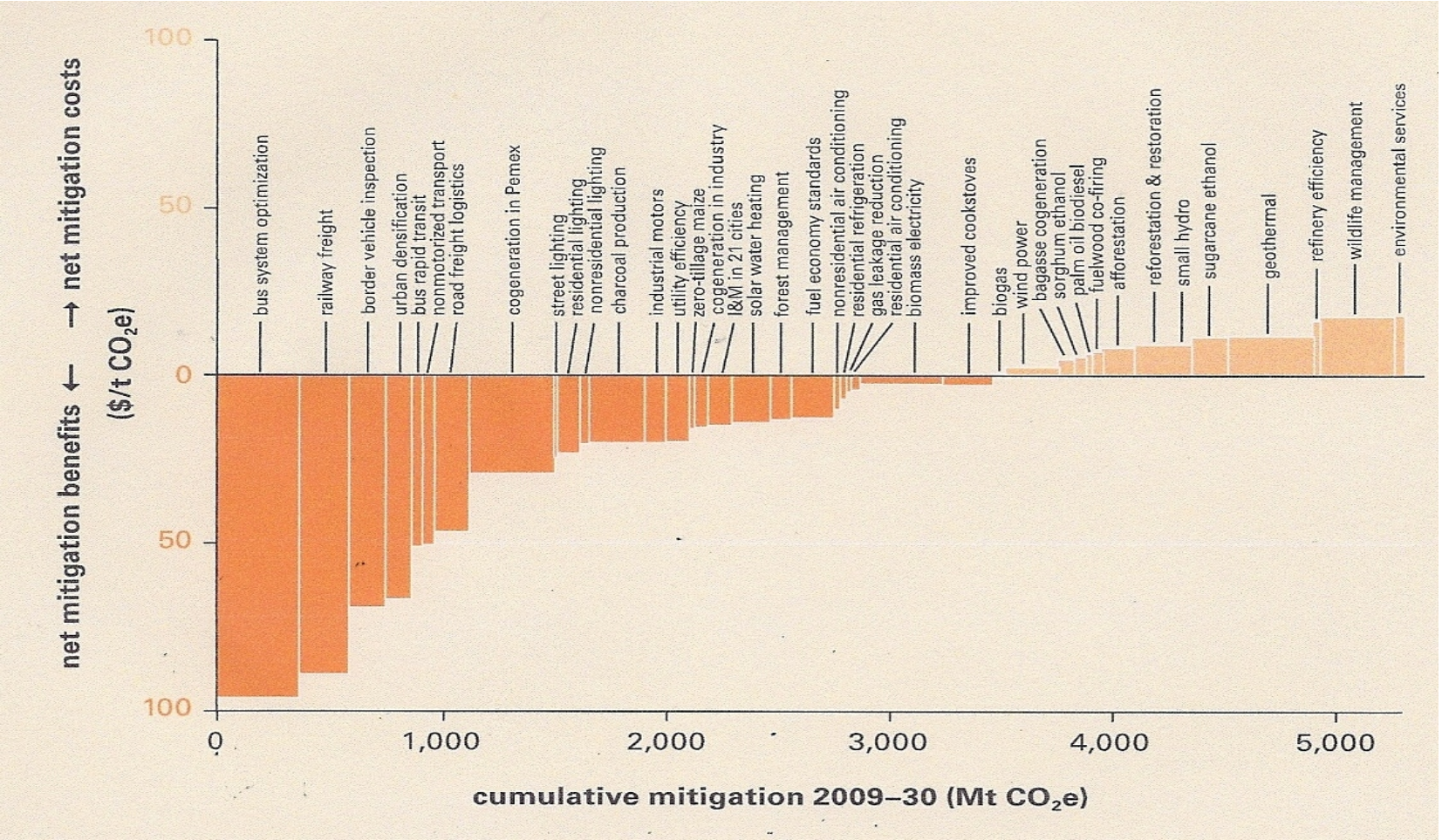
- 24 of 25 projects were attractive in financial terms
- Economic analyses without health co-benefits also were very attractive – e.g., ***Metallurgy Industry***:

	Fin IRR	**Econ IRR**
Openhearth vs BOF Project	16.08%	15.71%
Continuous Casting Project	18.63%	19.42
Steel Rolling/Furnace Project	35.90%	37.65%
Blast Furnace Gas Recovery	28.21%	41.44
Aluminium Plant Renovation	84.31%	82.80%

Health Co-Benefit Analysis in Mexico (2007-2009)

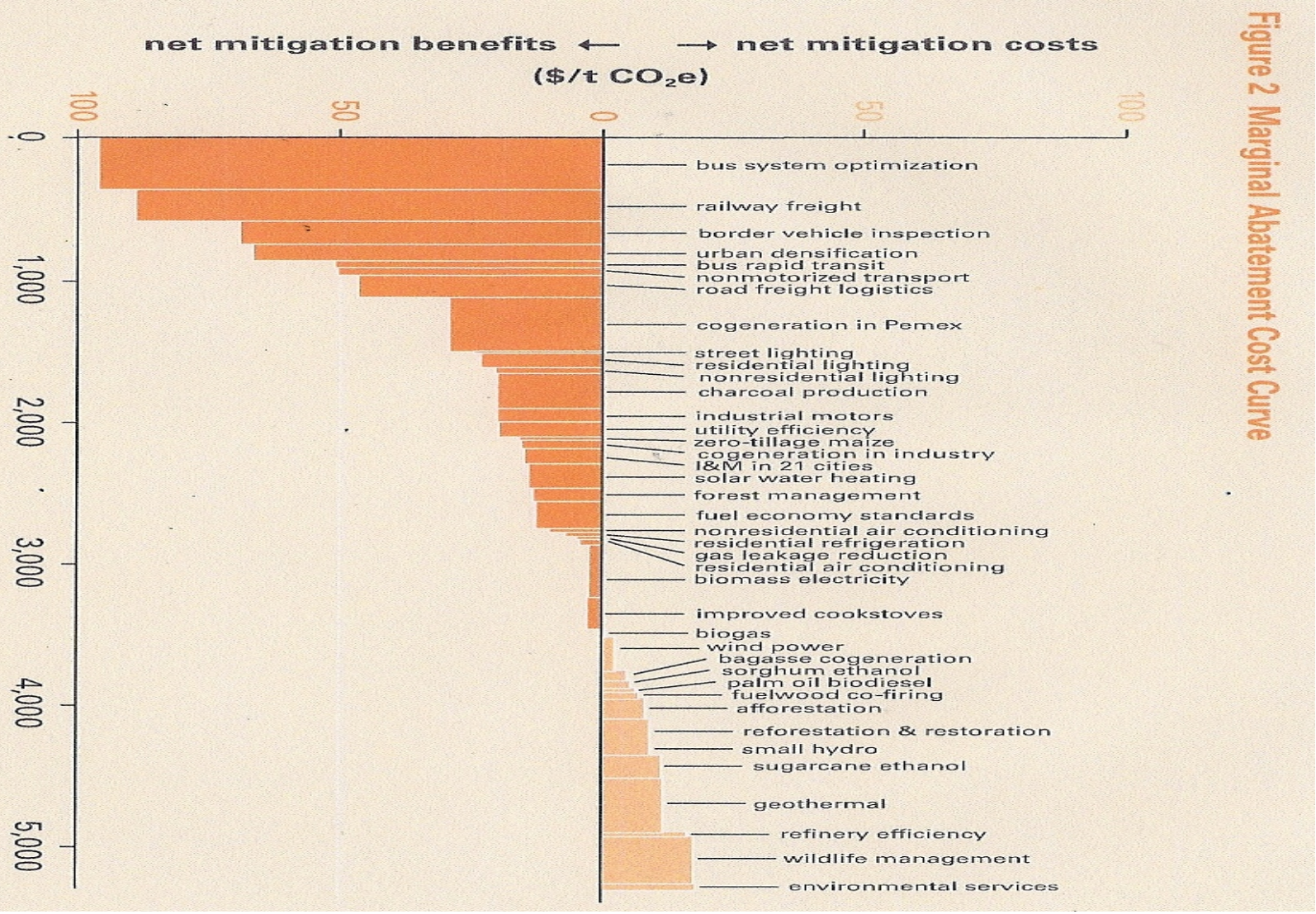
- Sectors included in Mexico
  - Electric Power
  - Energy End-use
  - Oil & Gas
  - **Transport**
  - Agriculture & Forestry
- Health co-benefit analysis came into play only for Transport
- Spent more time supervising Transport Group than all other groups combined….

The Mexico MACC…



Todd M. Johnson, Claudio Alatorre, Zayra Romo and Feng Liu.2009. *Low-Carbon Development for Mexico.* The World Bank. Washington, D.C.

Same MACC, flipped side-ways



Source: Authors, based on MEDEC study results.

Transport dominated win-wins….

- Bus System Optimization
- Railway Freight
- Border Inspection of Vehicles
- Urban Densification
- Bus Rapid Transit
- Non-motorized Transport
- Road Freight Logistics

GEF “Manual” list of co-benefits*

a. Travel time savings ***(commensurate)***

b. Expanded travel options and opportunities

c. Job growth

d. Technical capacity building

e. Economic development

f. Income growth

g. Additional employment

h. Air pollution reductions ***(commensurate**)***

i. Increases in physical activity that improve public health

j. User cost savings ***(commensurate)***

*** Next Slide**

**** Much bigger in LDCs than in developed countries**

Take-aways

- Teams from different sectors tend to compete with each other to have lowest cost (or highest win-win) C/E ratios
- Co-benefit potential much higher in some sectors than others – especially those impacting human health
- Health co-benefits from transport & fuel combustion ***potentially huge*** in comparison to rich countries
- Transport co-benefits—multiple sources of potential abuse
  - Valuation of time
  - Valuation of lives-saved
  - Valuation of health benefits

GEF Manual for Transport Projects

Michael A. Kinder (ed.). Undated. ***Manual for Calculating Greenhouse Gas Benefits of Global Environment Facility Transportation Projects***. Institute for Transportation and Development Policy. Prepared for Scientific & Technical Advisory Panel. http://www.thegef.org/gef/sites/thegef.org/files/publication/GEF_CalculatingGHGbenefits_webCD.pdf

WHO. 2011. *Health in the Green Economy: Health co-benefits of climate change mitigation – Transport sector.*

http://www.who.int/hia/examples/trspt_comms/hge_transport_lowresdurban_30_11_2011.pdf

Economic Analysis and Planning for Global Climate Change Mitigation

Marginal Abatement Cost Curves (MACCs) for LEDS Programming

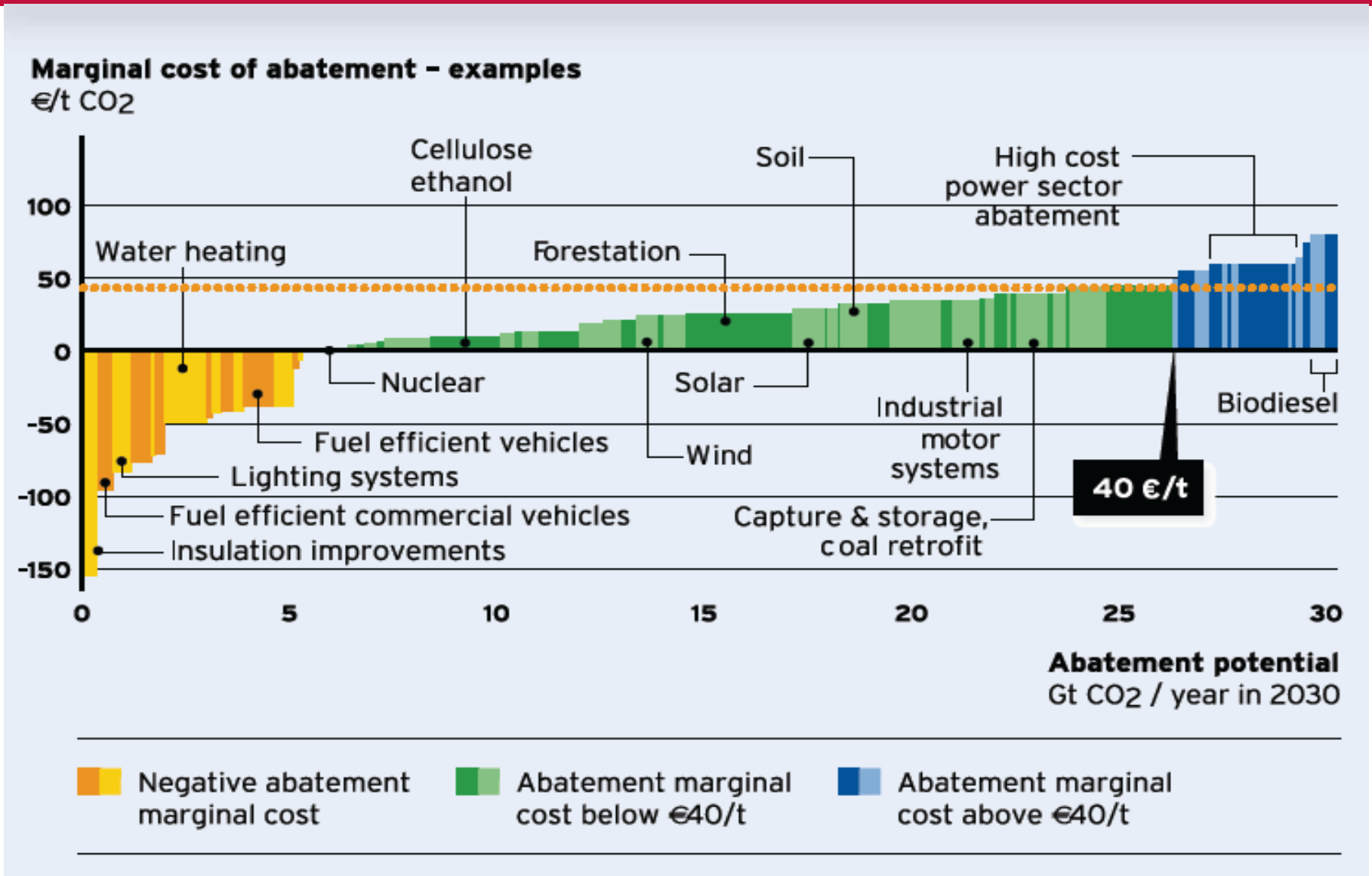
William A. Ward
E3/EP
USAID-Washington

30 April 2014

Objectives of this session

- Improve ability to interpret typical MACC presentations
- Reveal the most relevant questions to ask about the MACC
- Describe process for deriving bottom-up MACCs
- Translate lessons from deriving MACCs into skills for lighting the black box

First of all…what does one look like?



MACC is a marginal cost curve

- It slopes up-to-right
- Axes matter – here ‘x’ is Mt of CO_2e
- ‘y’ axis is cost for incremental Mt of CO_2e
- Increments NOT infinitesimally small—width has meaning

What are the rectangles on the MACC?

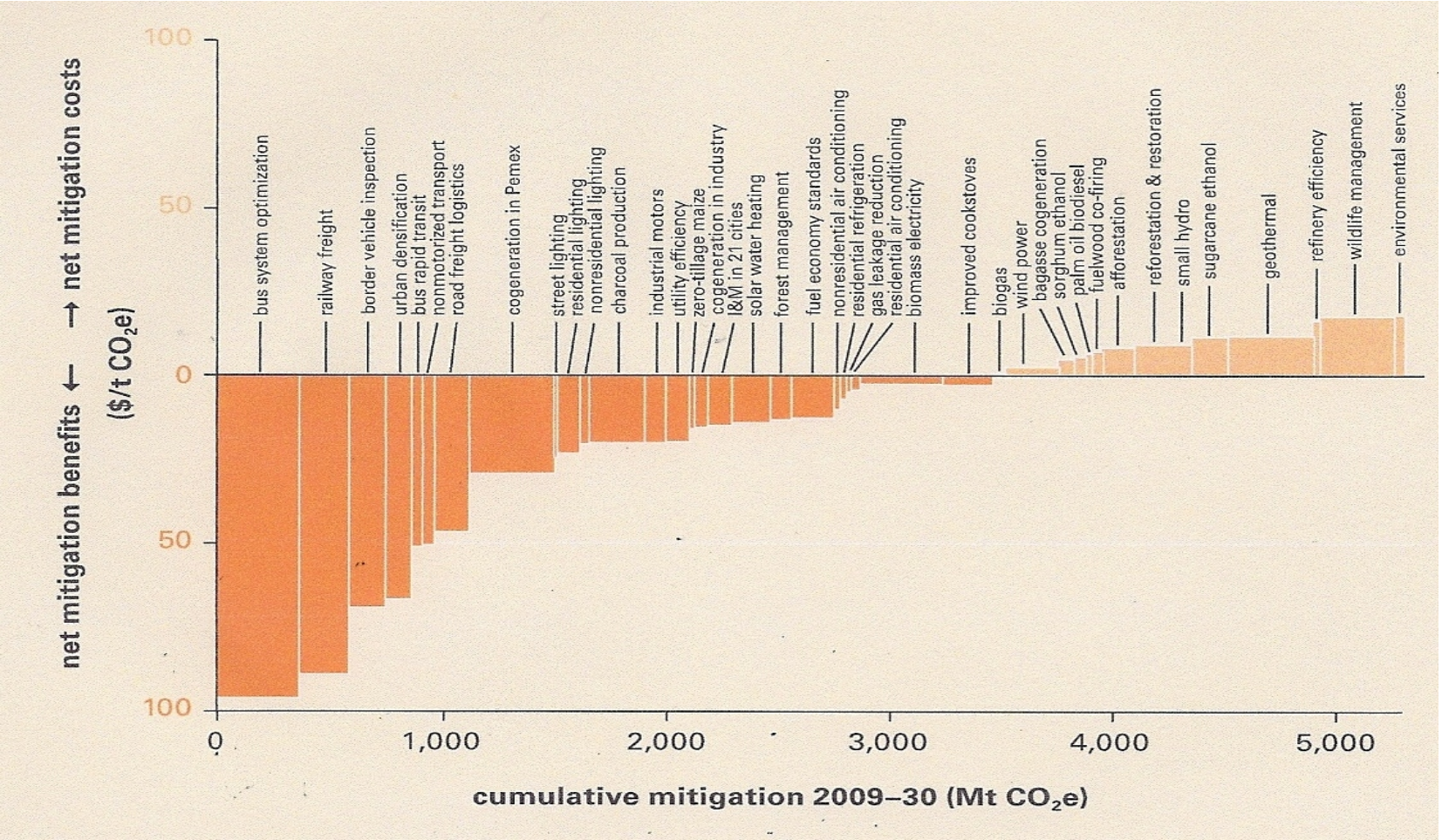
- **<u>HEIGHT</u>**: Generated from cost-effectiveness **(C/E or CEA) Ratios** comparing pairs of alternatives – this gives the ***height*** of rectangle

- **<u>WIDTH</u>: Scale (Replicability)** of the alternative gives ***width*** of that rectangle (e.g., 'avoided deforestation' on McKinsey MACC)

- **Arrayed low-to-high** by C/E ratio – costs per tonne of GHG (Mt of CO2e)

- **Sum** of widths = Mt of CO2e abated by program

Here is another one…

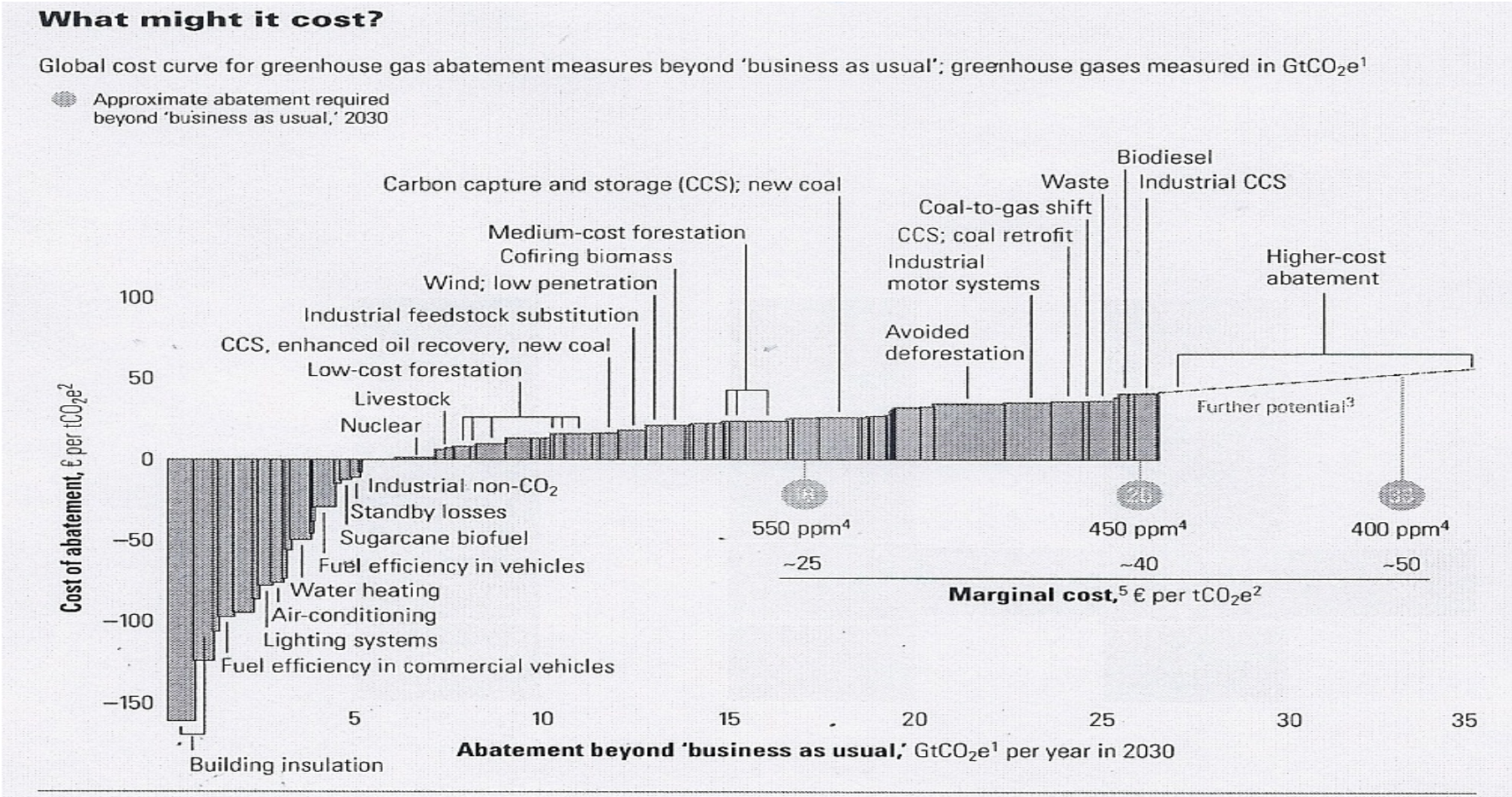


Todd M. Johnson, Claudio Alatorre, Zayra Romo and Feng Liu.2009. *Low-Carbon Development for Mexico.* The World Bank. Washington, D.C.

4 Questions MACCs Should Answer

- Are the **negative cost options** logical? (also called “win-win”, “no regrets”)
- Does the **‘knee’** of the MACC function (also called the ‘elbow’) limit us to a small number of options?
- Is the MACC presented as **financial** or **economic** analysis?
- What is the **nature of the options** on the curve – Technologies? Projects? Meta Interventions? Chimera?

What are the McKinsey MACC negative cost options?

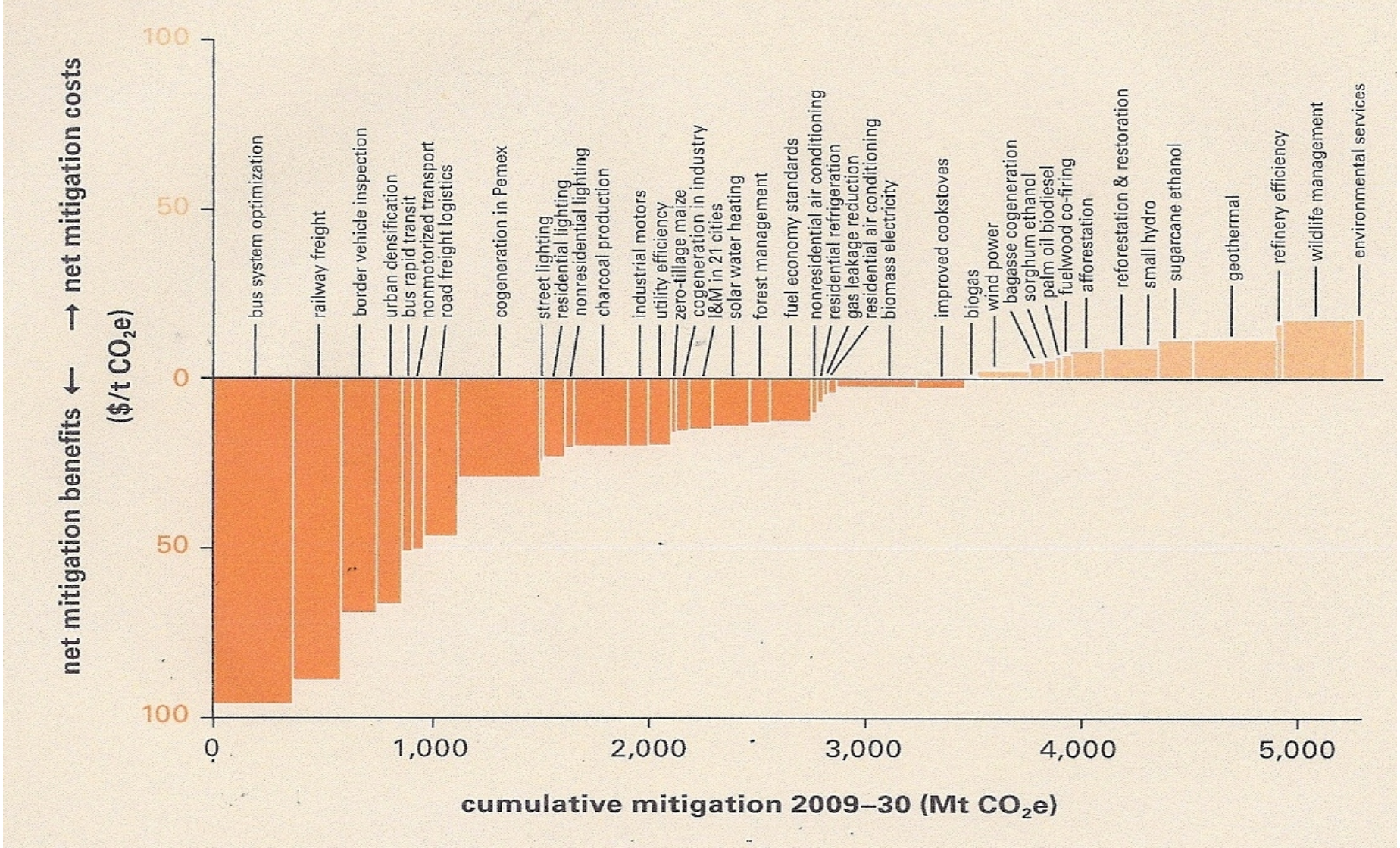


[1] $GtCO_2e$ = gigaton of carbon dioxide equivalent; "business as usual" based on emissions growth driven mainly by increasing demand for energy and transport around the world and by tropical deforestation.
[2] tCO_2e = ton of carbon dioxide equivalent.
[3] Measures costing more than €40 a ton were not the focus of this study.
[4] Atmospheric concentration of all greenhouse gases recalculated into CO_2 equivalents; ppm = parts per million.
[5] Marginal cost of avoiding emissions of 1 ton of CO_2 equivalents in each abatement demand scenario.

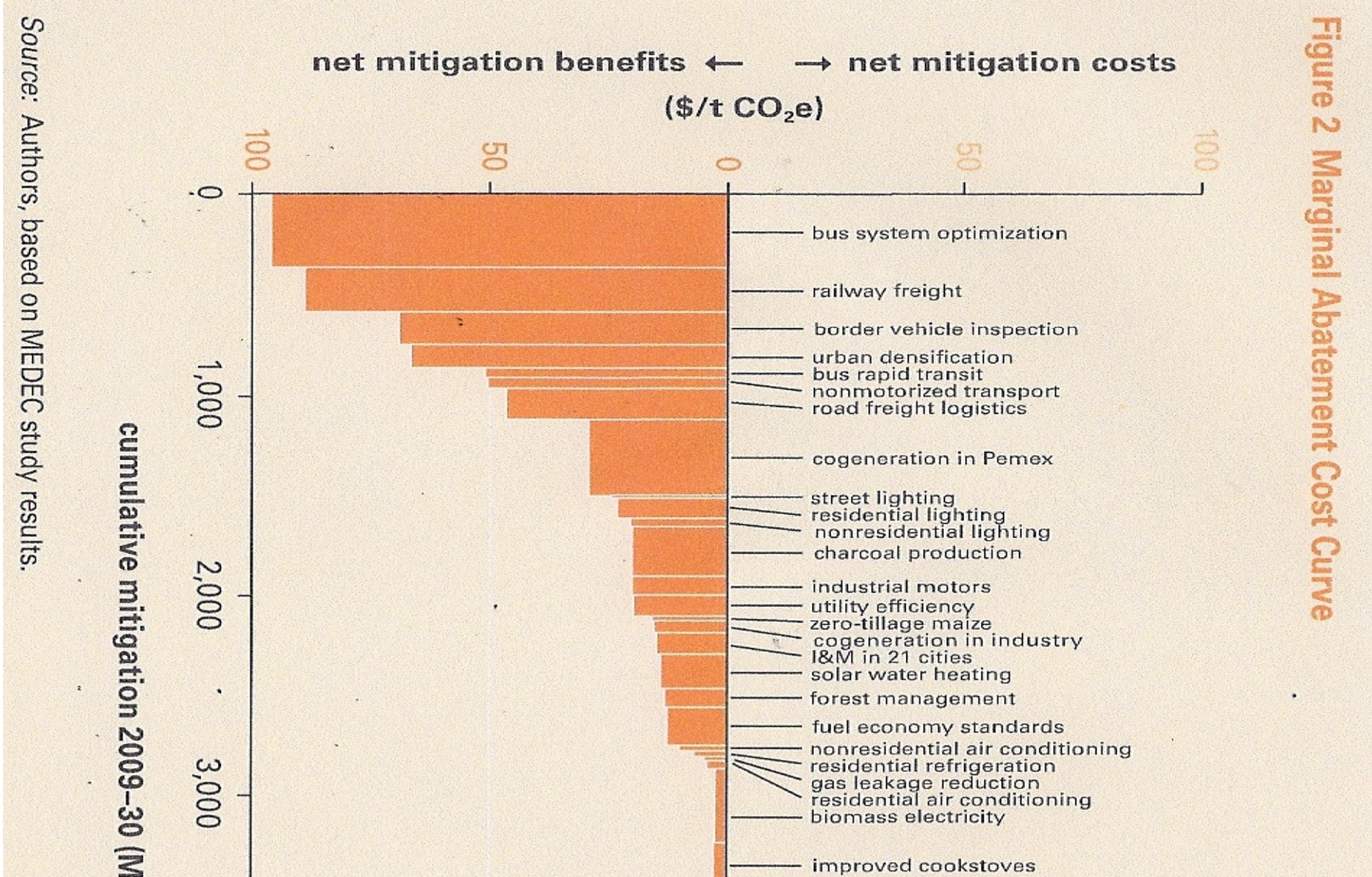
McKinsey MACC negative cost options

- Building insulation (2 options)
- Fuel efficiency in commercial vehicles
- Lighting systems
- Air-conditioning
- Water heating
- Industrial non-CO_2

The Mexico MEDEC GHG negative cost options?



Same MACC, flipped side-ways



Source: Authors, based on MEDEC study results.

What causes ‘negative’ (net) costs?

- ***Co-benefits*** that exceed the gross costs of saving CO2e
- ***Incorrectly-handled*** non-carbon attributes
- ***‘Irrational’ behavior*** on the part of the technology user(s)

Co-benefits

- Co-benefits are the secondary (i.e., non-carbon) impacts that accompany the technology choice
  - Burning less fuel not only reduces CO2 emissions, it also reduces particulate and sulfur emissions
  - Improving bus routes not only reduces fuel use and GHG emissions, it also saves passengers' time

GEF “Manual” list of co-benefits

a. Travel time savings ***(commensurate)***

b. Expanded travel options and opportunities

c. Job growth

d. Technical capacity building

e. Economic development

f. Income growth

g. Additional employment

h. Air pollution reductions ***(commensurate*)***

i. Increases in physical activity that improve public health

j. User cost savings ***(commensurate)***

*** Much bigger in LDCs than in developed countries**

Co-benefit analysis versus Standardization of Impacts

- MACC has ***2 axes*** – Costs & Mt of CO2e
  - ‘Objective’ is on horizontal axis, and
  - ‘Cost’ on vertical axis
- ***Co-benefits*** are non-carbon attributes convertible into +/- ***vertical axis*** values – i.e., into $
- Everything not convertible to an ‘axis’ value must be ***standardized*** between the BAU and the proposed alternative technology—e.g., number of passengers, amenities, etc.

One objective but multiple attributes

EXAMPLE: Optimized bus system saves carbon— the primary objective

Also achieves other objectives

- Time savings by passengers
- Health benefits from reduction in particulate matter and sulfur compounds
- Reduced traffic congestion…

Two (alternative) Ways to Handle Non-Carbon Attributes

1. STANDARDIZE:

Non-carbon attributes ≥ counterfactual's non-carbon attributes

- In terms of quantity
- In terms of quality
- In terms of timing

Two (alternative) Ways to Handle Non-Carbon Attributes (Cont.)

2. VALUE:

If difference in non-carbon attributes can be valued, then add to (subtract from) incremental costs (benefits) of carbon savings

('co-benefit analysis')

Mis-handled Standardization

Major source of incorrectly identified win-win options

- Cooking stoves with attributes wives do not like….
- Fuel-efficient vehicles that are not as convenient to re-fuel, do not accelerate…
- Generation alternatives not as easily integrated into production…

Some terminology

Aggregate Consumption Objective:

- The economic efficiency objective
- Measured by willingness to pay (WTP)
- Costs (benefits) expressed
  - Using revealed preference analysis, or
  - Using stated preference analysis

Terminology (Cont.)

- COMMENSURATE. If the non-carbon attribute can be valued in WTP terms, then it is said to be ***commensurate*** with respect to the aggregate consumption objective

- NON-COMMENSURATE (INCOMMENSURATE). If not expressible in WTP terms, then the attribute is ***non-commensurate*** with respect to the objective function that is being optimized

Negative Cost Options

If MACC is in ***economic terms***, then negative cost options are explainable by ***Public Goods & Market Failures***

- *Externalities/spillovers (TCs, missing markets)*
- *Split Incentives*
- *Asymmetric Information*
- *Imperfect competition/Hierarchical organization*

Negative cost options in private, financial terms

If MACC is expressed in financial terms, then negative cost options must be explained by

- Behavioral failures (e.g., bounded rationality)
- Faulty set-up of CEA (e.g., failure to handle secondary attributes correctly)

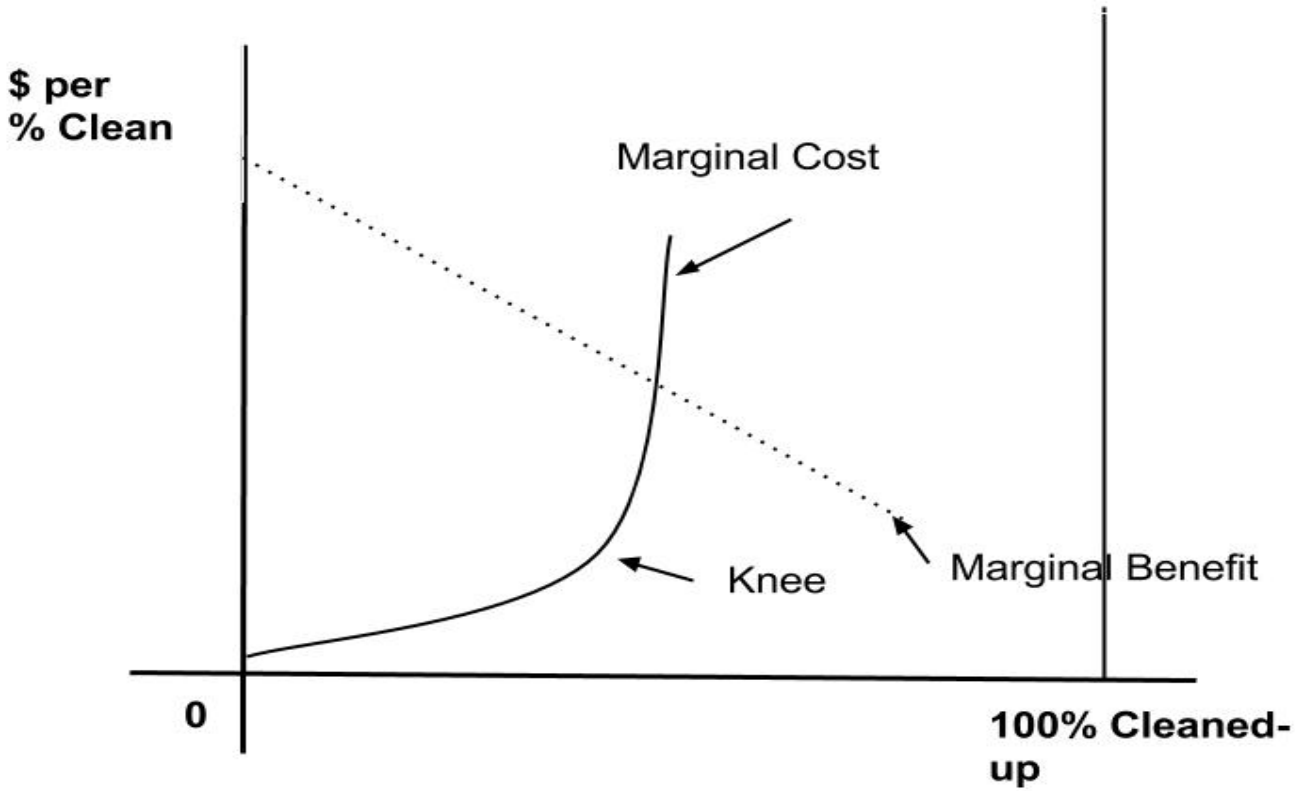
Negative cost options

EXPECT negative costs options if the MACC is built in economic terms.

Do NOT expect negative cost options on MACCs built in financial terms – WHY?

“That cannot possibly be a $5 bill laying on the sidewalk – somebody already would have picked it up!”

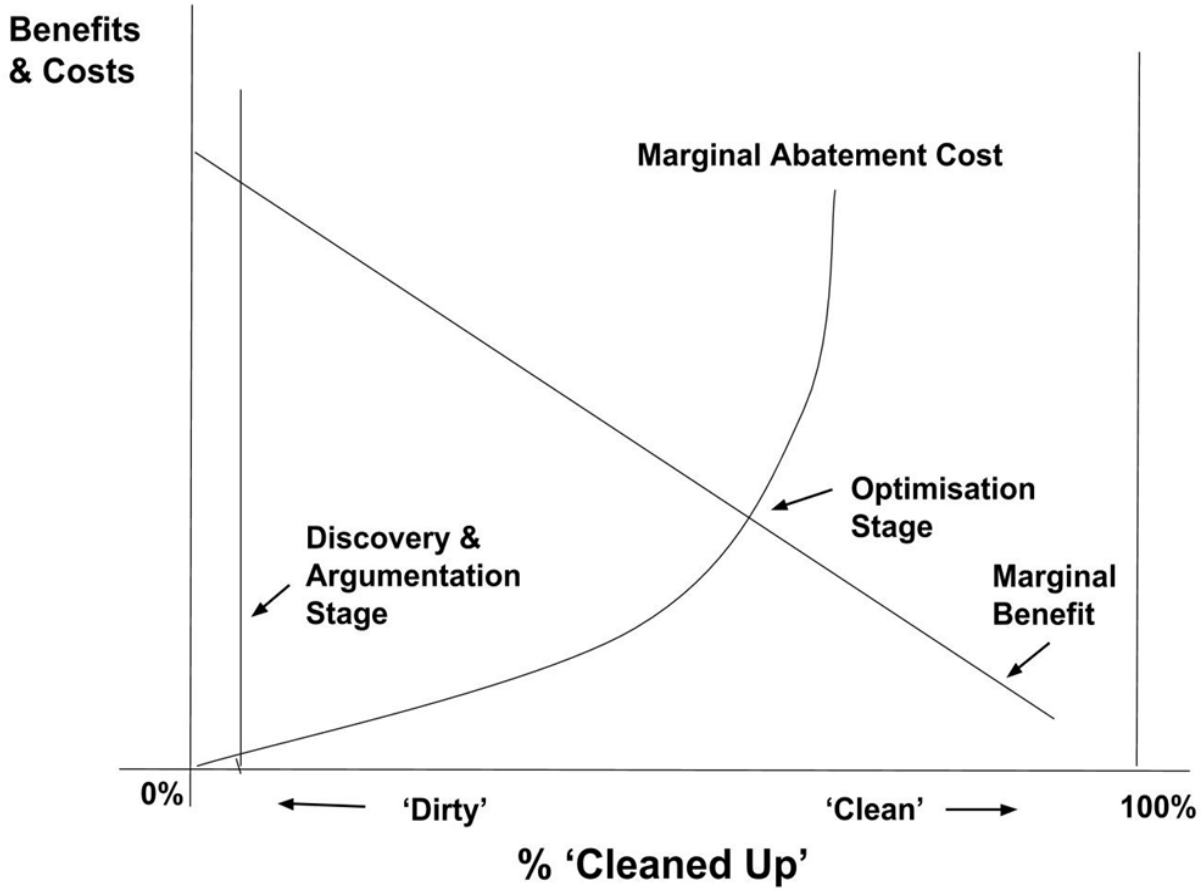
Knee of the Cost Function



Take-aways

1. Negative cost options need a reason…
2. Negative cost options in financial terms questionable
3. Co-benefits (co-costs) are secondary attributes that can be converted into WTP values
4. Don’t implement options beyond the ‘knee’ of the cost (technology) function
5. Seek clarity on what the options represent

Annex: Socially-Optimal Level of Pollution



China MACC exercise debriefing

Bob Taylor’s work on energy efficiency in China – From 1994 to present as follow-up to study

Steam trap technology

A **steam trap** is a device used to discharge condensate and non-condensable gases with a negligible consumption or loss of live steam. Most steam traps are nothing more than automatic valves. They open, close or modulate automatically. The three important functions of steam traps are:

- Discharge condensate as soon as it is formed.
- Have a negligible steam consumption.
- Have the capability of discharging air and other non-condensable gases.

Continuous Casting

Continuous casting, also called **strand casting**, is the process whereby molten metal is solidified into a "semifinished" billet, bloom, or slab for subsequent rolling in the finishing mills. Prior to the introduction of continuous casting in the 1950s, steel was poured into stationary molds to form ingots. Since then, "continuous casting" has evolved to achieve improved yield, quality, productivity and cost efficiency. It allows lower-cost production of metal sections with better quality, due to the inherently lower costs of continuous, standardised production of a product, as well as providing increased control over the process through automation. This process is used most frequently to cast steel (in terms of tonnage cast). Aluminium and copper are also continuously cast.

Coal Washing

A **coal preparation plant** (CPP) is a facility that washes coal of soil and rock, crushesit into graded sized chunks (sorting), stockpiles grades preparing it for transport to market, and more often than not, also loads coal into rail cars, barges, or ships. A CPP may also be called a **coal handling and preparation plant** (CHPP), **coal handling plant**, **prep plant**, **tipple** or **wash plant**.

The more of this waste material that can be removed from coal, the lower its total ash content, the greater its market value and the lower its transportation costs.

Micro-analytics of China Industrial Energy

- WELFARE OUTCOME: Reduced Agg Cons
- LOCAL ECONOMIC ENVIRONMENT:
  - Hierarchically-organized firms dominated
  - Firms focused on growth rather than internal efficiency
  - Banks accustomed to lending for growth, not efficiency
  - Limited mkt specialization in the economy, thus
    - Few industry clusters
    - No ESCO industry (very contract-intensive business model)
  - *Doing Business Database* shows weak contracting institutions – but not as weak as expected

Analysis of economic causes

- *Hierarchical organization & Limited firm-level specialization* – from New Industrial Organization Theory (Coase-Williamson), high TCs for market form of value chain
- *Bank lending for growth but not efficiency* – High up-front TCs for new lending lines
- *Absence of ESCO industry* – contracting institutions AND financial/capital market difficulty with performance contracting, up-front learning costs for ESCO start-up

China Industrial Energy Efficiency Tasks?

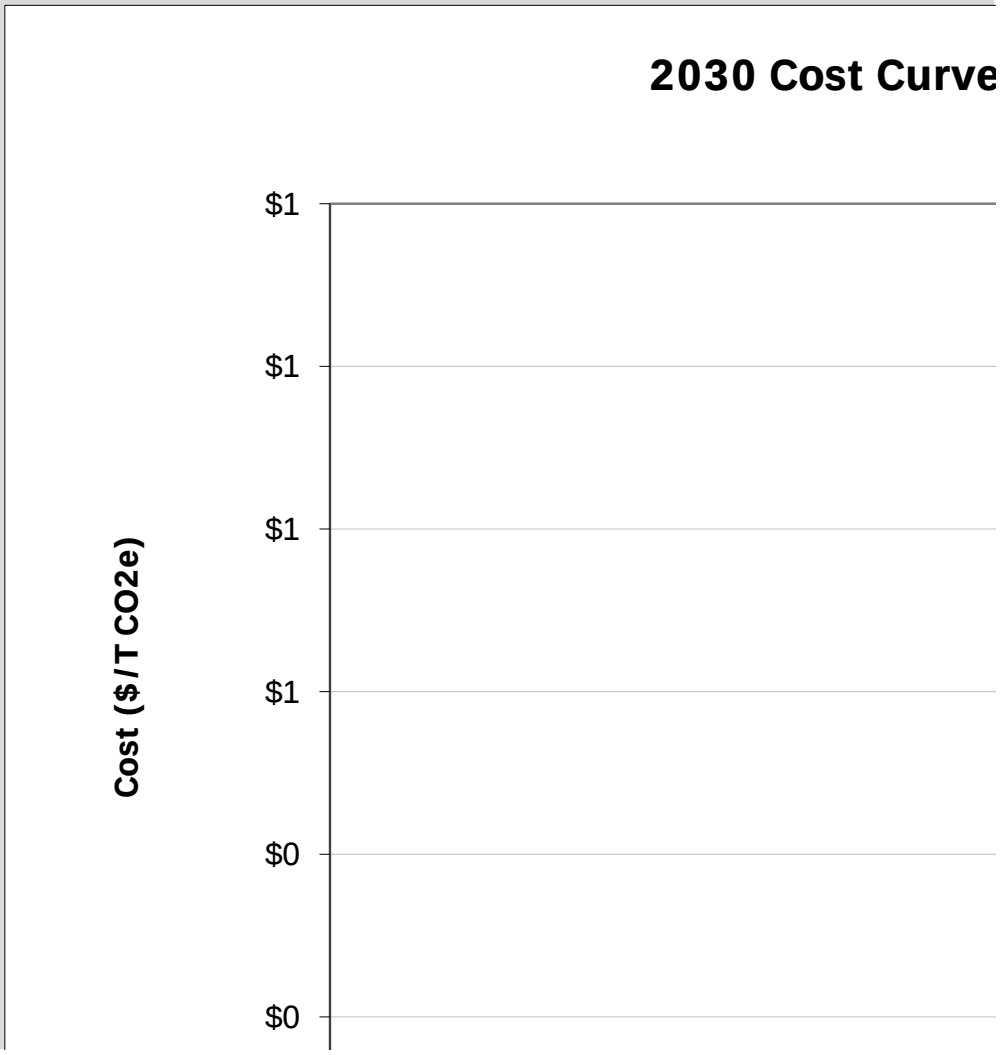
- Get the industrial enterprises interested in efficiency
- Get the financial system to lend for efficiency
- Develop a (Williamson) ‘market’ approach to solving EE problems (outsourcing to ESCOs perhaps) to address affects of (Williamson) ‘hierarchy’ approach to industrial organization

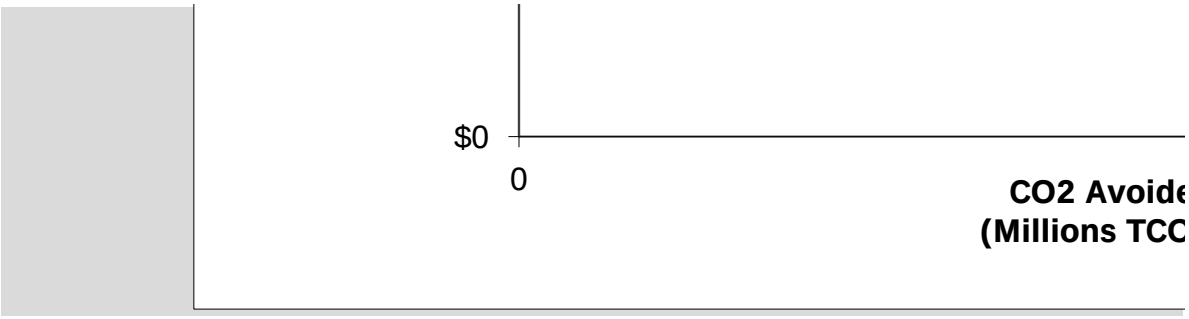
How to accomplish these tasks: See Taylor (2009)

Annex: Citation for Taylor (2009)

Robert P. Taylor. 2009. “Achieving Sustainability in World Bank Energy Efficiency Projects: Lessons Learned Developing ESCOs in China”, *Strategic Planning for Energy and the Environment*, Vol. 29, No. 1, pp. 32–41.

Option Name	Million Tons CO2 Option Mitigation	Million Tons CO2 Cumulative Mitigation
Baseline	-	-
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A




$0
0
CO2 Avoide
(Millions TCC

$ / Ton CO2 Cost of Saved CO2
#N/A
#N/A
#N/A
#N/A
#N/A
#N/A
#N/A
#N/A
#N/A
#N/A

ed
O2e)

Options in intial order	Mil Tonnes Redu	$/Tonne	Rank low-hig	Altered Ran
LPG Stoves	0.00	0.00	#DIV/0!	#DIV/0!
Industrial Motors	0.00	0.00	#DIV/0!	#DIV/0!
Efficient Refrigerators	0.00	0.00	#DIV/0!	#DIV/0!
Hybrid Vehicles	0.00	0.00	#DIV/0!	#DIV/0!
Electric Vehicles	0.00	0.00	#DIV/0!	#DIV/0!
Industrial CHP	0.00	0.00	#DIV/0!	#DIV/0!
CCS	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Hydropower	0.00	0.00	#DIV/0!	#DIV/0!
Solar Power	0.00	0.00	#DIV/0!	#DIV/0!
Forestry	0.00	0.00	#DIV/0!	#DIV/0!

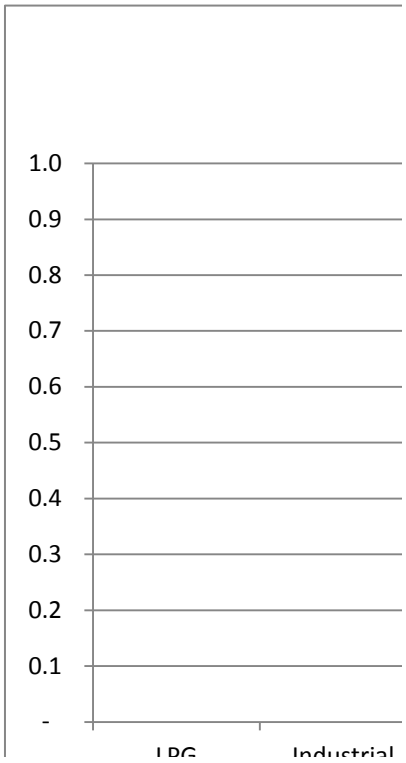
Options ranked in low-high cost /	1	Mil Tonnes Redu	$/tonne	Cumulative re	x
1	#N/A	#N/A	#N/A	#N/A	#N/A
2	#N/A	#N/A	#N/A	#N/A	#N/A
3	#N/A	#N/A	#N/A	#N/A	#N/A
4	#N/A	#N/A	#N/A	#N/A	#N/A
5	#N/A	#N/A	#N/A	#N/A	#N/A
6	#N/A	#N/A	#N/A	#N/A	#N/A
7	#N/A	#N/A	#N/A	#N/A	#N/A
8	#N/A	#N/A	#N/A	#N/A	#N/A
9	#N/A	#N/A	#N/A	#N/A	#N/A
10	#N/A	#N/A	#N/A	#N/A	#N/A

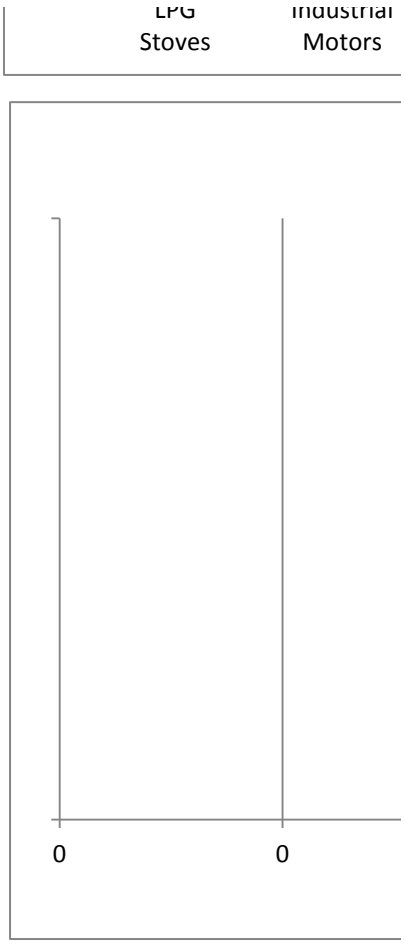
Options ranked by MCA		
1	#N/A	#N/A
2	#N/A	#N/A
3	#N/A	#N/A
4	#N/A	#N/A
5	#N/A	#N/A
6	#N/A	#N/A
7	#N/A	#N/A
8	#N/A	#N/A
9	#N/A	#N/A
10	#N/A	#N/A

New Rank	MCA Rank
#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!

y
#N/A
#N/A
#N/A
#N/A
#N/A
#N/A
#N/A
#N/A
#N/A

Examples of Criteria	Criteria Weight (Sum to 100 across all criteria)
Criteria Taken from Cost Curve	
Mitigation Potential (Million Tons CO2e)	
- Mitigation Potential Score (0=lowest, 10=highest)	
Direct Unit Costs ($/Ton CO2e)	
Direct Total Costs (Million $)	
- Direct Total Cost Score (0=highest, 10=lowest)	
Other Criteria (add your own)	
- Reliance on Local Technologies (0=bad-10=good)	
- Reliance on Domestic Energy Sources (0=bad-10=good)	
- Potential for poverty alleviation (0=bad-10=good)	
- Potential for improving air quality (0=bad-10=good)	
- Technical Feasibility (0=bad-10=good)	
- Political/Social Popularity (0=bad-10=good)	
- add your own….	
-	
-	
-	
Totals	-
Overall Rank (1=best to 10=worst)	




LPG
Stoves
Industrial
Motors
0
0

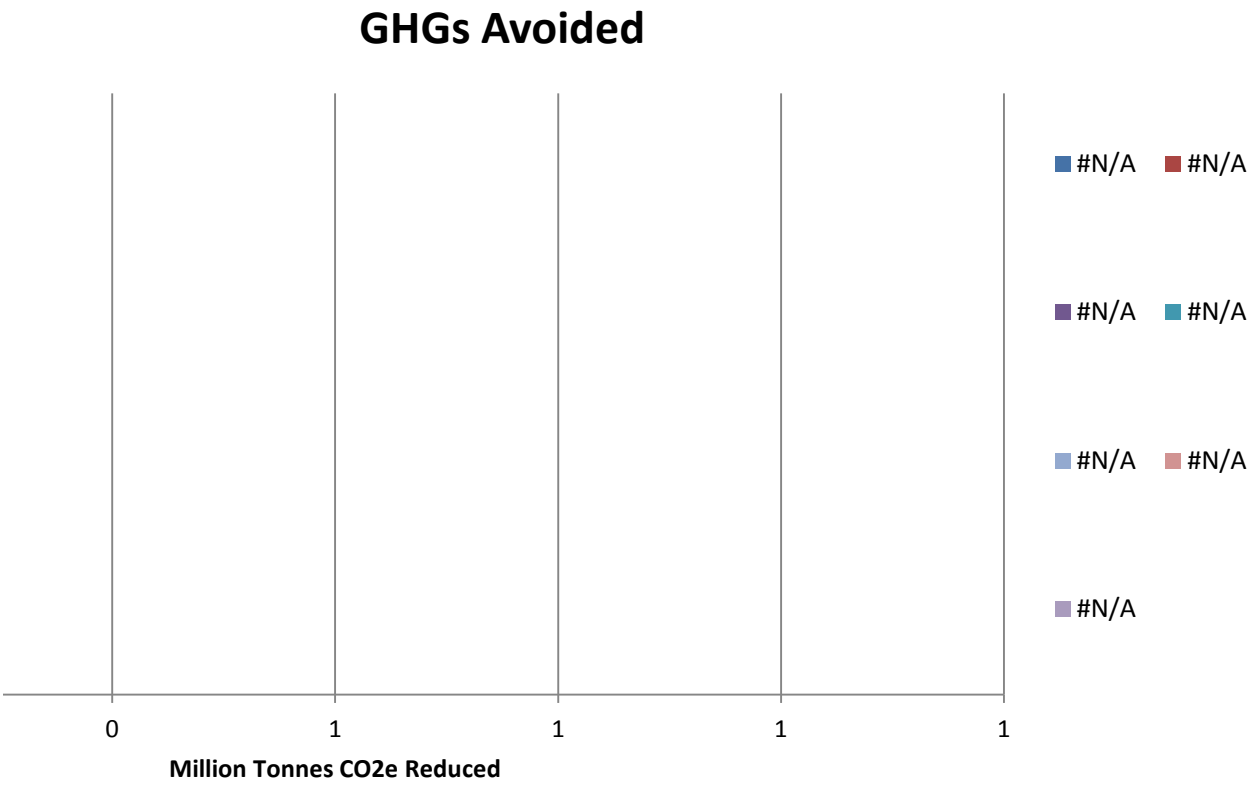
LPG Stoves	Industrial Motors	Efficient Fridges	Hybrid Vehicles	Electric Vehicles	Industrial CHP	CCS	Hydro Power	Solar Power
-	-	-	-	-	-	#DIV/0!	-	-
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
-	-	-	-	-	-	#DIV/0!	-	-
$0	$0	$0	$0	$0	$0	#DIV/0!	$0	$0
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Overall Scores

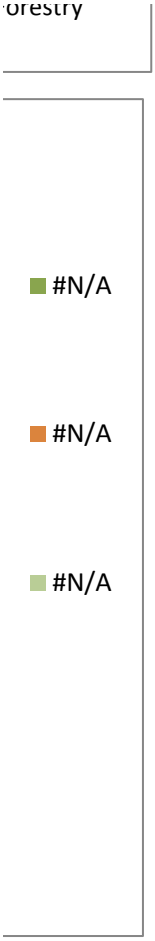
(10=Perfect Score!)

Efficient Hybrid Electric Industrial CCS Hydro Solar F

Efficient Fridges	Hybrid Vehicles	Electric Vehicles	Industrial CHP	CCS	Hydro Power	Solar Power	F



Forestry
-
#DIV/0!
-
$0
#DIV/0!
#DIV/0!
#DIV/0!


orestry
#N/A
#N/A
#N/A

Intermediate Calculations	LPG Stoves	Industrial Motors	Efficient Fridges	Hybrid Vehicles
Mit Poten Score	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Weighted Score	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Cost Score	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Weighted Score	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Other Criteria (weighted scores)				
- Reliance on Local Tec	-	-	-	-
- Reliance on Domestic	-	-	-	-
- Potential for poverty a	-	-	-	-
- Potential for improving	-	-	-	-
- Technical Feasibility (	-	-	-	-
- Political/Social Popula	-	-	-	-
- add your own….	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
Total Score	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Rank	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Electric Vehicles	Industrial CHP	CCS	Hydro Power	Solar Power	Forestry	Max	Min
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
-	-	-	-	-	-		
-	-	-	-	-	-		
-	-	-	-	-	-		
-	-	-	-	-	-		
-	-	-	-	-	-		
-	-	-	-	-	-		
-	-	-	-	-	-		
-	-	-	-	-	-		
-	-	-	-	-	-		
-	-	-	-	-	-		
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		

Diff
#DIV/0!
#DIV/0!

LPG Stoves

Number of Stoves

The mitigation option - LPG Stoves

Fuel:	Electricity	
Unit fuel consumption:		GJ/stove-year
Total Fuel Use:	0	GJ/Year

Replaces the baseline option - Kerosene Stoves

Fuel:	Electricity	
Unit fuel consumption:		GJ/stove-year
Total Fuel Use:	0	GJ/Year

Ann Costs	Mitigation	Baseline	Increase (Mit - Bas)
Unit Investment Cost ($/stove)			$ -
Lifetime (years)			-
Unit Annualized Investment ($)	$ -	$ -	$ -
Total Investment Cost (Million $)	$ -	$ -	$ -
Annual Fuel Cost (Million $)	$ -	$ -	$ -
Total Annual Cost (Million $)	$ -	$ -	**$ -**

GHG Emissions (tonnes)	Mitigation	Baseline	Reduction (Bas - Mit)
Fuel CO2	-	-	-
Fuel N2O	-	-	-
Fuel CH4	-	-	-
Total CO2 equiv. (Tonnes)	-	-	**-**
Tonne CO2 reduction/stove			**#DIV/0!**

$/Tonne CO2 eq.			$ -

What does this mean in terms of fuel consumption?

Increases LPG use in 2030 by:	0	million GJ
Decreases Kerosene use in 2030 by:	0	million GJ

How do we enter this into LEAP's Mitigation scenario?

Copy this formula to the Demand/Residential/LPG:Final Energy Intensity branch:
BaselineValue+Interp(2010,0,2030,0) ?Extra LPG used (m GJ)

Copy this formula to the Demand/Residential/Kerosene:Final Energy Intensity branch:
BaselineValue-Interp(2010,0,2030,0) ?Kerosene avoided (m GJ)

Industrial Motors

The mitigation option - Efficient electric motors

Fuel:	Electricity	
Unit fuel consumption:		GWh/year
Total Fuel Use:	0	GJ/Year

Replaces the baseline option - Conventional electric motors

Fuel:	Electricity	
Unit fuel consumption:		GWh/year
Total Fuel Use:	0	GJ/Year

Ann Costs	Mitigation	Baseline
Unit Cost ($/kWh)		
Investment Cost (Million $)	$ -	
Annual Fuel Cost (Million $)	$ -	$ -
Total Annual Cost (Million $)	$ -	$ -

Ann GHG Emissions (tonnes)	Mitigation	Baseline
Fuel CO2	-	-
Fuel N2O	-	-
Fuel CH4	-	-
Total CO2 equiv.	-	-
Tonne CO2 reduction (Million tonnes)		
$ / Tonne CO2 eq		

What does this mean for fuel consumption?

Reduces electricity demand by: - milliion GJ

How do we enter this into LEAP's Mitigation scenario?

This option is not included in the LEAP scenarios.

Increase (Mit - Bas)
-
$ -
$ -
$ -

Reduction (Bas - Mit)
-
-
-
-
0.00

$ -

Efficient Refrigerators

Number of Refrigerators:

The mitigation option - Efficient refrigerators

Fuel:	Electricity		
Unit fuel consumption:		kWh/unit-year	0 G
Total Fuel Use:	0	GJ/Year	

Replaces the baseline option - Conventional refrigerators

Fuel:	Electricity		
Unit fuel consumption:		kWh/unit-year	0 G
Total Fuel Use:	0	GJ/Year	

Ann Costs	Mitigation	Baseline	Increase (Mit - Bas)
Unit Investment Cost ($/refrigerator)			$ -
Lifetime (years)			-
Unit Annualized Investment ($)	$ -	$ -	$ -
Total Investment Cost (Million $)	$ -	$ -	$ -
Annual Fuel Cost (Million $)	$ -	$ -	$ -
Total Annual Cost (Million $)	$ -	$ -	**$ -**

Ann GHG Emissions (tonnes)	Mitigation	Baseline	Reduction (Bas - Mit)
Fuel CO2	-	-	-
Fuel N2O	-	-	-
Fuel CH4	-	-	-
Total CO2 equiv.	-	-	-
Tonne CO2 reduction/refrigerator			0.00

$/Ton CO2 eq	**$ -**

What does this mean for fuel consumption?

Reduces electricity demand by: 0 milliion GJ

How do we enter this into LEAP's Mitigation scenario?

Copy this formula to the Demand/Residential/Electricity:Final Energy Intensity branch:
BaselineValue-Interp(2010,0,2030,0) ?Electricity saved (m GJ)

J/unit-year

J/unit-year

Hybrid Vehicles

Number of Vehicles:

The mitigation option - Hybrid cars

Fuel:	Electricity	
Unit fuel consumption:		GJ/vehicle-year
Total Fuel Use:	0	GJ/Year

Replaces the baseline option - Conventional internal combustion engine (ICE) cars

Fuel:	Electricity	
Unit fuel consumption:		GJ/vehicle-year
Total Fuel Use:	0	GJ/Year

Ann Costs	Mitigation	Baseline	Increase (Mit - Bas)
Unit Investment Cost ($/vehicle)			$ -
Lifetime (years)			-
Unit Annualized Investment ($)	$ -	$ -	$ -
Total Investment Cost (Million $)	$ -	$ -	$ -
Annual Fuel Cost (Million $)	$ -	$ -	$ -
Total Annual Cost (Million $)	$ -	$ -	**$ -**

Ann GHG Emissions (tonnes)	Mitigation	Baseline	Reduction (Bas - Mit)
Fuel CO2	-	-	-
Fuel N2O	-	-	-
Fuel CH4	-	-	-
Total CO2 equiv.	-	-	-
Tonne CO2 reduction/vehicle			0.00

$/Tonne CO2 eq	**$ -**

What does this mean for fuel consumption?

Decreases gasoline use in 2030 by - Million GJ

How do we enter this into LEAP's Mitigation scenario?

Refer to the Electric Vehicles tab for guidance on how to enter data for both Hybrid and Electric vehicles into LEAP.

Electric Vehicles

Number of Vehicles:

The mitigation option - Electric cars

Fuel:	Electricity		
Unit fuel consumption:		kWh/vehicle-year	
Total Fuel Use:	0	MWh/year	=

Replaces the baseline option - Conventional ICE cars

Fuel:	Electricity	
Unit fuel consumption:		GJ/vehicle-year
Total Fuel Use:	0	GJ/Year

Ann Costs	Mitigation	Baseline
Unit Investment Cost ($/vehicle)		
Lifetime (years)		
Unit Annualized Investment ($)	$ -	$ -
Total Investment Cost (Million $)	$ -	$ -
Annual Fuel Cost (Million $)	$ -	$ -
Total Annual Cost (Million $)	$ -	$ -

Ann GHG Emissions (tonnes)	Mitigation	Baseline
Fuel CO2	-	-
Fuel N2O	-	-
Fuel CH4	-	-
Total CO2 equiv.	-	-
Tonne CO2 reduction/vehicle		
$/Tonne CO2 eq		

What does this mean for fuel consumption?

Decreases gasoline use in 2030 by	0.00	Million GJ
Increases electricity use in 2030 by	0.00	Million GJ

How do we enter this into LEAP's Mitigation scenario?

Copy this formula to the Demand/Transport/Gasoline:Final Energy Intensity branch:
BaselineValue-Interp(2010, 0,2030, 0+0) ?Includes gas saved from both hybrid and electric vehicles

Copy this formula to the Demand/Transport/Electricity: Final Energy Intensity branch:
BaselineValue+Interp(2010,0,2030,0) ?Extra electricity demand from electric vehicles (m GJ)

- GJ/year

Increase (Mit - Bas)
$ -
-
$ -
$ -
$ -
$ -

Reduction (Bas - Mit)
-
-
-
-
0.00

$ -

(m GJ)

Industrial Combined Heat and Power

Heat Required (both options):

The mitigation option - Natural Gas-fired CHP

Consumes: Electricity Produces:

Total Fuel Use: GJ/Year

Replaces the baseline option - Oil-fired boilers

Fuel: Electricity

Total Fuel Use: GJ/Year

Ann Costs (Million $)	Mitigation	Baseline
Unit Investment Cost		
Lifetime (years)		
Total Annualized Investment	$ -	$ -
Annual Fuel Cost	$ -	$ -
Total Annual Cost	$ -	$ -

Annual GHG Emissions (tonnes)	Mitigation	Baseline
Fuel CO2	-	-
Fuel N2O	-	-
Fuel CH4	-	-
Total CO2 equiv.	-	-
Tonne CO2 reduction		
$/Tonne CO2 eq		

What does this mean for fuel consumption?

In 2030, mitigation option:

Reduces fuel oil consumption by:	-	million GJ
Increases natural gas consumption by:	0	million GJ
Reduces net electricity consumption by:	0	million GJ

How do we enter this into LEAP's Mitigation scenario?

Copy this formula to the Demand/Industry/Fuel Oil:Final Energy Intensity branch:
BaselineValue-Interp(2010,0,2030,0) ?Fuel oil saved

Copy this formula to the Demand/Industry/Natural Gas: Final Energy Intensity branch:
BaselineValue+Interp(2010,0,2030,0)? Extra natural gas in CHP plants

Copy this formula to the Demand/Industry/Electricity: Final Energy Intensity branch:
BaselineValue-Interp(2010,0,2030,0)? Electricity generation avoided by CHP plants

GJ

Electricity

GJ/Year

Increase (Mit - Bas)
$ -
-
$ -
$ -
$ -

Reduction (Bas - Mit)
-
-
-
-
0

$ -

Figure 1: Mitigation Option

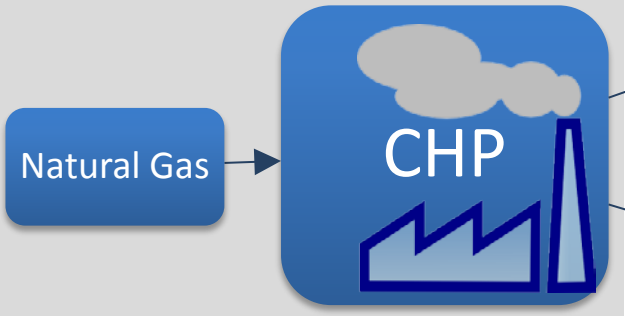
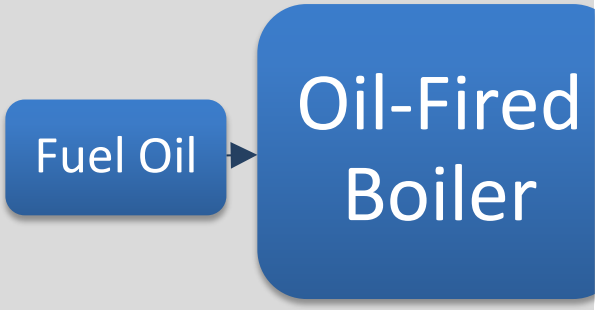
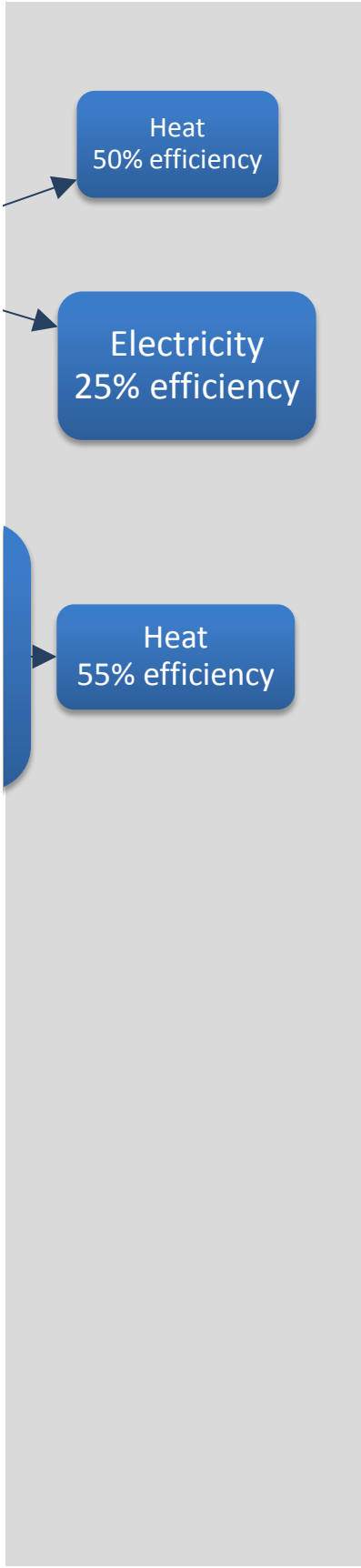


Figure 2: Baseline Option




Heat
50% efficiency
Electricity
25% efficiency
Heat
55% efficiency

Carbon Capture with Coal Electricity Generation

The mitigation option - Coal with CCS

Fuel:	Coal w/ CCS		
Capacity (MW)			
Availability			
Efficiency:			
Fuel consumption:	#DIV/0!	MWh/year	=

Replaces the Baseline option - Existing Coal

Fuel:	Electricity		
Efficiency:			
Fuel consumption:	#DIV/0!	MWh/year	=

Ann Costs ($)	Mitigation	Baseline
Unit Capital Cost ($/kW)		
Total Capital Cost (Million $)	$ -	$ -
Lifetime (years)		
Total Investment Cost (Million $)	$ -	$ -
Annual Fuel Cost (Million $)	#DIV/0!	#DIV/0!
Total Annual Cost (Million $)	#DIV/0!	#DIV/0!

Ann GHG Emissions (tonnes)	Mitigation	Baseline
Fuel CO2	#DIV/0!	#DIV/0!
Fuel N2O	#DIV/0!	#DIV/0!
Fuel CH4	#DIV/0!	#DIV/0!
Total CO2 equiv.	#DIV/0!	#DIV/0!
$/Tonne CO2 eq		

What does this mean for fuel consumption?

In 2030, mitigation option:

Decreases coal consumption by: #DIV/0! million GJ

How do we enter this into LEAP's Mitigation scenario?

Refer to the LEAP training materials for more information on how to add supply side mitigation options.

#DIV/0! GJ/year

#DIV/0! GJ/year

Increase (Mit - Bas)
$ -
$ -
0
$ -
#DIV/0!
#DIV/0!

Reduction (Bas - Mit)
#DIV/0!
#DIV/0!

Hydro Power

The mitigation option - Hydroelectric Power Plant

Unit Size		MW
Fuel:	Electricity	
Electricity Production (MWh):		MWh/year
Electricity Production (GJ):	0	GJ/Year

Replaces the Baseline option - Existing Coal Power Plant

Fuel:	Electricity	
Unit fuel consumption:		MWh/year
Total Fuel Use:	0	GJ/Year

Ann Costs (Million $)	Mitigation	Baseline
Unit Investment Cost	$ -	$ -
Lifetime (years)	35	35
Unit Annualized Investment	$ -	$ -
Total Investment Cost	$ -	$ -
Total Annual O&M	$ -	$ -
Annual Fuel Cost	$ -	$ -
Total Annual Cost	$ -	$ -

Ann GHG Emissions (tonnes)	Mitigation	Baseline
Fuel CO2	-	-
Fuel N2O	-	-
Fuel CH4	-	-
Total CO2 equiv	-	-
Tonne CO2 reduction		
$/Tonne CO2 eq		

How do we enter this into LEAP's Mitigation scenario?

Refer to the LEAP training materials for more information on how to add supply side mitigation options.

Increase (Mit - Bas)
$ -
$ -
$ -
$ -
$ -
$ -

Reduction (Bas - Mit)
-
-
-
-
0

$ -

Solar Power

The mitigation option...

Fuel:	Hydro/Renewables		
Capacity (MW)			
Availability			
Electricity Production:		MWh/year	=

Replaces the Baseline option...

Fuel:	Coal		
Capacity:			
Fuel consumption:		MWh/year	=

Ann Costs	Mitigation	Baseline
Unit Capital Cost ($/kW)		
Total Capital Cost (Million $)	$ -	$ -
Lifetime (years)		
Total Investment Cost (Million $)	$ -	$ -
Unit Variable O+M Costs ($/MWh)		
Total Annual O&M Costs (Million $)	$ -	$ -
Annual Fuel Cost (Million $)	$ -	$ -
Total Annual Cost (Million $)	$ -	$ -

Ann GHG Emissions (tonnes)	Mitigation	Baseline
Fuel CO2	-	-
Fuel N2O	-	-
Fuel CH4	-	-
Total CO2 equiv.	-	-
$ / Tonne CO2 eq		

How do we enter this into LEAP's Mitigation scenario?

Refer to the LEAP training materials for more information on how to add supply side mitigation options.

- GJ/year

- GJ/year

Increase (Mit - Bas)
$ -
$ -
$0
$ -
$ -
$ -
$ -
$ -

Reduction (Bas - Mit)
-
$ -

Forestry

Area Planted (ha)	
Unit Annual C sequestered (Tonnes C/ha)	
Total CO2 Sequestered (Tonnes)	-
Cost ($/Tonne C)	
Cost ($/Tonne CO2)	$ -

How do we enter this into LEAP's Mitigation scenario?

Copy this formula to the Non Energy Sector/Forestry branch:
BaselineValue-Interp(2010,0,2030,0) ?CO2 sequestered (m Tonnes CO2)

See the LEAP training materials for more information.

Assumptions

Discount rate =	5%

Emission factors (kg/GJ)	CO2	CH4	N2O	Price (USD/GJ)
Fuel oil	77.4	0.0020	0.0006	6.0
Diesel oil	74.1	0.0020	0.0006	6.0
Gasoline	69.3	0.0200	0.0006	10.0
Kerosene	71.9	0.0070	0.0006	8.0
Charcoal	80.0	0.0010	0.0006	2.5
Firewood (Unsustainably Grov	110.0	0.0040	0.0001	1.0
Modern Biomass	-	0.0040	0.0001	2.0
LPG	63.1	0.0010	0.0006	14.0
Natural gas	56.9	0.0040	0.0001	8.0
Coal	94.6	0.0010	0.0014	1.0
Coal w/ CCS	14.2	0.0002	0.0002	1.0
Electricity	89.7	0.0011	0.0009	25.0
Hydro/Renewables	-	-	-	-

Global warming potentials:		
1 Ton CH4 =	23	Ton CO2
1 Ton N2O =	296	Ton CO2

Baseline Electric Mix	Percent
Coal	0.5
Hydro	0.3
Oil	0.2

Mitigation Electric Mix	Percent
Coal	0.2
Hydro/Renewables	0.6
Oil	0.2

Local number formatting	
List Separator	,

CBA Q&A

MACCs

- In offset systems, projects need to account for crediting level method used (e.g., historical vs. projected)

Explanation: Re offset systems: while CDM and REDD+ projects use reductions below a projected baseline to estimate the number of credits eligible for sale, historical emission levels (emissions in a past year) have also been suggested as a possible crediting baseline. Under such a system, a project can begin to sell credits only after they have reduced emissions to the historical level; the advantage is that rather than simply offsetting emissions somewhere else, this ensures that each project contributes to global net reductions in emissions. In such a scenario project developers cannot simply compare the MAC with the carbon price to estimate the economic viability, and governments may have to establish additional incentives to ensure private sector investment.

- Q: What are existing and future carbon markets?

Existing carbon markets include the REDD+ voluntary market and Japan's Joint Crediting Mechanism (JCR). Future compliance markets for REDD+ or Nationally Appropriate Mitigation Actions (NAMAs) could also be created under the UNFCCC or bilateral systems.

- Comment from Economic Office on forest mitigation: Also, planting of trees does not mean they are properly planted and established. High seedling mortality rates in donor projects. Also does not mean communities and governments will be able to protect them.

A: That is all true, there are many other potential weaknesses in such projects. But leakage and permanence are two of the most fundamental difficulties, observed even in the most well-designed and implemented projects. So I use them here in the slide to illustrate how opp cost/MAC analysis is only one part of successful SL programs.

Modeling

- Q: Did USAID support development of ICF Consulting's Integrated Planning Model (IPM®)

A: No, but USEPA has employed ICF extensively to use IPM for its work

- Q: Is USAID de-emphasizing support for emission trading?

A: Emissions trading is one potential mitigation option. USAID backs a number of alternative approaches. In the past USAID placed a greater emphasis on emissions trading, but since the effort to establish cap and trade in the USA faltered USAID has looked for broader approaches that can include emissions trading or other options. USAID currently supports emissions trading in countries like Kazakhstan.

APPLICATION OF MARGINAL ABATEMENT COST ANALYSIS TO CLIMATE POLICYMAKING

APRIL 30, 2014

MATTHEW OGONOWSKI

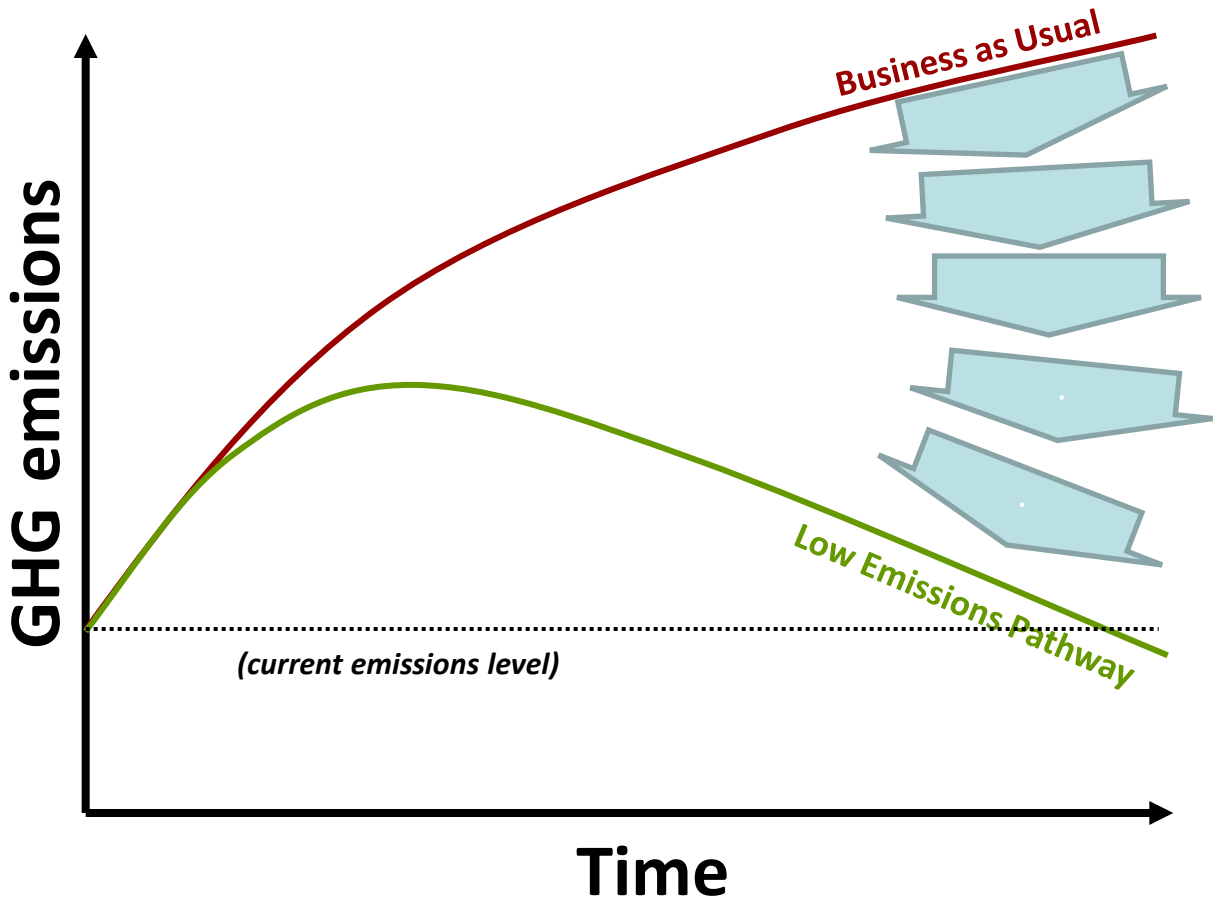
E3/GLOBAL CLIMATE CHANGE OFFICE

WHAT IS A LOW EMISSION DEVELOPMENT STRATEGY ?

A Low Emission Development Strategy is…

- …a strategic economic development and environmental planning framework
- …that articulates **actionable** programs and policies
- …to put a country on a climate-resilient development path
- …while working toward long-term measurable greenhouse gas (GHG) emission reductions.

BUSINESS-AS-USUAL VS. LOW EMISSION PATHWAYS



LEDS AND ECONOMIC ANALYSIS

- In the **Enhancing Capacity for Low Emission Development Strategies (EC-LEDS) program**: USAID Clean Energy and Sustainable Landscapes funding used for activities that support improvement or implementation of a partner country's LEDS

- Low emission development: Long-term, transformative development and sustainable, climate resilient economic growth that reduces GHG emissions

- **LEDS requires sound analysis, understanding of broad-based economic issues (including marginal abatement costs, or MACs) in multiple sectors**

APPLICATIONS: NATIONAL POLICY (1)

- Development of marginal abatement cost curves (MACCs) can assist with key climate policy goals
- Estimate **up-front investment** required
  - Help evaluate barriers to net negative cost measures
- Identify potential **low-hanging fruit** not yet picked
- Estimate **total costs** of measures
- Prioritize **mitigation options, sectors** for study
  - Rank by cost
  - De-emphasize low impact, high-cost actions
  - Map against measures prioritized for other needs, co-benefits

APPLICATIONS: NATIONAL POLICY (2)

- Estimate minimum revenues/carbon prices needed as incentives
- Assist with setting levels of carbon taxes
- Identify industries likely to be most impacted through carbon regulation
- Identify future emission drivers, how the mix may change over time

LIMITATIONS: DATA AND ASSUMPTIONS

- MACCs depend on long-term business-as-usual (BAU) assumptions
  - Fast growth in major emitting economies = uncertainty
  - Volatility in some sectors -- makes accurate predictions more difficult
- Reference/crediting emission levels
  - Dependent on technology and fuel source assumed under BAU conditions – can be highly uncertain
  - In offset systems, need to account for crediting level method used (e.g., historical vs. projected)
- Based mainly on opportunity costs -- may not account for others (implementation, transaction)

LIMITATIONS: MITIGATION/LEDS PLANNING (1)

- Aggregation of individual MACs into “policy packages” can miss **interactive effects** (e.g., multiple energy efficiency actions)
  - Over- or underestimate costs, GHG reductions

- Do not account for broad **economy-wide** impacts
  - Requires macro analysis / computable general equilibrium (CGE) modeling
  - Can be expensive and data-intensive to apply

LIMITATIONS: MITIGATION/LEDS PLANNING (2)

- Difficult to analyze **broad-scale policies** with MACs -- e.g., renewable energy standards, nationally appropriate mitigation actions (NAMAs)
  - Very important for LEDS implementation
  - World Resources Institute (WRI) is developing a tool to evaluate similar policies

- Less relevant for decisions **not** based solely on economics
  - Important to combine with consideration of other **political/social** factors

LIMITATIONS: INTERPRETING NEGATIVE COSTS (1)

- **Negative cost** measures may not reflect willingness to invest
  - Often associated with high up-front costs, long payback periods

- Technical, regulatory, institutional and legal **barriers**, market failures, transaction costs can **inhibit deployment**
  - Is fruit really “low-hanging”?

- Need to account for impact of variable product lifetimes on net present value
  - Advanced vehicles, new unproven technologies

LIMITATIONS: INTERPRETING NEGATIVE COSTS (2)

- **Negative co-impacts** may not be captured
  - Examples: Employment falls as inefficient units are replaced; pollution from agricultural intensification
  - Can distort net cost
  - May create political opposition

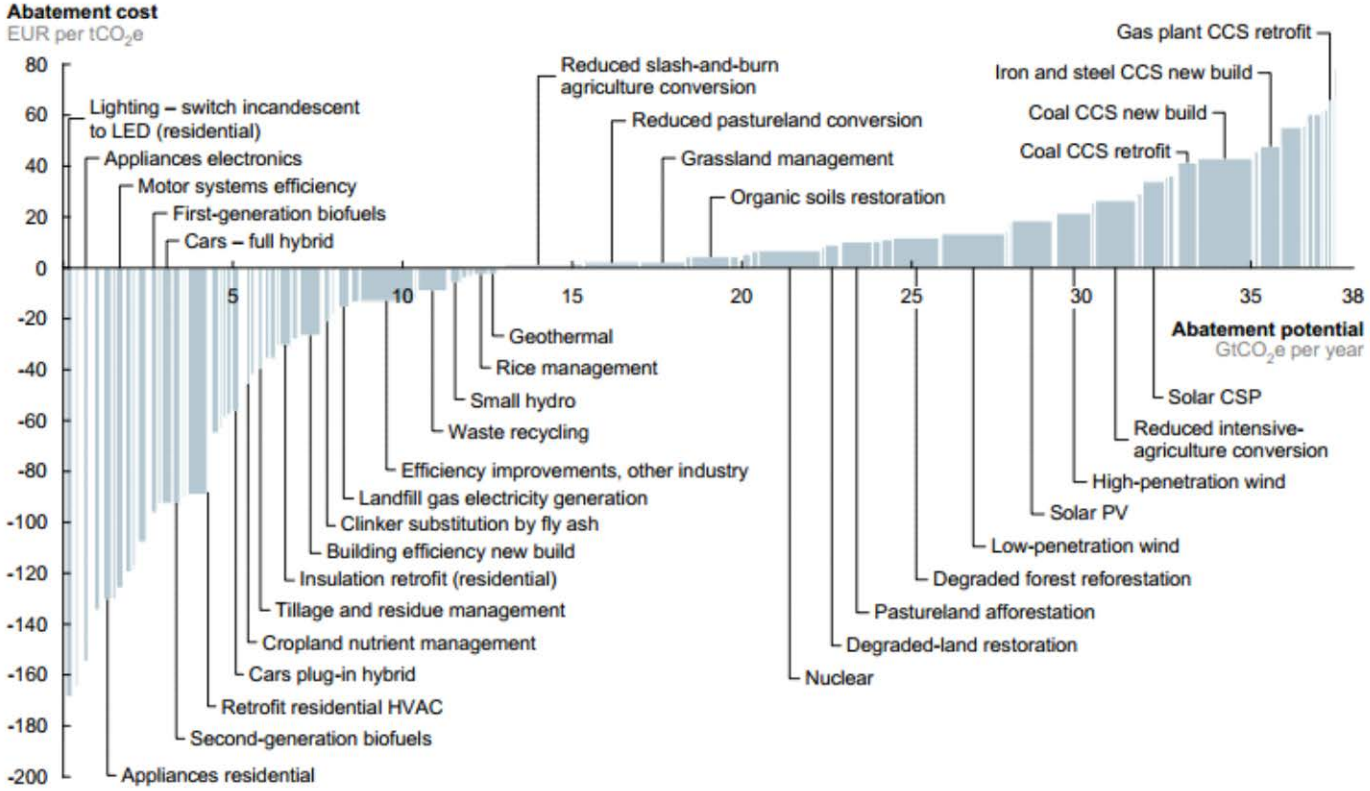
- No link between end-use mitigation policies and reductions
  - Energy efficiency reduces emissions off-site – implementers differ from permit holders in trading systems
  - MACs insufficient to evaluate effectiveness of incentives in such cases

LIMITATIONS: INTERPRETING POSITIVE COSTS

- MACs typically **do not include direct co-benefits** (e.g., reduced air pollution, protection of ecosystem services)
  - Often difficult to quantify, monetize
  - Makes net cost appear higher than actual
- Capturing co-benefits may require economic/ social policy changes
- Can reinforce perceptions that mitigation in some sectors is too costly
  - How to interpret high-impact, high-cost measures

GLOBAL GREENHOUSE GAS MACC

V2.1 Global GHG abatement cost curve beyond BAU - 2030



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below EUR 80 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play

Source: McKinsey & Company, Global GHG abatement cost curve v2.1

APPLICATIONS: INTERNATIONAL POLICY

- Country and global MACCs can help international and bilateral funding institutions identify key sectors for mitigation, create funding “windows,” estimate scale of potential funding needed

- Can help international/bilateral institutions:
  - Identify options that can be readily done with domestic resources
  - Identify low-hanging fruit that may require capacity building due to barriers
  - Identify high impact, higher cost measures that may be challenging to achieve without international assistance
  - Identify type of assistance needed – finance, training, technology, etc.
  - Assist with leveraging, identify where private sector may play

LIMITATIONS: INTERNATIONAL POLICY

- Care must be taken in utilizing MACCs when developing national emission reduction targets, negotiating an international climate change agreement

- MACCs can help to inform policy, but their use can also encourage **sub-optimal decisions**

MACCs AND INTERNATIONAL POLICY: RISKS

- Reinforce perceptions that countries should only do negative cost measures, or implement mitigation only with international assistance
  - Problematic in countries/sectors where MACCs may show fewer available negative cost options
  - Developing multiple MAC scenarios, coupling with co-benefits potential may reduce risk
- Encourage countries to sell low-hanging fruit as offsets on existing or future carbon markets
  - Used instead as national reductions will contribute to global mitigation efforts, can encourage greater ambition
- Encourage competition for funds, equity concerns

LIMITATIONS: INTERNATIONAL POLICY ANALYSIS

- Global GHG emissions today: ~50 GT CO_2e annually
- 2030 emissions and abatement potential (McKinsey & Company global greenhouse gas abatement cost curve v2.1, 2010)
  - **66** GT **BAU emissions**
  - **38** GT **abatement potential (**13 GT net negative cost)
- GHG levels in 2050 consistent with likely chance to keep temperature increase < 2 ^{o}C by 2100: 14 to **29** GT (Intergovernmental Panel on Climate Change (IPCC), Working Group III AR5)
- MACCs **less relevant** for analysis of **long-term global GHG mitigation**
  - Alternative emission/economic modeling with dynamic technological change more appropriate

RECOMMENDATIONS: INTEGRATING MACCs INTO GCC PROGRAMS

- Integrate MACCs into a broader analytical and implementation framework for LEDS
- Address limitations and barriers up front
- Include a major focus on co-impacts (plus and minus), incorporate into MACCs as feasible
- Utilize co-benefits, CGE modeling to encourage large-scale mitigation actions

RECOMMENDATIONS: MACCs AND CLEAN ENERGY

- Use MAC analysis to identify and target barriers to “win-win” energy efficiency (EE) options
- Focus and educate stakeholders on benefits of renewable energy (RE)
- MACs for RE are often higher compared to energy efficiency, but RE **replaces** emission sources rather than just reducing GHG growth
  - Essential to building effective, broad-scale, long-term LEDS

- Aim for a mix of **low-cost** EE options and a **long-term transition** to high-impact RE in LEDS planning

RECOMMENDATIONS: MACCs AND SUSTAINABLE LANDSCAPES

- Opportunity cost/MAC analysis typically used to support REDD+ projects and sales of carbon credits – but economic analysis only one component of a more complex picture to create robust and effective SL projects
- Addressing **space and time** are key factors
- Include measures to address **leakage** into other forest areas
- Focus on activities that **integrate** forest and land protection into alternative livelihoods, **long-term national and community development**
  - Evaluate and educate stakeholders about the value of ecosystem services, non-timber forest products
  - Utilize performance payments or carbon sales as a temporary transition measure toward sustainability

Greenhouse Gas Mitigation Screening Exercise

For LEAP and Excel

July 2nd 2013

STOCKHOLM ENVIRONMENT INSTITUTE

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1 Introduction

These computer exercises are designed to introduce you to some of the basic techniques used in a GHG Mitigation Assessment.

You will undertake two very simple exercises that will help you to learn some of the skills needed to conduct a GHG Mitigation assessment.

1. **In Exercise One,** you will conduct a simplified static screening of mitigation options. This will consist of two basic parts.

    - In part one, you will complete a simple spreadsheet that calculates some of the main quantitative indicators used in a mitigation screening, including the GHG emissions reductions potential from each mitigation option (in Tons of CO2 equivalent) and the costs (in annualized $ per ton of CO2 equivalent).

    - In part two you will combine these numbers with a qualitative assessment of various different screening criteria in order to develop an overall screening matrix.

2. **In Exercise Two,** you will use LEAP to create a simple GHG mitigation scenario. The scenario will be created by taking some of the data developed in the first simple static screening exercise and using it as input to LEAP's dynamic integrated energy and GHG mitigation analysis. You will use LEAP to create some of the charts and tables that would typically be included in a national communication on mitigation.
3. In **Exercise Three** you will enter additional data to quantify the costs and benefits of the scenario within LEAP.

2 Logistics

Organize yourselves to work in groups of 2 or 3 for the quantitative aspects of these exercises. For the qualitative exercises, form teams of about 5-10 people each, appoint a chair, who will moderate the discussion, and a reporter, who will take notes and prepare a brief (5 minute) presentation to plenary.

The workshop presenters will provide further information about how you will be divided into groups and which rooms will be used by each group.

3 Country Context

While the information presented in these exercises is fictional, it may be useful to imagine a hypothetical country so that you can better assess some of the qualitative criteria.

The country is a rapidly growing developing country. Its urban population is fully electrified and has average income levels close to those in the OECD, while its poorer rural population has very limited access to modern energy services, and is heavily reliant on biomass fuels to meet basic needs.

The country has a warm climate and is only sparsely populated. It has a large potential for forestation, and solar energy and also has good wind resources. It also has good but limited potential for expanding its hydropower system. However, all potential areas for hydropower development are already densely populated and hence any hydropower development will require large numbers of people to be resettled.

4 Exercise One: Mitigation Screening Exercise

4.1 Part One: Constructing a Cost Curve

The goal of this exercise is to conduct a simplified quantitative screening of GHG mitigation options. To complete this exercise you will need to work with Microsoft Excel. We assume basic familiarity with Excel.

Start by opening the Excel spreadsheet "**Screening_partial.xls**".

This spreadsheet is a partly completed GHG mitigation screening calculation developed for a fictitious set of data[1]. The spreadsheet is made up of various worksheets: with one worksheet devoted to each potential mitigation option. You can access the different worksheets by clicking the tabs at the foot of the screen in Excel.

The options included in the spreadsheet are only meant to illustrate the use of the screening techniques: they are NOT intended as recommendations of mitigation options for any particular country and they are specified using entirely fictitious data. Moreover, the options are not intended as a comprehensive list of mitigation options that might be available in a country.

The potential mitigation options included in the spreadsheet are:

- LPG cooking stoves used to substitute for kerosene stoves in urban households.
- Efficient motor drives in the industrial sector.
- Efficient refrigerators in the domestic sector.
- Hybrid cars in the transport sector.

[1] The spreadsheet is based on a screening tool named "GACMO" developed by UNEP and SEI.

- Electric cars in the transport sector.
- Combined heat and power (CHP) in the industrial sector.
- Hydro power for electric generation.
- New coal power plants with carbon capture and storage (CCS) technologies
- Solar photovoltaics for electric generation.
- Reforestation as a way of enhancing GHG sinks.

The workbook includes three additional tabs (worksheets) labeled "Assumptions," "Screening Matrix" and "Cost Curve".

- **The Assumptions sheet** includes the basic characteristics of the fuels used in the spreadsheets including their emissions factors and prices. It also includes other defaults such as the discount rate used to annualize costs and the Global Warming Potential (GWP) of the three GHGs included in this simplified analysis: CO2, N2O and CH4.

- **The Cost Curve sheet** is used to plot a cost curve for all of the options analyzed in the worksheet. The cost curve plots cumulative GHG reduction from successive mitigation options (Tons of CO2 avoided) against cost per unit of GHG reduction (e.g. $/Ton). A property of the curve is that the area under the curve yields the total cost of avoided emissions. As you complete the data for the options in each tabbed worksheet the Cost Curve will be plotted.

- **The Screening Matrix** will be used for the qualitative component of the exercise.

This exercise illustrates a simple approach to developing a cost curve, the so-called **"partial approach"**. In this approach:

- Each technology is evaluated separately and compared to a reference technology.
- Overall emission reductions and costs are created by combining options while assuming no interaction between options.

This approach is simple to conduct but does not consider the possible interactions between options. For example, the costs and mitigation potential of demand-side efficiency options will depend on what kind of supply technologies are used to generate electricity. In these simple exercises we ignore these problems and simply assume that electricity is provided by the average baseline electricity mix. In reality, supply-side mitigation options (e.g. more hydro) might affect the carbon intensity of the supply mix, and hence the actual level of emissions that can be avoided by a demand-side efficiency measure.

A second issue is that our spreadsheet analysis will be static: we will only consider the savings that might be achieved in a single year: 2030. Later on, in the second exercise we will use a dynamic modeling tool, LEAP, to create integrated scenarios that examine how both the baseline and the mitigation options might evolve over time from the base

year in 2010 to 2030. In this latter approach we will be able to consider interactions between measures.

In spite of its limitations, the **partial approach** can still be a useful approach for getting a rough first estimate of GHG mitigation costs and potentials and therefore it is the approach we will use here in this first exercise.

Spreadsheet Exercise

Use the following descriptive information for each option to complete the worksheet and prepare a cost curve and accompanying data table that describes the GHG emissions reductions potential from each mitigation option (in Tons of CO2 equivalent) and their costs (in annualized $ per ton of CO2 equivalent). Bear in mind that the descriptions and data provided here are simplified for the purpose of this analysis and use fictitious data.

NB: Some cells may be locked or protected to indicate that the calculations have already been completed. You may be interested in viewing the formulas, but we do not recommend editing them.

The options are as follows…

- **LPG Stoves:** By 2030, efficient LPG stoves could replace kerosene stoves in 3 million households. Kerosene stoves annually consume 8 GJ of energy per household and work at an efficiency of 30% while the LPG stoves work at an efficiency of 60%. LPG stoves cost $40 and have an expected lifetime of 8 years. Kerosene stoves cost $15 and last 5 years.

- **Efficient Motor Drives in Industry:** By 2030, the introduction of efficient electric motors throughout the industrial sector is expected to be able to save 10,000 GWhr of electricity at a cost of 10 cents ($0.10) per kWh.

  NB: For this example, try entering an incremental cost and electricity saving.

- **Efficient Refrigerators in the Residential Sector:** By 2030, efficient refrigerators could replace standard refrigerators in 1 million households. Efficient fridges will use 400 kwh/year, while standard fridges consume 700/kwh/year. Efficient fridges cost $500 and have a lifetime of 10 years. Standard fridges cost $300 and last 8 years. Assume one fridge per household.

- **Hybrid Cars in the Transport Sector:** New affordable hybrid vehicles are quickly becoming available in the country, expecting to replace one million conventional ICE vehicles by 2030. This will decrease the fuel consumption in these vehicles from 10 liters/100 km (for conventional vehicles) to 6 liters/100 km by 2030. Each vehicle drives 18,000 km/year. Hybrid vehicles will cost approximately $5,000 more than a conventional car. Assume that vehicles have a lifetime if 15 years. Note that 1 liter of gasoline is equivalent to 0.033152 GJ.

- **Electric Cars in the Transport Sector:** Under a new transportation policy, electric cars are expected to replace 500,000 conventional internal combustion engine (ICE) cars) by 2030. These cars will require an average of 30 kWh/100 km. Each electric vehicle will cost about $10,000 more than a conventional car. Assume the lifetime and mileage from the hybrid example above. Note that for this simplified example we have not included infrastructure costs of the policy, which could include necessary investments in plug-in stations.

- **Combined Heat and Power (CHP) in Industry:** By 2030, 20 million GJ of industrial process heat produced from oil-fired boilers could instead be produced from more efficient natural gas fired CHP plants. The oil-fired boilers operate at 55% efficiency, while the CHP plants would produce heat at 50% efficiency together with electricity at 25% efficiency (for a combined efficiency of 75%). The electricity can be sold back to the grid and is assumed to displace the average baseline mix. To produce this amount of heat, 800 MW of CHP plant will be required at an incremental cost of $1400/kW. CHP plants have a lifetime of 35 years.

- **Coal Power Plants with Carbon Capture and Storage (CCS) Technology:** Carbon capture and storage (CCS) is emerging as an alternative technology that may allow up to 85% of CO2 to be collected and transported for long-term storage when combined with coal power plants. CCS technologies are not yet commercially available, but in this policy scenario it is assumed that by 2030 2000 MW of this new technology could replace existing coal power plants. The existing coal power plants have a 30% thermal efficiency, a capital cost of $1000/kW and have a lifetime of 35 years. CCS capital costs are estimated to be $3000/kW and the technology has a lifetime of 35 years. The new coal power plants are more efficient, but also suffer an energy penalty because of the CCS requirements, which gives them an overall efficiency of 35%. Both power plants have an availability of 80%.

  Note: *to make sure emission factors are calculated correctly in the spreadsheet it is important to select "Coal w/CCS" as the fuel used by the CCS plant.*

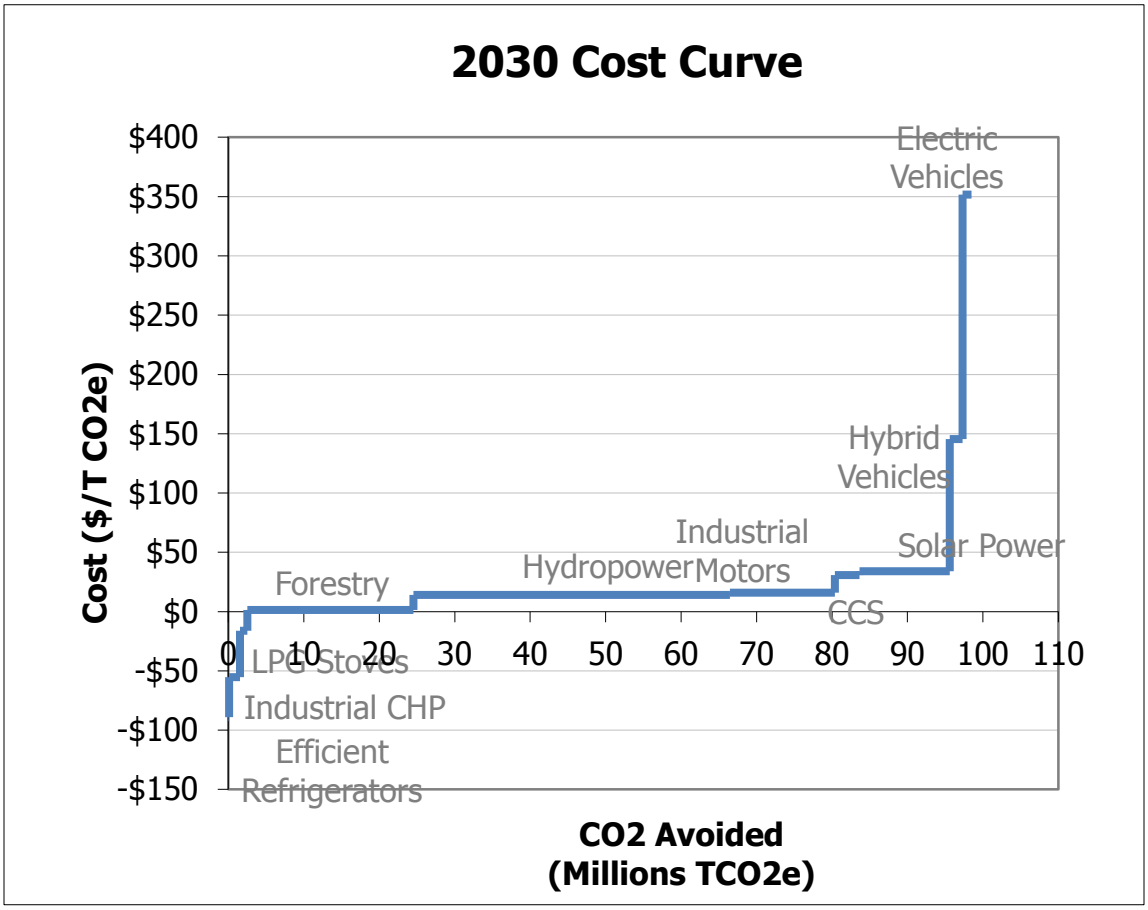
- **Hydro power for electric generation:** Approximately 6000 MW of hydropower could be built by 2030 displacing coal which is expected to be built in the future as the main base load power plant in a baseline scenario. The hydro plants will have an efficiency of 100%, an expected availability of 70% and a plant lifetime of 35 years. Hydropower capital costs are expected to be $4000 per KW. Variable O&M costs are expected to be $1 per MWhr. The hydropower plant would be built and run to replace coal fired plant that would have an expected availability of 70%, a thermal efficiency of 30%, a lifetime of 35 years, a capital cost of $1000 per KW, and variable O&M costs of $3 per MWhr.

- **Solar Photovoltaics for Electric Generation:** 4000 MW of solar power could be built by 2030, again displacing coal-fired base load plant. The solar plants would have an efficiency of 100%, an expected availability of 30% and a lifetime of 30 years. As solar technologies become more competitive, total capital costs are expected to decrease to $2000 per KW in 2030. Variable O&M costs are expected to be $20 per MWhr. Because of solar's low availability; the 4000 MW of solar would only displace about 1500 MW of coal plant. The coal fired plant would have a thermal efficiency of 30%, an expected availability of 80%, a lifetime of 35 years, a capital cost of $1000 per KW, and variable O&M costs of $3 per MWhr.

- **Reforestation (Enhancing GHG sinks):** Reforestation projects are expected to cover 4 million ha by 2030. Each hectare is expected to sequester about 1.5 tonnes of carbon per year at a cost of $5 per tonne of carbon.

Use the above information to complete the spreadsheet. You should end up with a cost curve looking like the one shown on the next page.

Option Name	Million Tons CO2 Opton Mitigation	Million Tons CO2 Cumulative Mitigation	$/Ton CO2 Cost of Saved CO2
Baseline	-	-	
Efficient Refrigerators	0.1	0.1	-$89
Industrial CHP	1.4	1.5	-$55
LPG Stoves	1.0	2.5	-$16
Forestry	22.0	24.5	$1
Hydropower	42.0	66.5	$14
CCS	13.9	80.4	$16
Industrial Motors	3.2	83.6	$31
Solar Power	12.0	95.6	$34
Hybrid Vehicles	1.7	97.3	$146
Electric Vehicles	1.2	98.5	$352



Notice that the curve shows costs increasing from left to right. The options on the far left actually have negative costs, indicating that for these options GHG mitigation can be achieved with net benefits to the economy. The area under the curve yields the total cost of avoided emissions.

NB: The cost curve will reorder automatically based on the numbers you enter in each worksheet. If your options appear in a different order than above, this likely indicates a problem in your analysis. Use the chart to help troubleshoot your analysis.

4.2 Part Two: Developing a Screening Matrix

In part two of this exercise you will work together as groups using a **multi criteria attribute** (MCA) approach to decide on an overall ranking for the mitigation options you began to examine in part one. In this exercise you will go beyond thinking only about GHG mitigation cost and potential to consider additional criteria such as potential development benefits.

To do this, complete the empty screening matrix sheet provided in the screening Excel spreadsheet. The matrix uses a multi criteria attribute (MCA) approach to automatically calculate overall scores and rankings based on the scores you give for each criteria for each individual option. Fill in the cells of the sheet so as to score each option against each criterion from zero (worst) to ten (best). Scores are already entered for the overall GHG abatement cost and GHG mitigation potential of each option based on the data you entered earlier.

You should also enter the weightings for each criterion in column C. Each criterion can have a weighting from 0 to 100, but make sure that the total weighting across all criteria is 100.

At the bottom of the matrix, the spreadsheet automatically calculates an overall score for each option, again scaled from zero (worst) to ten (best), and also shows the options ranked from best to worst.

If you have time you may want to make multiple copies of this spreadsheet. Try completing different versions of the matrix to reflect the views of different stakeholders. For example, you may want to try playing the roles of:

- a national government's energy or environmental ministry,
- a local non-governmental environmental or development organization, or
- a national or international donor agency.

Each stakeholder may have different opinions about the scores assigned to each option. They may also have different opinions about the importance of each criterion. How do changes in criteria and scores affect your overall ranking of options?

Presenting Your Results

With either approach, once you have completed at least one screening matrix as a group, you will be asked to present your findings in plenary in a short (3-5 minute max) presentation.

Start by appointing one member of your group as your reporter. That person will be asked to present the cost curve you developed, along with the screening matrix. Try to answer these questions:

- As a group: what process did you use to develop the screening matrix?

- Which options seem the best and worst based on your process?
- In what ways is this analysis too simplified to reflect real-world conditions?
- How might you improve upon it in a real mitigation assessment?
- What finance and support mechanisms could support any of these measures?
- Do you believe that developing a screening matrix will be useful as a step in your own national mitigation assessments?

5 Exercise Two: Creating a Mitigation Scenario in LEAP

In this second exercise you will work with LEAP, the Long range Energy Alternatives Planning System to create a very simple example of a mitigation scenario.

The exercise is not intended to fully train you in the use of LEAP. It is intended only to give you a brief introduction to some parts of the system, to give you a chance to create a simple mitigation scenario and to produce various reports of the type that might be included when reporting on a mitigation assessment in a National Communication.

Exercise 2 builds upon the data and results developed for static screening you undertook in Exercise one. In this second exercise you will take the basic information for selected mitigation options, and enter this into LEAP to create a dynamic mitigation scenario that examines how energy and emissions savings might occur over the period 2010-2030.

You will then use LEAP to create a few charts and tables that report the overall emissions savings in the mitigation scenario compared to the baseline scenario.

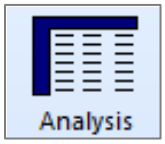
To keep things simple, you will work with a partially completed LEAP data set that already has a fully defined Baseline scenario.

5.1 A Very Brief Introduction to LEAP

Start **LEAP** from the **Start/Programs/LEAP** menu or by double-clicking the LEAP Icon (shown left) on the desktop. Once started, LEAP will display a title screen and then the main screen will appear (shown below).

As much as possible LEAP works like other standard Windows software, so if you are familiar with other Windows tools like Microsoft Excel or Windows Explorer, then you should be able to start using it straight away.

LEAP is structured as a set of different *views* of an energy system. The **View Bar** located on the left of the screen, displays an icon for each view. For this exercise we will only use three views:

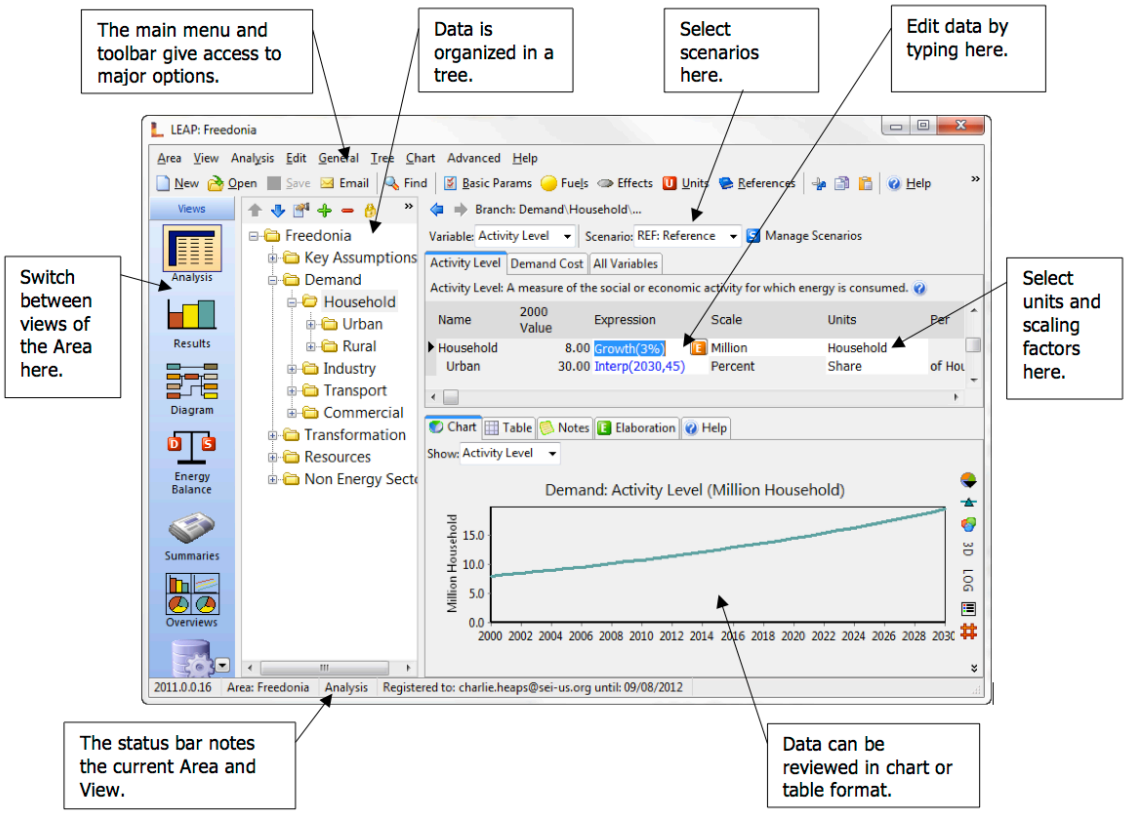


The **Analysis View** in which you will enter data and construct your mitigation scenario.

The **Results View** where you will examine the calculated scenarios as graphs and tables.

The **Overviews View** where you view a specific set of pre-defined "favorites" results charts.

The **Analysis View** (shown below) contains a number of controls apart from the view bar. On the left is a tree that is the main organizational tool for the data in LEAP. On the right are two linked panes. At the top is a table in which you view or edit data the data describing your scenarios. Below it is an area containing charts and tables that summarize the data you entered above. Above the data table are toolbars that give access to commonly used commands and a standard menu.



The main parts of the **Analysis View** are described in more detail below:

- **The tree** is the place where you organize your data for both demand and supply (Transformation) analyses. The tree contains different types of branches:

  - **Category branches** are used mainly for the hierarchical organization of data in the tree.
  - **Technology branches** contain data on the actual technologies that consume, produce and convert energy.
  - **Fuel branches** are used to indicate resources as well as the feedstock fuels and outputs of Transformation processes.
  - **Environmental loading branches** represent the various pollutants emitted by energy demand and transformation technologies.

- **Data Table:** The top-right part of the screen shows a data table where you can view or edit the data associated with the variables at each branch in the tree. As you click on different branches in the tree, the data table shows a series of "tabs". Each tab corresponds to one variable. The variables you see depend on which part of the tree you click on. For each tab, a table presents the data associated with that variable. Each row in the table represents data for a branch in the tree.

- **Chart/Table/Notes:** The lower-right part of the screen summarizes the data entered above as a chart or a table.

- **Scenario Selection Box**: Above the data table is the scenario selection box, which you can use to select between **Current Accounts** and any of the scenarios in an area. Current Accounts are the data for the base year of your study. Different scenarios in LEAP all begin from the base year. In this exercise you will be given a completed **baseline** scenario, and you will then enter the data for a **Mitigation** scenario. Use the scenario selection box to select among the Current Accounts and the scenarios.

5.2 Reviewing Historical Data

In this exercise we will work on a partially completed data set or **Area** named "GHG Screening Exercise". An Area in LEAP is a complete description of a particular energy system, typically a country. Start by opening the area named **GHG Exercise Partial**. To do this select menu option **Area: Open** and then select the area named "GHG Screening Exercise partial". If the exercise cannot be found there, you may have to download it from the COMMEND website. To do this, go to **Area: Install: Install from Internet**.

Let's begin by reviewing the Current Accounts and Baseline scenario that has already been completed for you (to keep this exercise short!)

First, in the **Scenario Selection Box**, choose **Current Accounts.** The Current Accounts scenario includes multiple years of historical data. In this simple exercise we have entered future baseline data into current accounts as well.

Baseline scenarios are not a prediction of the future; instead they are plausible stories of how an area could involve in the absence of mitigation policies. There is also no "right" way to build a baseline scenario. Some baseline scenarios are based on historical trends while others may focus on expected trends for the future. The key thing to understand is that your baseline scenario is what you will be comparing back to; you will not be only looking at your baseline, but instead you will be looking at how your mitigation scenarios relate to the baseline.

Now use the tree to navigate the structure of this data set. First open up the tree branches under the main category "Key Assumptions." This folder contains macroeconomic and

demographic variables that can be used to help model future energy demand. You will see entries for population and gross domestic product (GDP).

Now open up the folders under the Demand branch. You will see that this data set is very simple and aggregate. Demands are broken down by major sector (Residential, Industry, and Transport). Each sector has a simple set of branches listing the final fuels consumed in each sector. Each fuel is shown in the tree as a technology branch ( ). Finally under each fuel, are a set of branches that specify the emissions for each fuel ( ). In this exercise there are emissions specified for CO2, CO, CH4, VOCs, NOx, N20 and SO2.

Now let's look at the data associated with these branches. Click on one of the sector branches in the tree and then look at the tabs and data pane on the right. You will see that energy consumption data is also specified in a very simple way. Normally in LEAP you would specify separate data describing **activity levels** (e.g. number of households, or pass-km of transport) and **energy intensities** (GJ/households per year or GJ/pass-km). LEAP then multiplies these together to calculate total final energy demand. That is, it uses this relationship:

Total Final Energy Consumption = Activity Level x Final Energy Intensity

But in this exercise the data are specified in an even more simple fashion. The Activity Level variable has simply been set to "No data" and total energy consumption data is specified on the tab marked **Final Energy Intensity**. In other words we have used this relationship:

Total Final Energy Consumption = Final Energy Intensity

Select the **Final Energy Intensity** tab now. You will see the values of the total final energy consumption for each branch specified as data in Millions of Gigajoules. In the lower part of the screen the data is echoed back as a chart.

All the time-series values in this data set are specified using LEAP's built-in ***Interp*** function. The Interp function works by letting you specify values for any years. It then assumes a straight line change between the years calculated by simple linear interpolation. For example, this function…

Interp(2010,28, 2020,60, 2030,80)

…specifies a value of 28 in the year 2010 and a value of 60 in 2020. Thus the interpolated value that LEAP calculates in 2015 is 44.

Now open up the branches below one of the fuels and look at the **Environmental Loading** Tab. You will see a series of expressions that specify the emissions factors for each pollutant per unit of fuel consumption for that fuel. Typically emissions factors are specified in Tonnes/Terajoule or kg/Terajoule. To calculate total emissions of each

pollutant, LEAP simply multiples total energy consumption by each emission factor using this relationship:

Total Emission = Total Final Energy Consumption x Emission Factor

Now let's have a look at how the data is specified for the Energy Supply system. This data is entered under the **Transformation** branches in the LEAP tree. In LEAP, energy supply data is specified by first making a list of ***modules*** immediately below the Transformation branch. These modules correspond to major energy supply sectors like electricity generation, transmission and distribution, oil refining, charcoal making, ethanol production, coal and oil extraction, etc. Each module can be further divided into different ***processes***, each of which can have one or more ***feedstock fuels***. A process might be a particular type of power plant or a type of oil refining facility for example. Each module is dispatched to produce one or more ***output fuels***.

In our simple example, there are only two modules: one dealing with the **Transmission and Distribution** (T&D) of electricity and a second one below it dealing with **Electricity Generation**. The T&D module is very simple: it simply specifies expected losses during transmission and distribution. The Electricity Generation module has four processes describing the capacity, availability, efficiency and merit order dispatch characteristics of four types of power plants: hydro, coal, oil and solar. The first three exist in the base year, while solar is listed as a potential future type of power plant.

Now, let's switch to the **Results View** to see some results associated with the already complete Baseline scenario. Click on the results view, and if prompted allow LEAP to calculate results. This should only take a few seconds.

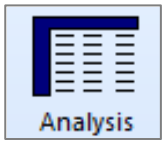
Now let's look at some results in Chart form. The Results view has numerous options for selecting results.

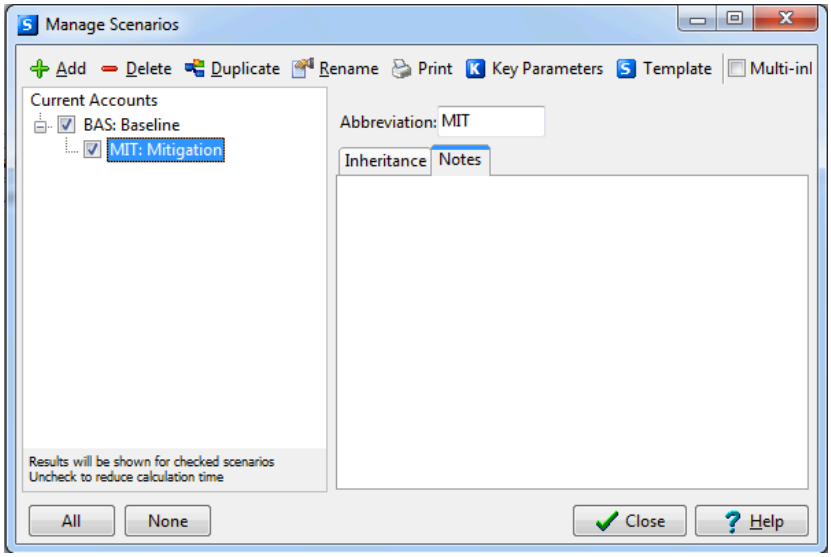
- First use the **tree** to pick the branches for which you wish to see results. For example, you might choose to see demands in the household sector, or GHG emissions for the whole area.
- The **Result** selection box at the top of the screen is used to pick the category of results you are interested in. Different types of results are available at different tree branches. For example, final energy demand results are only available at demand branches while emissions and GHG results are available at both demand and supply branches.
- Two tabs at the top of the view let you switch between **Charts** and **Tables**: both formats contain the same basic information.

Reports can be viewed for one or more scenarios and can be customized in a wide variety of ways. You can also use the "**Favorites**" option to bookmark the most useful charts for your analysis.

To make things easy, we have preconfigured a set of **Favorite** charts you can use to examine results. Take a look now at the Favorite results for **Total Final Energy Demand in 2030**, **Electric Generation** and **Global Warming Potential** (by sector and by greenhouse gas).

5.3 Entering Mitigation Data into LEAP





Now you are ready to create a mitigation scenario. Switch back to the **Analysis View** and click on the **Manage Scenarios** button ( ). In the resulting Manage Scenarios screen (shown right), use the Add button ( ) to add a new scenario named Mitigation.

Important: Make sure the mitigation scenario *inherits* from the Baseline scenario. That is, it must appear in the scenario tree indented and below the Baseline scenario as shown above. In this way, all of the data and expressions for the Mitigation scenario will initially be exactly the same as those in the Baseline scenario.

To specify the data for the new scenario you will only need to specify the places where the mitigation scenario is different from the Baseline. Much of the data specified for the Baseline (such as emissions factors) will remain unchanged.

Now close this screen and return to the Analysis View. If necessary, select Mitigation as the active scenario in the **Scenario Selection Box.**

We will now enter data to represent some of the options we studied in Exercise One in our mitigation scenario.

In a real mitigation study it might be desirable to do a thorough end-use oriented analysis in which both the baseline and the mitigation scenario are described in terms of the likely penetration of different technologies. That kind of exercise is data intensive and time consuming and goes beyond what can be done in this simple exercise. Instead, in this exercise we will specify most of our options by simply entering the amount of fuel consumption that is avoided (or increased) relative to the Baseline scenario as a result of implementing the mitigation option.

Let's enter the data for the Household LPG stoves option. If you look at the spreadsheet **screening.xls** you will see that this option is expected to reduce consumption of kerosene by 24 million GJ in 2030 while increasing consumption of LPG in 2030 by 12 million GJ. The changes can be assumed to start from nothing in the base year (2010) and increase linearly to reach these values by 2030.

We can specify this information in LEAP as follows. First, select the Residential branch in the tree then select the **Final Energy Intensity** tab and then enter the following two expressions for the Kerosene and LPG branches. The expressions should override the expressions that were inherited from the Baseline scenario.

For Kerosene:

BaselineValue - Interp(2010, 0, 2030, 24.0)

This expression specifies that the energy consumption of kerosene in the mitigation scenario gradually decreases versus the baseline scenario, so that by 2030 it is 24 million GJ less.

For LPG:

BaselineValue + Interp(2010, 0, 2030, 12.0)

This expression specifies that the energy consumption of LPG in the mitigation scenario gradually increases versus the baseline scenario, so that by 2030 it is 12 million GJ more.

Tips:

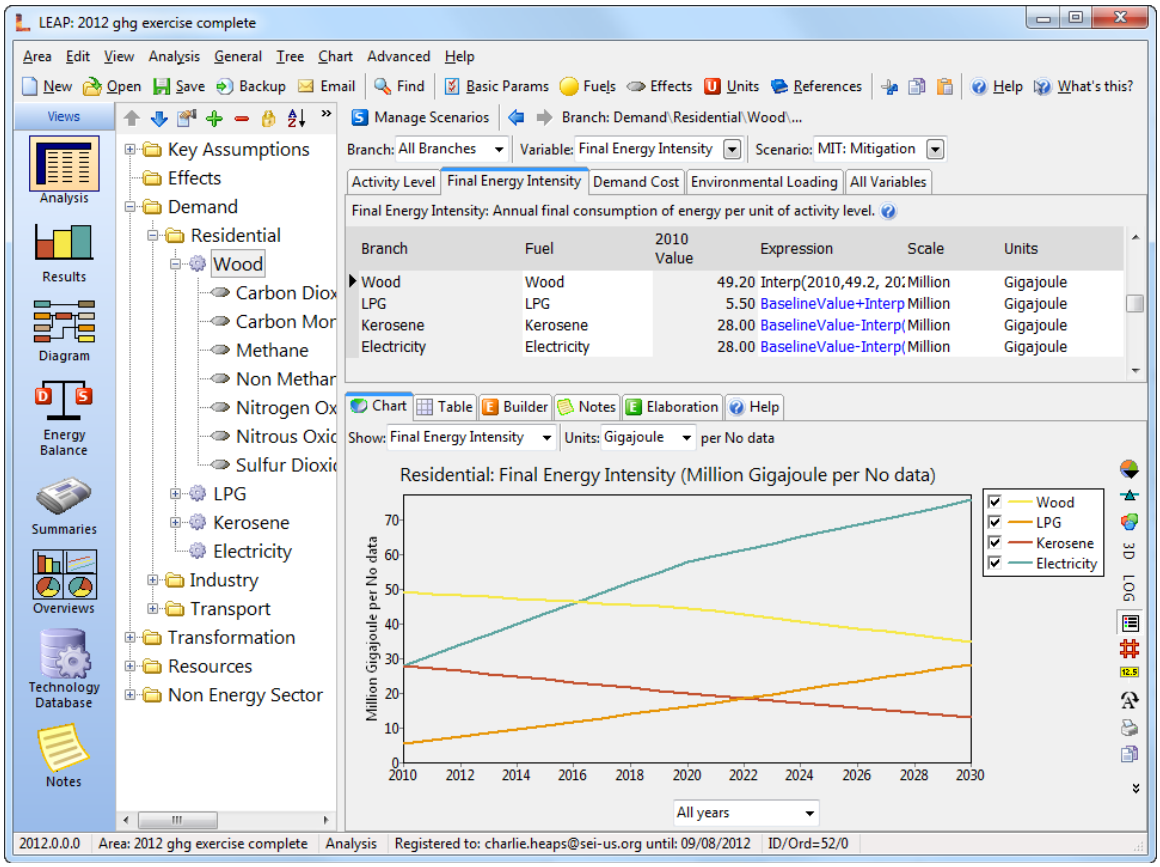
1. The screening spreadsheet automatically creates these formulae for each of the demand-side mitigation options, so you may find it easiest to simply copy and paste these formulae from Excel to LEAP.

2. Make sure the formulae you enter are adapted to the local number formatting conventions used on your PC. For example, in Spanish speaking countries the list separator will be the ";" character and the decimal separator will be the "." character. LEAP automatically uses the local number formatting of your PC. So for example, the first equation above would be entered as follows in Spanish speaking countries:

   BaselineValue - Interp(2010; 0; 2030; 24,0)

   Note also that to facilitate easy copying and pasting from Excel to LEAP, you can edit the list separator character used in equations via the Assumptions tab of the spreadsheet.

When entering the data in LEAP's Analysis View, the screen should look something like this:



Use this same approach to continue specifying the data for the other mitigation options that you wish to include in your mitigation scenario. For now only include the following measures (starred items have helpful tips listed below):

- LPG Stoves
- Efficient Refrigerators
- Hybrid and Electric Cars*
- Industrial CHP
- Hydro*
- CCS*
- Forestry*

Most of the other options can be entered into LEAP in a way similar to how you specified the LPG stoves option. However specifying either of the two supply-side options (CCS and hydro), the forestry option or the transport options requires a bit more explanation.

- **Entering data for the transportation measures:** Both of the hybrid and electric measures affect future gasoline usage. In LEAP, this would require entering two

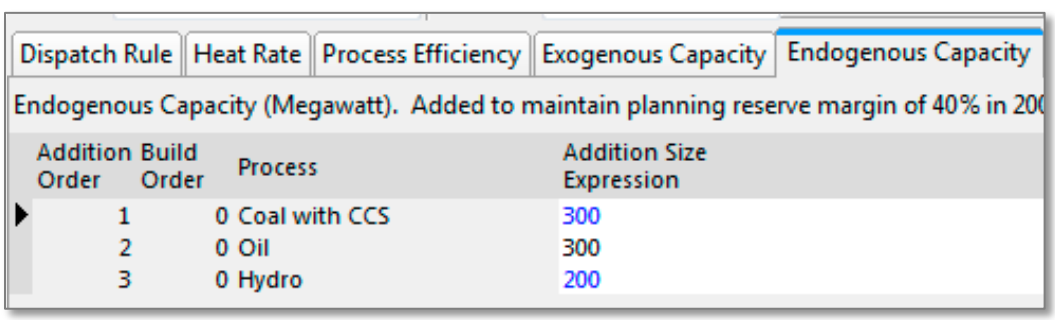
formulas in the same location and so for this simplified example we must combine the fuel usage estimates into one formula.

If you look at the screening spreadsheet you should see that the hybrid mitigation option is expected to decrease gasoline usage by 23.87 Million GJ in 2030 and the electric car mitigation option is expected to decrease gas consumption by 29.84 Million GJ. The two values can be added to give a total saving of 53.71 Million GJ so that the LEAP formula can thus be written as:

BaselineValue - Interp(2010, 0, 2030, 23.87+29.84)

Don't forget to add the additional requirements for electricity in a similar equation for the electric vehicle scenario.

- **Entering data for the Hydro and CCS Measures:** For these options you will need to enter data in the Transformation\Electricity Generation module. Click on the Processes branch and then select the **Endogenous Capacity** tab. This screen lets you specify a set of plants that will be added automatically and as needed as demands grow in order to meet a specified panning reserve margin. You can see that in the baseline LEAP will add Coal and Oil plants in amounts of 500 MW and 300 MW respectively as needed to keep the reserve margin on or above 40%. For the mitigation scenario, you will need to add the Hydro and Coal with CCS processes to the list. Click the Add button (+) at the right of the table to add two new processes to the **Endogenous Capacity** screen for Coal with CCS and Hydro. You will need to delete (−) the previous option for Coal and you will need to use the up (↑) and down (↓) arrows to make the Addition Order the same as the image below. Now change the **Addition size** values to read (Coal with CCS: 300, Oil: 300, Hydro: 200).



- **Entering data for the Forestry Option:** Unlike all the other options, the Forestry mitigation option is a non-energy sector option. Its implementation has no direct effect on the energy sector with which LEAP is primarily concerned. However, you can still characterize this option in LEAP in very simple terms. Select the **Non-Energy Sector Effects** branch to view the branch for forestry.

There is only one variable for non-energy sector branches, and that is environmental loading.

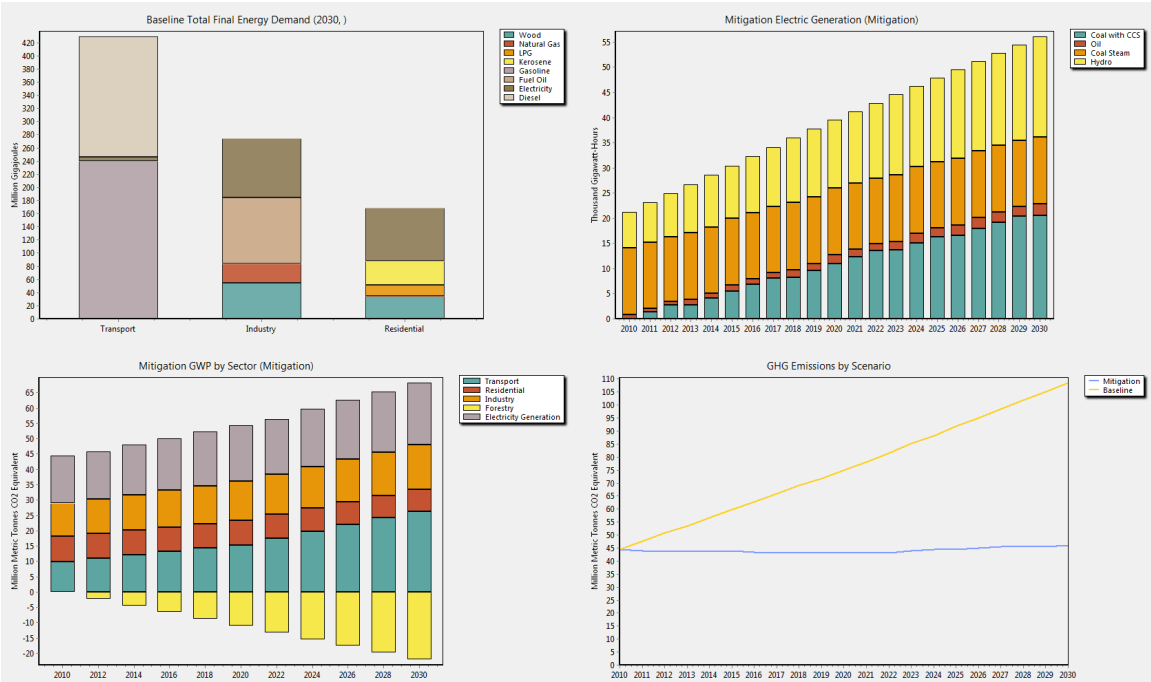
Now you can specify the emissions sequestered in the Mitigation scenario in 2030 (22 million tonnes of CO2). Don't forget to set the scaling factor and units to Millions and Tonnes respectively. Enter the emissions sequestered as a negative value because they are a net sink compared to the Baseline scenario. One way to enter this would be to use the following expression:

BaselineValue - Interp(2010, 0, 2030, 22)

5.4 Viewing Results in LEAP

Once you have completed specifying the data for the mitigation scenario, switch to the Overviews view. This view allows you to take advantage of favorites charts that you have already created so that you can quickly see changes in results. For the purposes of this exercise we have created an overview with four useful charts.

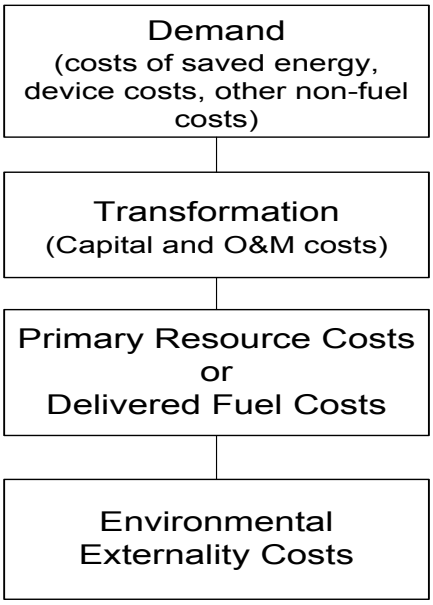
Compare your results to the ones produced here. These results are based on a scenario that includes all of the mitigation options except for Solar PV and Industrial Motors.



6 Exercise Three: The Costs and Benefits of the Mitigation Scenario.

In this third exercise we will enter data about the costs of the various policies and measures employed in the Mitigation scenario and then use LEAP to look at the overall costs of the scenario versus the "do nothing" baseline scenario.

LEAP performs cost-benefit calculations from a societal perspective by comparing the costs of any two policy scenarios. LEAP can include all of the following cost elements:



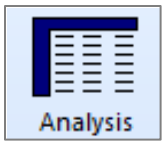
- Demand costs capital and operating and maintenance costs expressed as total costs, costs per activity, or costs of saving energy relative to some scenario.
- Transformation capital costs
- Transformation fixed and variable operating and maintenance costs.
- Costs of indigenous resources
- Costs of imported fuels
- Benefits of exported fuels
- Externality costs from emissions of pollutants
- Other miscellaneous user-defined costs such as the costs of administering an efficiency program.

To set-up a costing analysis in LEAP it is first necessary to draw a consistent boundary around your system, so that LEAP will not double-count costs and benefits. For example, if you count the costs of fuels used to generate electricity you should not also count the cost of the electricity in an overall cost-benefit calculation.

Contrast this integrated perspective with the rough project-by-project approach that we used in developing the original screening spreadsheets. Taking this integrated perspective has a number of distinct advantages:

1. It is able to capture interactivity: the effect that one measure has on another. For example: our efficient refrigerators measure was originally judged in terms of the CO2 saved based on a simple assumption about the baseline electric fuel mix. But in an integrated scenario we may be combining demand-side efficiency measures with supply-side fuel switching measures. Using LEAP we can see the interactive effects.

2. LEAP's analysis is dynamic: thus we can see what happens over time as demand-side measures penetrate the market and the electric supply sector grows accordingly to meet demands.



If you have not already done so, switch-on costing in LEAP by returning to the Analysis View, and going to **General: Basic Parameters; Scope** screen. Now go to the **Costing** tab and select the boundary that will be drawn around the system for the purposes of costing. For this exercise we will select "Complete Energy System" as the boundary, meaning that fuel costs are accounted for only when they are imported or exported or when indigenously produced fuels are extracted as primary resources.

Now go back to the Analysis View and select the **Current Accounts** scenario. We will first enter data into LEAP that describes the costs (or benefits) of each.

You will need to refer to the spreadsheets you used for evaluating each mitigation measure. Enter the following information:

6.1 Demand-Side Measures

- **LPG Stoves:** From the spreadsheet, calculate the total annualized non-fuel costs per GJ of kerosene saved for this measure ($/GJ). Enter this data in LEAP for the Residential\Kerosene branch on the Demand Cost tab using the "Cost Saved Energy" cost method. Notice that costs of saved energy are always defined relative to some counterfactual. In this case the cost is defined relative to the baseline scenario. Notice also that in LEAP we will assess fuel costs separately from non-fuel costs, so you will need to calculate all of the costs except for the fuel costs.

- **Efficient Refrigerators in the Residential Sector:** Here you will need to use the spreadsheet to calculate the annual electricity savings and the total non-fuel costs of the measure. Again, use the "Cost Saved Energy" method.

- **Hybrid and Electric Cars in the Transport Sector:** Here you will need to use the spreadsheet to calculate the annual gasoline savings and the total non-fuel costs of both transport sector measures ($/GJ).

Tip: *Note that in our screening cost curve some of the measures (vehicles, refrigerators, LPG stoves, CHP) had negative overall costs (since fuel savings for these measures outweighed the investment costs). These are NOT the costs we enter into LEAP's demand analysis. Instead in LEAP we need to specify only the non-fuel costs of each measure. We will deal with the fuel savings later on using LEAP's integrated cost-benefit analysis perspective.*

- **Combined Heat and Power (CHP) in Industry:** Here you can specify cost data in terms of the cost per GJ of fuel oil replaced with CHP. Again, you will need to

use the spreadsheet to calculate the annual fuel oil savings and the total non-fuel costs of the measure ($/GJ).

6.2 Transformation Measures

Entering data on the supply-side is more straightforward. We will take the data from the earlier exercises describing the capital, O&M, and lifetime of the four affected power plant types: coal, oil, hydro and coal with CCS and enter it on the various costing tabs under the Transformation: Electric Generation module. That data is repeated here for convenience:

Plant	Capital cost ($/kW)	Variable O&M Cost ($/MWh)	Lifetime (Years)
Coal	$1000	$3	35
Oil	$2000	$5	30
Hydro	$4000	$1	35
Coal with CCS	$3000	$3	35

Remember to use the default discount rate of 5% as the value for the Interest Rate for each plant. This is the value used to annualize the capital costs for each plant.

6.3 Non-energy Measures

LEAP is primarily an energy model. Currently it does not have the capability to include non-energy sector costs. Thus you cannot include the costs of the reforestation measure.

6.4 Resource Costs

Finally, we need to specify the costs of all of the various resources used in both scenarios. This data is entered under the Resource branches in LEAP for both indigenously produced primary fuels and for imported fuels.

Enter into LEAP the fuel prices specified on the **Assumptions** spreadsheet to complete the specification of the costs in your LEAP analysis. Enter costs into both the "Import Cost" variable and the "Indigenous Cost" variable for both primary and secondary fuels.

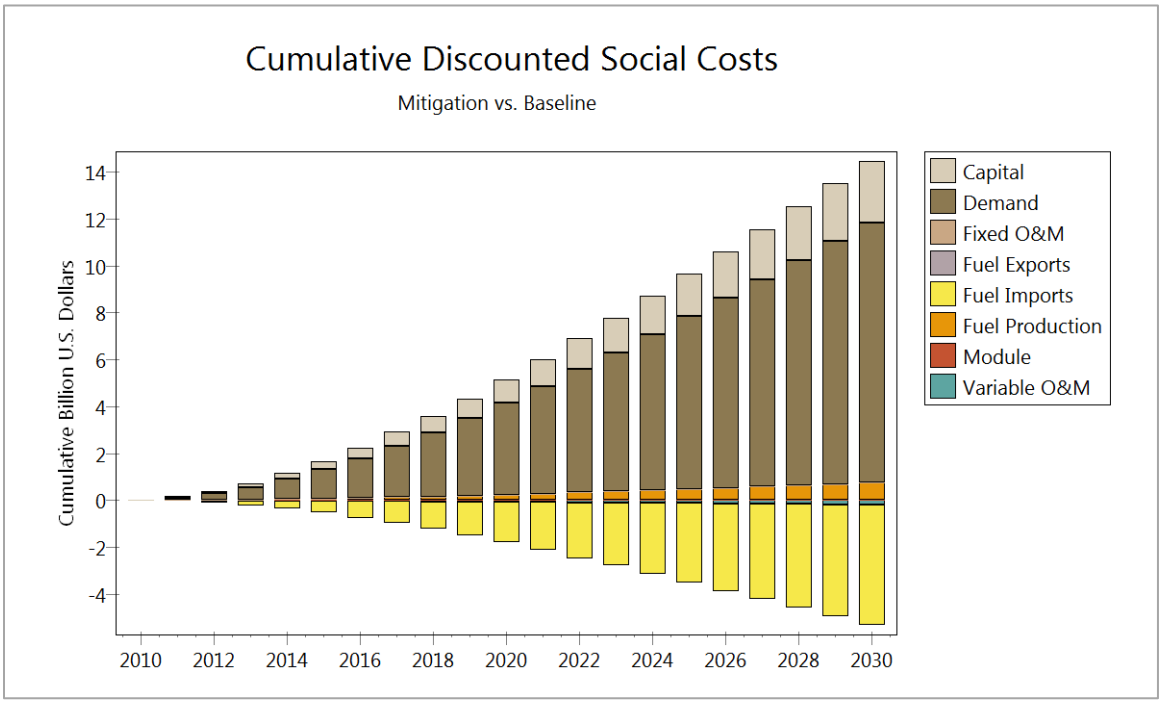
Finally, you should check that there are sufficient base year reserves of coal and natural gas available so that LEAP does not resort to importing these fuels. You can simply enter a very large number (e.g. 1 trillion GJ for each fuel) under the primary resources branch.

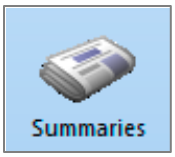
6.5 Viewing Results

You should now be ready to view some results. Click the results view and after LEAP has calculated review the overall cost results for the mitigation scenario minus the baseline scenario. Select a chart configured to show the following:

- Cost results for the whole area.
- Differences between the mitigation and baseline scenarios.
- Cumulative discounted costs
- X axis showing years, Legend showing cost categories.

You should see a chart like this:





You can also review a cost-benefit summary in the summaries view. It should look like the one shown on the right. Notice that the Net Present Value of the Mitigation scenario vs. the Baseline scenario is a cost of about 6.4 Billion US$.

Cumulative Costs and Benefits: 2010-2030. Compared to Scenario: Baseline.

Billion 2005 U.S. Dollar. Discounted at 5.0% to year 2010.

Costs	Mitigation
Demand	
Residential	0.4
Industry	0.4
Transport	10.3
Transformation	
Transmission and Distribution	0.0
Electricity Generation	7.1
Resources	
Production	0.7
Imports	-5.2
Exports	0.0
Unmet Requirements	0.0
Environmental Externalities	0.0
Net Present Value	13.8
GHG Savings (Mill. Tonnes CO2 Eq.)	664.6
Cost of Avoided CO2 (U.S. Dollar/Tonne CO2 Eq.)	20.8

Why are there positive costs for the demand and Transformation sectors but negative costs for Resources?

What are the main contributors to the high costs of the mitigation scenario?

AILEG Vietnam-LEDS and Marginal Abatement Cost Curve (MACC) of Rice and Livestock Production

Dr. Marcia Gowen Trump (Abt Associates)

USAID University Economics and Planning for Global Climate Change Mitigation Course

May 19, 2014

Learning Objectives

Understand:

- Key Definitions
- Background/Challenges
  - Vietnam's agriculture (ag.) sector emissions
  - Vietnam's CC policies
- Solutions: Ag. mitigation options
- MACC Methodology Used
  - Rice production survey
  - Modeling emissions
  - MACC/Net costs per option
- Participant MACC Exercises
  - Sensitivity analyses
  - Recommendations

Key Definitions (I)

- **Low Emission Development Strategies (LEDS)**
  - Country-driven, analytically rigorous low emission development strategies (LEDS)
  - Enables countries to transition to low carbon economic development
  - Sustained growth in employment and investment
  - Increased financial flows through carbon markets
  - Reduced greenhouse gas (GHG) emissions
  - Other social, economic, and environmental benefits.
  - http://en.openei.org/wiki/Gateway:Low_Emission_Development_Strategies

Key Definitions (II)

- **Activity Data:** Production values (e.g., tons rice/yr) of a commodity or good that emits greenhouse gasses (GHG)
- **[GHG] Emissions Factors**: the amount of GHGs emitted per ton of a good (e.g., $tCO_{2\text{-}eq}$/t rice)
- **Methane:** This GHG has 21 times the Global Warming Potential (GWP) of carbon dioxide (IPCC) http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html
- https://unfccc.int/ghg_data/items/3825.php
- **Units:**
  - $MMTCO_2$-Eq/yr = Million metric tons of carbon dioxide equivalents per year

Challenge: Agriculture GHG Emissions in Vietnam

Projected GHG emissions in Viet Nam (MMTCO$_2$-Eq/yr)

Sector	2010	2020	2030
Energy	113.1	251.0	470.8
LULUCF	-9.7	-20.1	-27.9
Agriculture**	**65.8**	**69.5**	**72.9**
TOTAL	169.2	300.4	515.8

Vietnam Environment and Sustainable Development Institute. 2012. Hanoi, Vietnam.
http://www.vesdi.org.vn/en/1700002/climate-change.html

** Government of Vietnam (GVN) does not:

- Collect rice cultivation data by variety & management type
- Does not have country-specific GHG emission factors for rice practices

LEDS Challenges in Vietnam

- Not much LEDS modeling and analysis outside of the energy sector (e.g. waste, agriculture)
- Unclear ministerial roles and uncertain legal mandates for data collection. Existing National Statistical Indicator System incomplete for LEDS
- Lack of country-specific emission factors (e.g. rice cultivation)

Vietnam’s Climate Change Policies

- **Green Growth Strategy**
  - 2013 national initiative to promote green or environmentally and economically sustainably policies and development in Vietnam
- **20-20-20 Strategy**
  - Ministry of Agriculture and Rural Development (MARD)
  - Reduce carbon emissions by 20% from the agriculture sector
  - Reducing poverty by 20 percent
  - Increase agriculture gross domestic product by 20 percent
  - All by 2020

AILEG Development of MACC Of Low-Emission Rice Cultivation

GHG Mitigation Options in Rice Production: Alter Rice Variety and/or Cultivation Method

1. Low fertilizer use (nitrogen primary GHG)
2. Short-duration rice variety
3. Water management (irrigation)
   - Alternate wetting or drying irrigation (AWDI) (drain paddy during growing season)
   - System of Rice Intensification (SRI) (incl. AWD)
4. Improved crop residue management

GHG Mitigation Option for Reducing Methane from Livestock Wastes

- **Mitigation Solution: Electricity Production from Livestock Wastes**
  - AILEG – larger village system biogasifiers
  - SNV – small farm level gasifiers

- **AILEG Cost-Benefit Analysis of Using Livestock Wastes for Electricity Generation**

AILEG LEDS Agricultural Support

- **AILEG Rice Production Mitigation MACC**
  - Assist GVN to get better sector data and know mitigation options
  - Help MARD to identify and monitor mitigation actions (20-20-20 plan)
  - Expand GSO's ability to support Green Growth Strategy
  - Be practical to implement
  - Integrate into existing GSO surveys

- **AILEG Livestock Wastes-to-Energy CBA Analysis**
  - Bloomberg New Energy Finance CBA analysis using livestock wastes to generate electricity

Data Collection: AILEG LEDS Agricultural Survey

- **Focus:** Survey rice and livestock management practices in three provinces of Vietnam, added questions to national farm surveys (households, gender)
- **Outputs:**
  - Survey recommendations
  - Report with results and recommendations including marginal abatement cost curve analyses
  - Initial presentation at AILEG Culminating Agricultural Workshop in July 2013

Local Counterparts: *General Statistics Office (GSO), Ministry of Planning and Investment (MPI), Ministry of Agriculture and Rural Development (MARD), District Statistics Office (DSOs, T&C Consulting (local survey firm)*

MACC Data Needs

1. GHG Emissions =

$$\Sigma_Z \left(\text{Activity}_Z \text{ X Emissions Factor}_z\right)$$

2. Average Cost per Emissions Reduction$_z$

$$= \frac{\text{Cost of Mitigation Option}_z}{\text{Emissions Reduction}_z}$$

Where:

Z = Mitigation option Z

Exercise 1A: What are the MACC data collection needs?

- **ACTIVITY DATA:**
  - **Alternative Rice Variety and Cultivation Practices – how much is being produced by variety and cultivation practice?**
  - What are the critical data needs to collect in a farm household rice cultivation survey?
  - Who do you work with to collect the data?
  - How can you Institutionalize survey changes?

Exercise 1B: What are the MACC data collection needs?

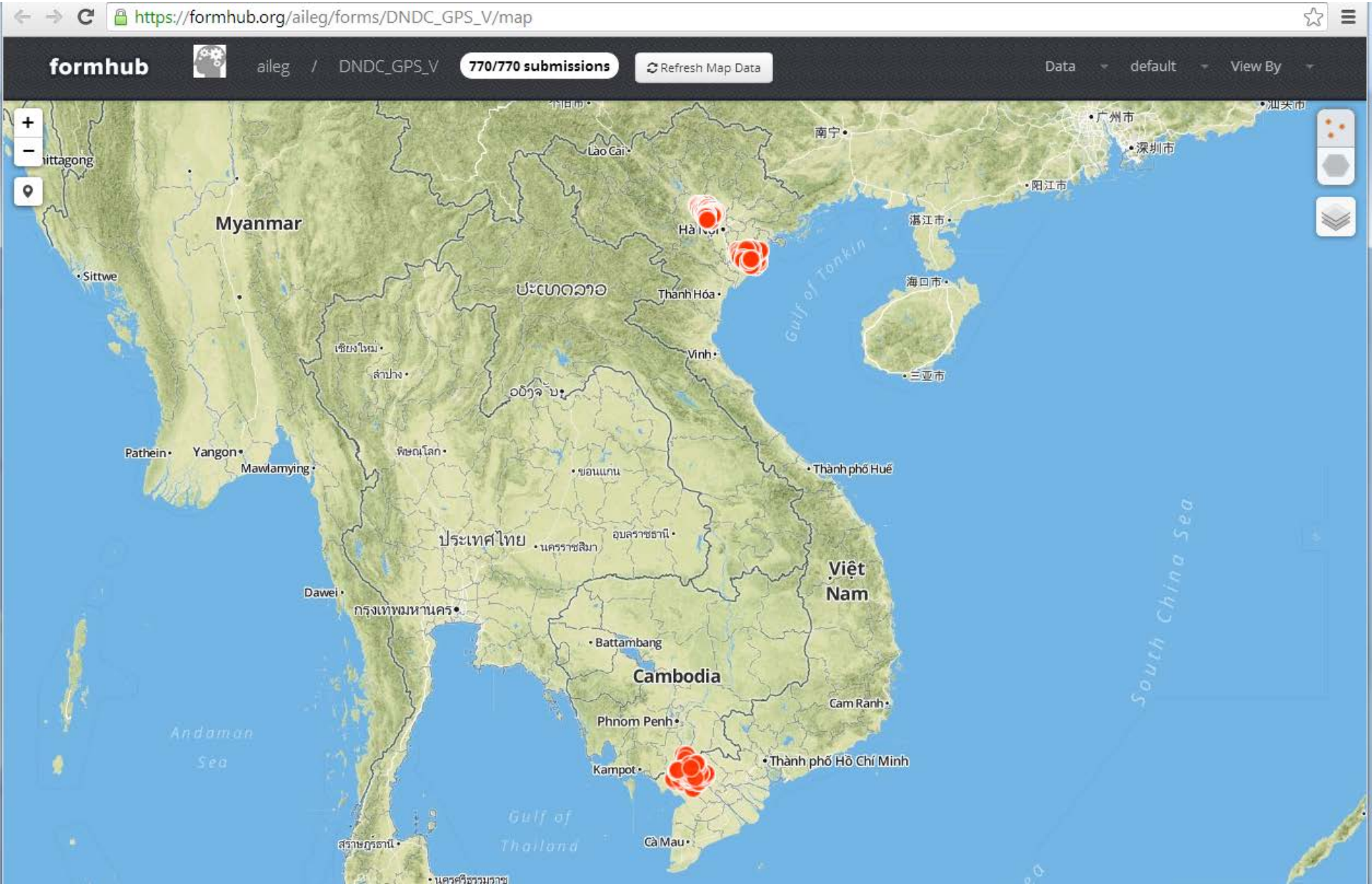
- **EMISSION FACTORS:**
  - What is an Monitoring, reporting and verification (MRV) Rice emissions Protocol?
  - How do you expect methane emission factors to vary by rice variety and cultivation practices?

- **NET COSTS OF ALTERNATIVE PRACTICES**?
  - What is the comparison scenario? How do you determine it?
  - How do you collect this information?

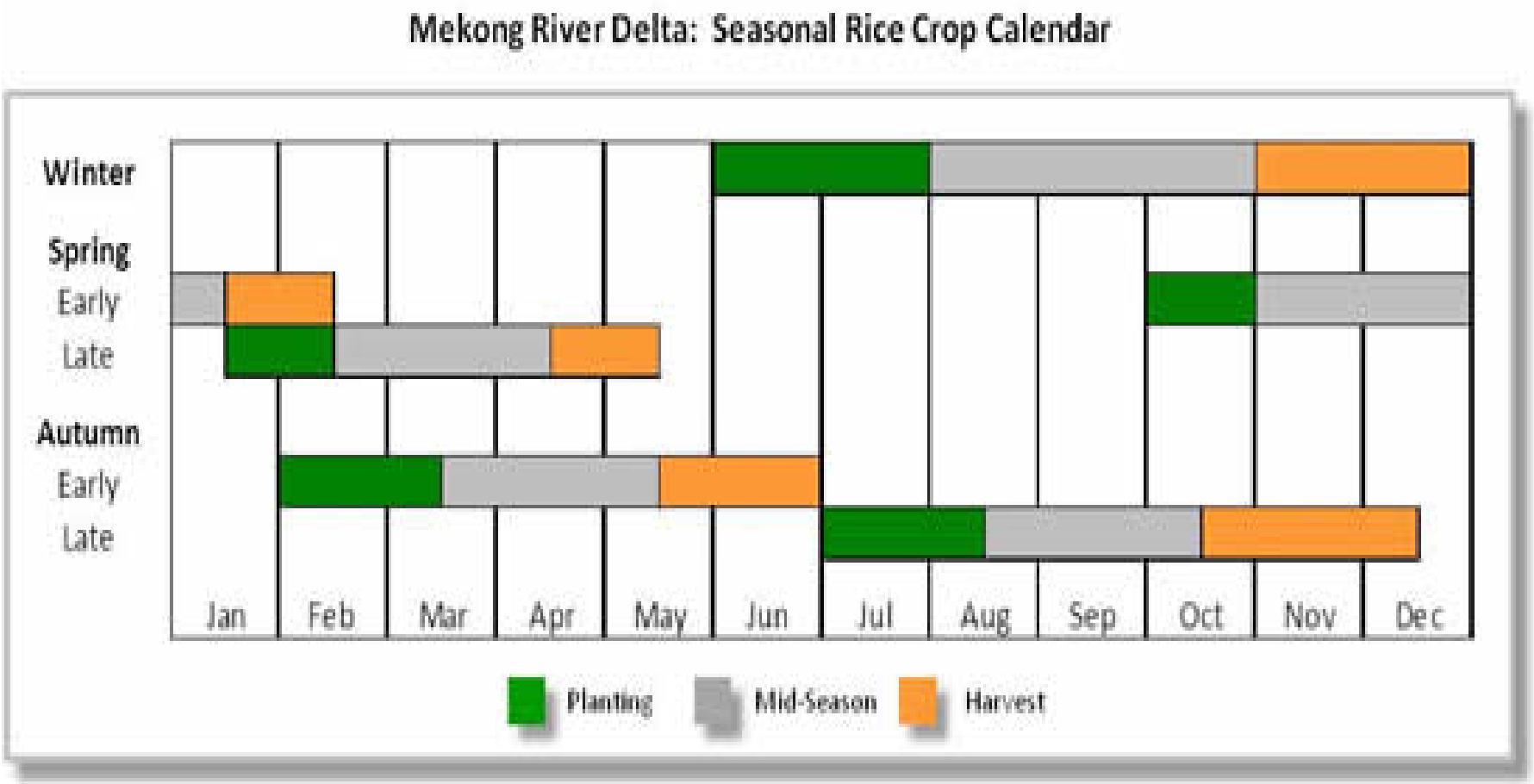
AILEG Rice/Livestock Survey Methodology

- Review gaps General Statistics Office (GSO) surveys
- 1,040 households surveyed (Thai Binh, Vinh Phuc, An Giang Provinces):
- 3 plots for each farmer (low, medium, high)
- Mobile phones used for geo-coding, basic data and rice plot images for rice model calibration
- Collected data on labor, input cost and production (MACCs)

Survey Locations



Rice Production in Vietnam



Source: Ministry of Agriculture & Rural Development (MARD), Vietnam 2010

Results Rice Emissions: Innovation with AILEG Rice Emissions MRV Tool

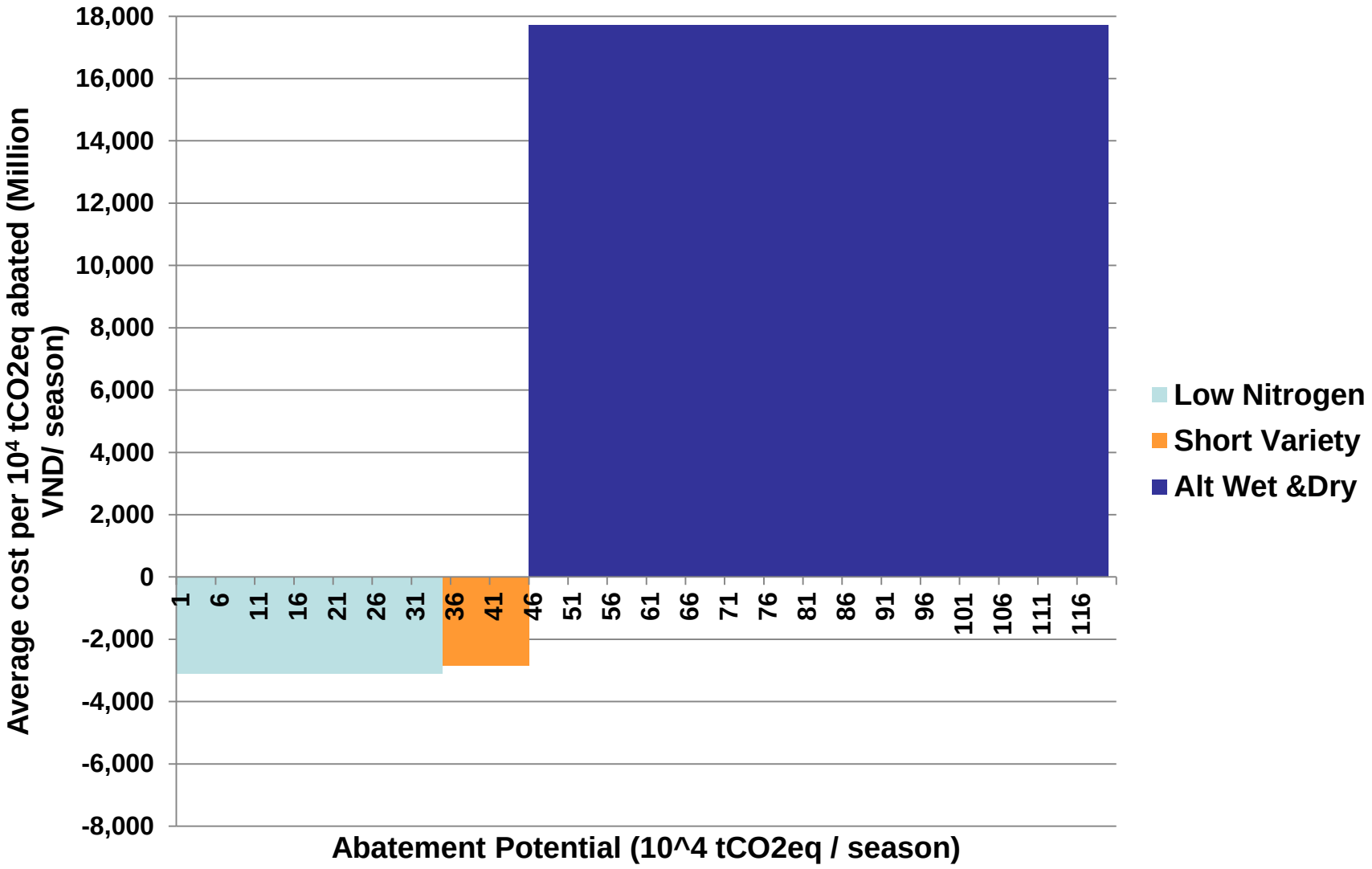
- **Focus:** Monitoring, Reporting and Verification Tool – determines the GHG emission factor for different rice varieties in Vietnam by combining remote sensing, spatial datasets, rice emissions model (DNDC)
- **Potential Use:**
  - National reporting on GHG emissions
  - Explore emissions trajectories for policymaking
  - Monitor the goals of Vietnam's Green Growth Strategy
- **Outputs:**
  - **Total GHG emissions by rice cultivation/variety practices**
  - Publicly-available tool provided to GVN by AILEG

Counterpart: Institute for Agricultural Environment (IAE, MARD)

Results: Net Costs by Rice Variety and Cultivation Practice

Net Incremental Cost Under Different Mitigation Options ('000VND/ha)				
Mitigation Options	South		North	
	Spring 2012	Fall 2012	Winter 2012	Spring 2012
Low Fertilizer	1,565	932	-1,725	-2,938
Short Duration Variety	387	342	-1,198	-2,533
AWD	15,534	8,116	15,804	9,867

Marginal Abatement Cost Curve of Rice GHG Mitigation Options in Vietnam



Results: % Area under Rice Mitigation Options

PERCENTAGE AREA UNDER COMBINATIONS OF MITIGATION OPTIONS

Mitigation Options	South		North					
			Winter 2012			Spring 2012		
	Spring 2012	Fall 2012	Overall	SRI/SRI	Non-SRI/SRI	Overall	SRI/SRI	Non-SRI/SRI
Low Fertilizer, Short Duration	9%	10%	23%	27%	13%	27%	25%	17%
	(0.03)	(0.03)	(0.04)	(0.06)	(0.06)	(0.04)	(0.06)	(0.06)
Low Fertilizer, AWD	2%	4%	0%	0%	0%	1%	0%	0%
	(0.01)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Short Duration, AWD	8%	15%	1%	0%	0%	1%	0%	0%
	(0.04)	(0.05)	(0.01)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)
Low Fertilizer, Short Duration, AWD	1%	2%	0%	0%	0%	1%	0%	0%
	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
No Mitigation	26%	24%	28%	6%	11%	15%	2%	8%
	(0.08)	(0.07)	(0.07)	(0.03)	(0.06)	(0.05)	(0.01)	(0.05)

Exercise 2. Interpretation of Results

- What does the graph tell you?
- Why are option costs positive vs. negative?
- What should the GVN do to promote low emission rice production?

AILEG Recommendations

Data Element	Frequency	AILEG Survey Elements	Existing General Statistics Office (GSO) Survey to Supplement	Sampling
Activity Data	Every Season	All elements in the AILEG survey not tagged as specific to emissions factor or MACC need to be included (see Appendix I)	Add questions to the existing season-specific survey – the "Rice Production and Productivity Survey" to create an extended survey.	Extended end-of-season survey can be implemented for a smaller sample of farmers such that the data representative only at the province level, or potentially even at regional level.
MACC –Cost Elements	Every second year, or potentially every 5 years with the census.	All elements in the AILEG survey tagged as "for MACC".	Add questions to "Agriculture and Fisheries Census - Rice Production Efficiency Questionnaire (Form No: 7A/ĐTHQ)". Include all questions for activity data.	Implement the extended survey for a smaller sample of farmers such that the data are representative only at the province level, or potentially even at the regional level.
Emissions Factor	Every 5 years, with the census.	Full AILEG survey.	Add questions to "Agriculture and Fisheries Census - Rice Production Efficiency Questionnaire (Form No: 7A/ĐTHQ)", Include all questions for activity data.	

AILEG Livestock Wastes to Electricity Analysis

Livestock Methane Capture for Electricity Generation

- **Focus:** Analysis of the viability of large-scale livestock methane capture for electricity production in Vietnam (Bloomberg New Energy Finance)
- **Major Results:**
  - Household scale bio-digesters already important for heating and cooking (SNV technical assistance on-going)
  - Large-scale village bio-digesters has huge potential for electricity generation (3,000 MW in 2020).
  - Capital-intensive (~$2.2M/MW)
  - LCOE higher than current wholesale electricity price. Financing needed, but CDM may not be answer (low carbon price)
  - But important co-benefits – health, employment

Survey Results: Awareness of Livestock Mitigation Options

Potential Mitigation Technology	Growers of the Animal Species		
	Cattle	Swine	Poultry
Use of molasses urea blocks			
Percentage of households/farmers who know about it, of those	13.01	14.30	9.39
	(3.82)	(4.43)	(2.88)
Percentage of households/farmers who use it	0	0	0
Use of highly digestible feed			
Percentage of households/farmers who know about it, of those	58.12	61.04	52.27
	(5.21)	(4.89)	(4.16)
Percentage of households/farmers who use it	94.27	92.79	96.99
	(3.20)	(3.49)	(1.53)
Use of solid manure management system			
Percentage of households/farmers who know about it, of those	56.12	46.60	48.30
	(4.88)	(2.99)	(3.56)
Percentage of households/farmers who use it	89.25	82.59	92.27
	(4.13)	(7.46)	(2.37)
Use of biodigesters for manure management			
Percentage of households/farmers who know about it, of those	69.72	74.64	67.12
	(4.54)	(4.01)	(4.77)
Percentage of households/farmers who use it	85.64	89.61	85.14
	(3.91)	(3.20)	(3.44)
Use of manure composting			
Percentage of households/farmers who know about it, of those	12.48	11.78	10.21
	(3.57)	(3.21)	(3.01)
Percentage of households/farmers who use it	36.14	38.53	42.85
	(10.66)	(13.88)	(9.89)

Exercise 3: Your MACC Conclusions and Recommendations

- What about subsidizing large bio-digesters?
- What would you recommend to GVN to achieve 20-20-20 strategy?
- What are the next steps?

AILEG Vietnam LEDS Recommendations

1. GSO adopts rice and livestock questionnaires in existing surveys and recommendations on sampling procedures
2. Rice emissions Monitoring, Reporting and Verification tool expanded to more provinces (donor support needed)
3. Inter-ministerial working group on LEDS data

References

- Narayan, Tulika. Anna Belova, and Michael Westphal. October 2013. Vietnam Data Collection to Support LEDS for the Agriculture Sector. USAID AILEG Project. Washington, D.C.
- Openei. Low emission development strategies. See: http://en.openei.org/wiki/Gateway:Low_Emission_Development_Strategies
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USAID AILEG Project on Greenhouse Gas (GHG) Marginal Abatement Cost Curve (MACC) for Energy Efficiency Options in Colombia and Philippines

Dr. Marcia Gowen Trump (Abt Associates)

USAID University Economics and Planning for Global Climate Change Mitigation Course

May 1, 2014

Learning Objectives

Understand:

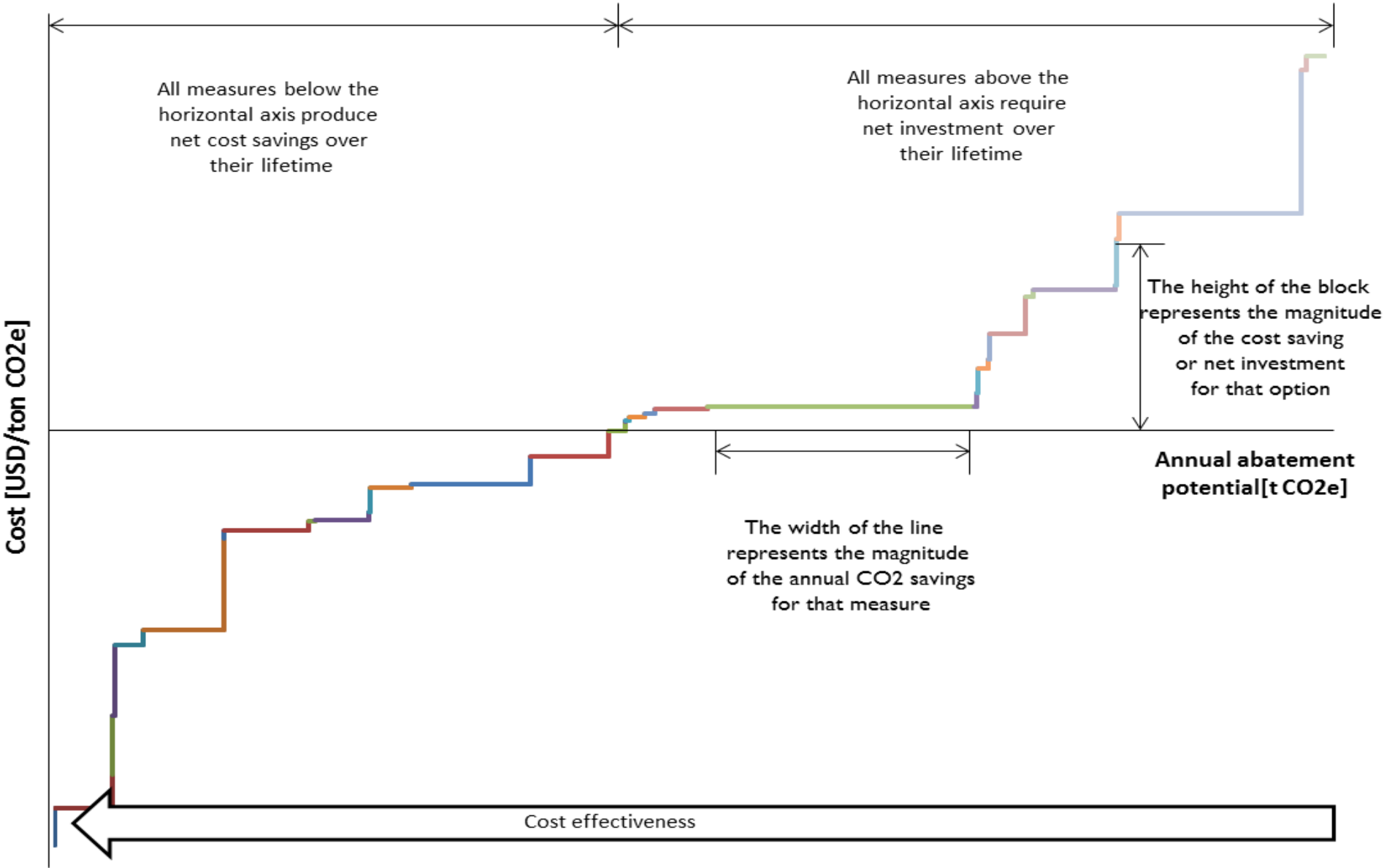
- Key Definitions (moved to country analyses)
- Looking inside the MACC Process
- Background/Challenges of MACC
- Country Analyses
  - Data Collection
  - Modeling issues and solutions
  - MACC/Net costs per EE option
- Participant MACC Exercises
  - Data/methodology
  - Recommendations

Looking Inside the GHG MACC Process

Review of AILEG Project GHG MACC Goals

- **MACCs highlight the net costs per emission reduction of greenhouse gases (GHG) for climate change mitigation measures that:**
  - Can produce net cost savings over the project lifetime (“win-win” options)
  - Have higher abatement potentials
  - Are more cost-effective than alternatives
  - Need to be assessed within a broader decision making framework

Basics: GHG MACC Development and Analysis



Steps to Build Bottom-Up GHG MACCs

1. **BASELINE:** Develop GHG emissions baselines for commercial sector, considering base year (2010) energy consumption data and to forecasts (2040)

2. **MITIGATION OPTIONS:** Select group of GHG emissions reduction measures

3. **EMISSIONS REDUCTION POTENTIAL BY OPTION:** Estimate emissions abatement potential and implementation costs associated with each measure

4. **COSTS OF MITIGATION PER OPTION:** Apply adoption rates to the measures and convert costs to NPV

5. **PREPARE MACCS:** Formulate MACCs

6. **ANALYZE AND RECOMMEND:** Analyze co-benefits and make recommendations

AILEG GHG Marginal Abatement Cost Curve of Commercial Building Energy Efficiency Options

Colombia

Universidad de los Andes
Facultad de Ingeniería

Key Definitions (I)

- **Energy Efficiency:**
  - Products or systems using less energy to do the same or better job than conventional products
  - Helps reduce greenhouse gas emissions (GHGs) and protect the environment
  - Energy emissions are major global GHG contributor (75%) http://www.epa.gov/greenpower/pubs/glossary.htm#e
- **Baselines: Business as Usual (BAU) Scenario**
  - Projected GHGs emissions over a time period without or in the absence of a low-emissions development strategy
  - http://en.openei.org/wiki/Stage_3a:_Developing_BAU_Scenario

Challenge: Colombia's LEDS and GHG MACCs

- **Problem: Incomplete MACCs of Colombia's GHG Mitigation Options**
  - Ministry of Environment and Sustainable Development of GHG MACC curves covered only 4 sectors with World Bank support
  - Lacked analysis of energy efficiency options for the commercial building sector
- **Solution:**
  - AILEG supported the development of a Commercial Building Sector EE Options Marginal Abatement Cost Curve (MACC)
  - Collaborated with University of Los Andes Engineering School, which is managing all MACC analysis in Colombia

Exercise 1: What data do you collect?

- How do you calculate the BAU scenario?
- What EE commercial building mitigation options do you consider? Where?
- How do you collect cost data?

AILEG GHG MACC Development for Commercial Buildings in Colombia

- Illustrate GHG reduction measures for three Colombian cities in different climate zones
- Show GHG mitigation opportunities in the commercial building sector in Colombia (hotels, hospitals, shopping malls, and office buildings)
- Demonstrate many GHG reduction measures can save money while reducing emissions
- Present recommendations for policies that can reduce GHG emissions between 2010 to 2040

Data Collection: BAU Baseline Development for Commercial Building EE Options MACC

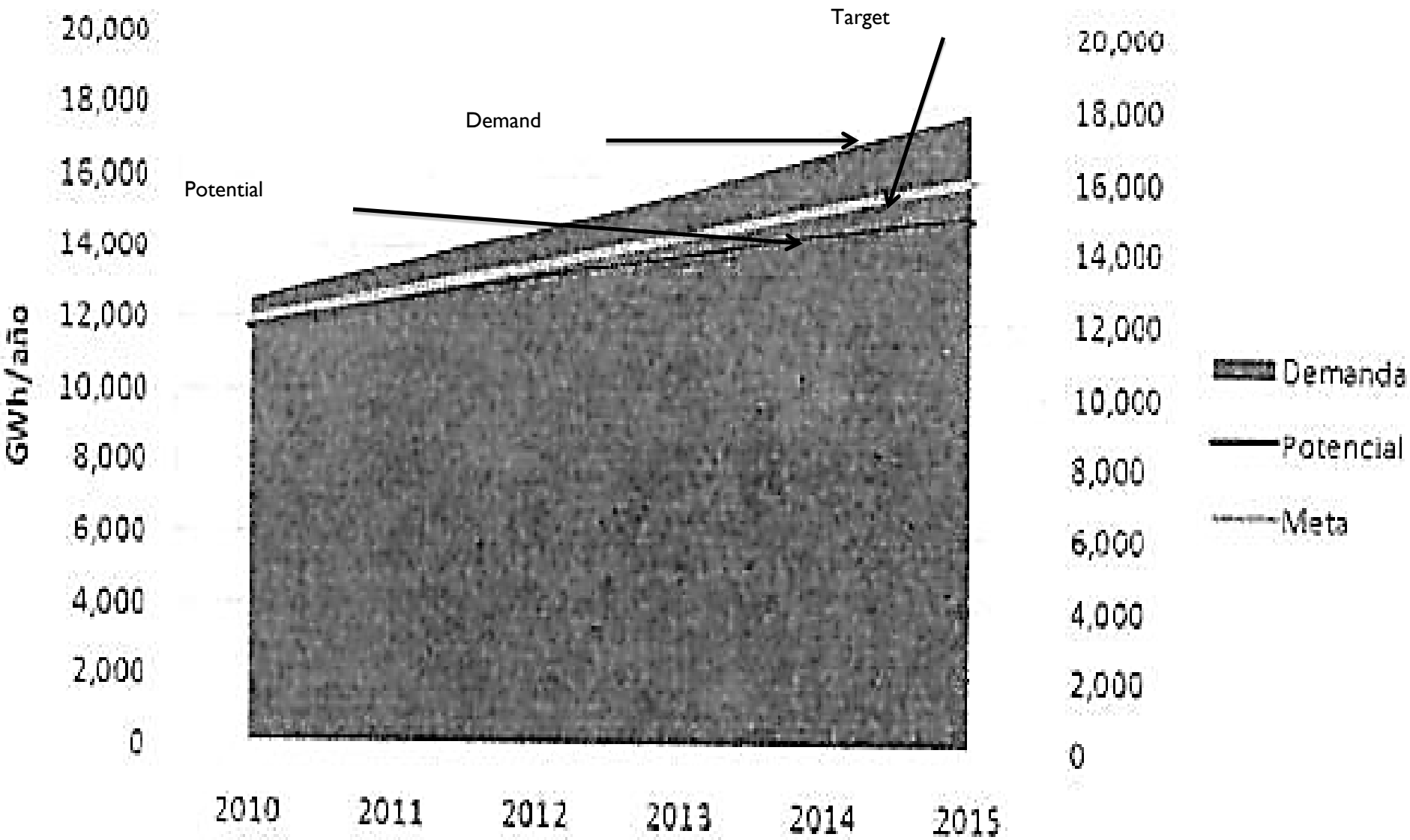
- The first step in MAC curve is to
  - prepare the Business as Usual (BAU) GHG emission baselines
  - BAU based on current energy use of traditional (not efficient or low carbon) technologies

- Methodological approaches used:
  - Bottom-up (surveys)
  - Top-down
  - Discrepancies between reconciled in study

Data Collection: BAU Baseline Development Approaches

- **Micro-level analysis**
  - Survey of EE options by cities: UDLA conducted in-depth building surveys
  - Sub-sector commercial building “prototype” in the three cities
  - baselines are the emissions of conventional technologies (without mitigation technology) for building sub-sectors
- **Top-down or macro-level analysis**
  - GHG baseline estimation) based on historic “macro-level” energy use by the building prototypes in these cities
  - Used national energy balances
  - Percentage distribution of energy consumed in a city by users by sub-sectors

Step 1: AILEG Colombia MACC BAU Scenario



Step 2: EE Commercial Building Data Surveys

Bogotá

Medellín

Baranquilla

- **Shopping Malls**
- **Office Buildings**
- **Hospitals**
- **Hotels**

EE Commercial Building Mitigation Options

	Measures	Bogotá				Medellín				Baranquilla			
		Shopping Centers	Offices	Hospitals	Hotels	Shopping Centers	Offices	Hospitals	Hotels	Shopping Centers	Offices	Hospitals	Hotels
1	Roof insulation	X	X	X	X	X	X	X	X	X	X	X	X
2	Facade insulation	X	X	X	X	X	X	X	X	X	X	X	X
3	Single-layer glass	X	X	X	X	X	X	X	X	X	X	X	X
4	Double-layer glass	X	X	X	X	X	X	X	X	X	X	X	X
5	Tinted double-layer glass	X	X	X	X	X	X	X	X	X	X	X	X
6	Sunbreaks	X	X	X	X	X	X	X	X	X	X	X	X
7	Building orientation	X	X	X	X	X	X	X	X	X	X	X	X
8	Lighting efficiency	X	X	X	X	X	X	X	X	X	X	X	X
9	Light dimming	X	X	X	X	X	X	X	X	X	X	X	X
10	Lighting automation	X	X	X	X	X	X	X	X	X	X	X	X
11	HVAC premium	X	X	X	X	X	X	X	X	X	X	X	X
12	HVAC energy savers	X	X	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
13	AC occupancy	X	X	X	X	X	X	NO	X	X	X	X	X
14	Infrastructure improvements	X	X	X	X	X	X	X	X	X	X	X	X
15	Efficient cooling	X	NO	X	X	X	NO	X	X	X	NO	X	X
16	Efficient cooking	X	NO	X	X	X	NO	X	X	X	NO	X	X

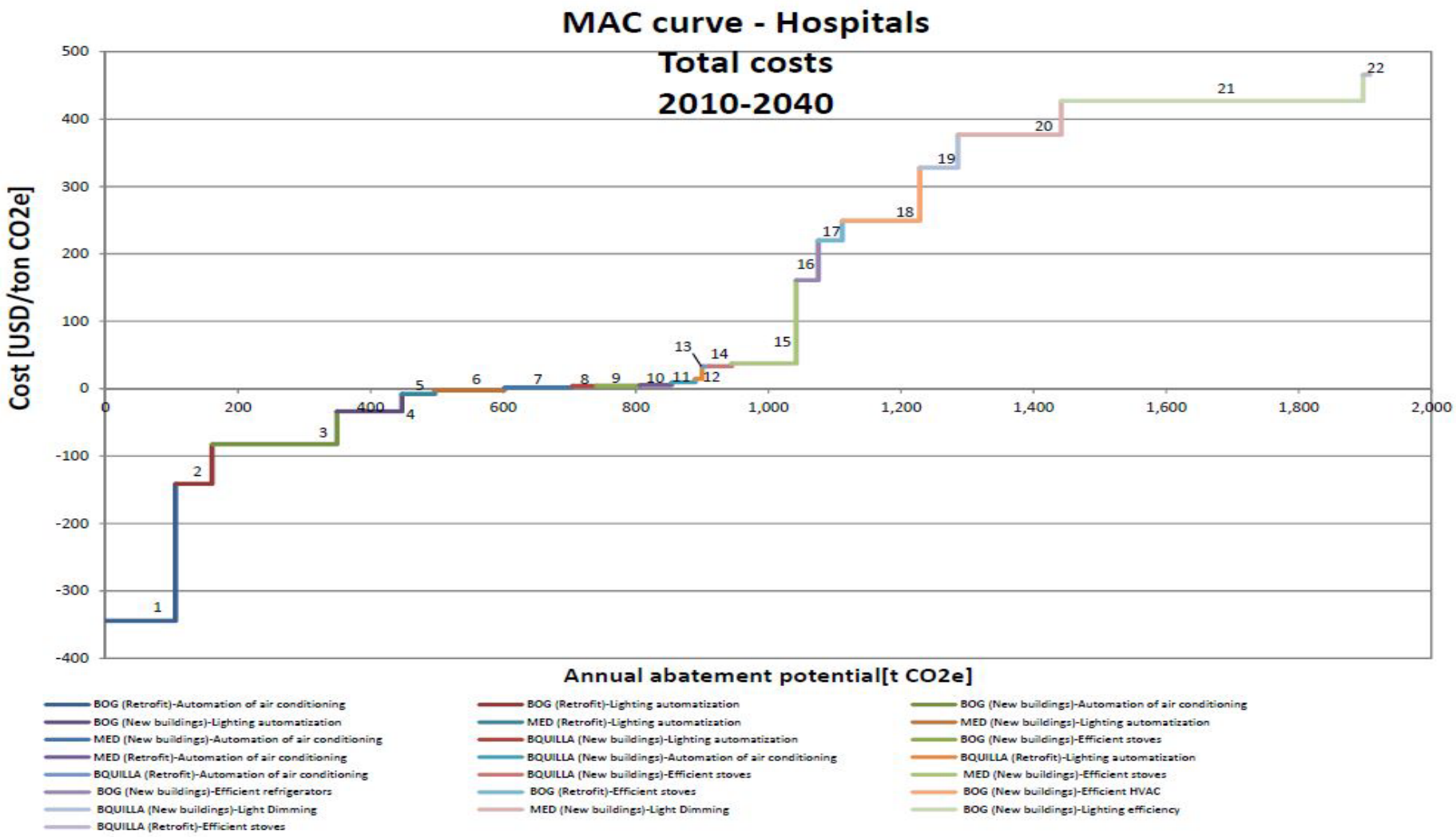
Current Mitigation Option Use in Cities

City	Existing Buildings			New Buildings			Buildings Built During the Study Period Since 2010
	Short-Term	Medium-Term	Long-Term	Short-Term	Medium-Term	Long-Term	
Bogotá	20%	30%	40%	50%	70%	100%	82%
Medellín	20%	30%	40%	50%	70%	100%	68%
Baranquilla	20%	30%	40%	50%	70%	100%	97%

Steps 3 & 4: Emission Reductions by Costs (Hospitals)

No.	Mitigation Measure	Annual Potential (Tons CO_2e)	Cost ($/ton CO_2e)
1	Bogotá (Retrofit) Automation of air conditioning	105.72	-344.36
3	Bogotá (New buildings) Automation of air conditioning	188.21	-82.19
4	Bogotá (New buildings) Automated lighting	98.28	-33.61
5	Medellín (Retrofit) Automated lighting	49.55	-7.81
6	Medellín (New buildings) Automated lighting	104.91	-2.26
7	Medellín (New buildings) Automation of air conditioning	102.46	1.57
9	Bogotá (New buildings) Efficient stoves	64.69	4.38
15	Medellín (New buildings) Efficient stoves	97.41	37.33
18	Bogotá (New buildings) Efficient HVAC	116.65	249.34
19	Baranquilla (New buildings) Light dimming	57.66	328.00
20	Medellín (New buildings) Light dimming	155.85	376.87
21	Bogotá (New buildings) Lighting efficiency	455.27	427.07

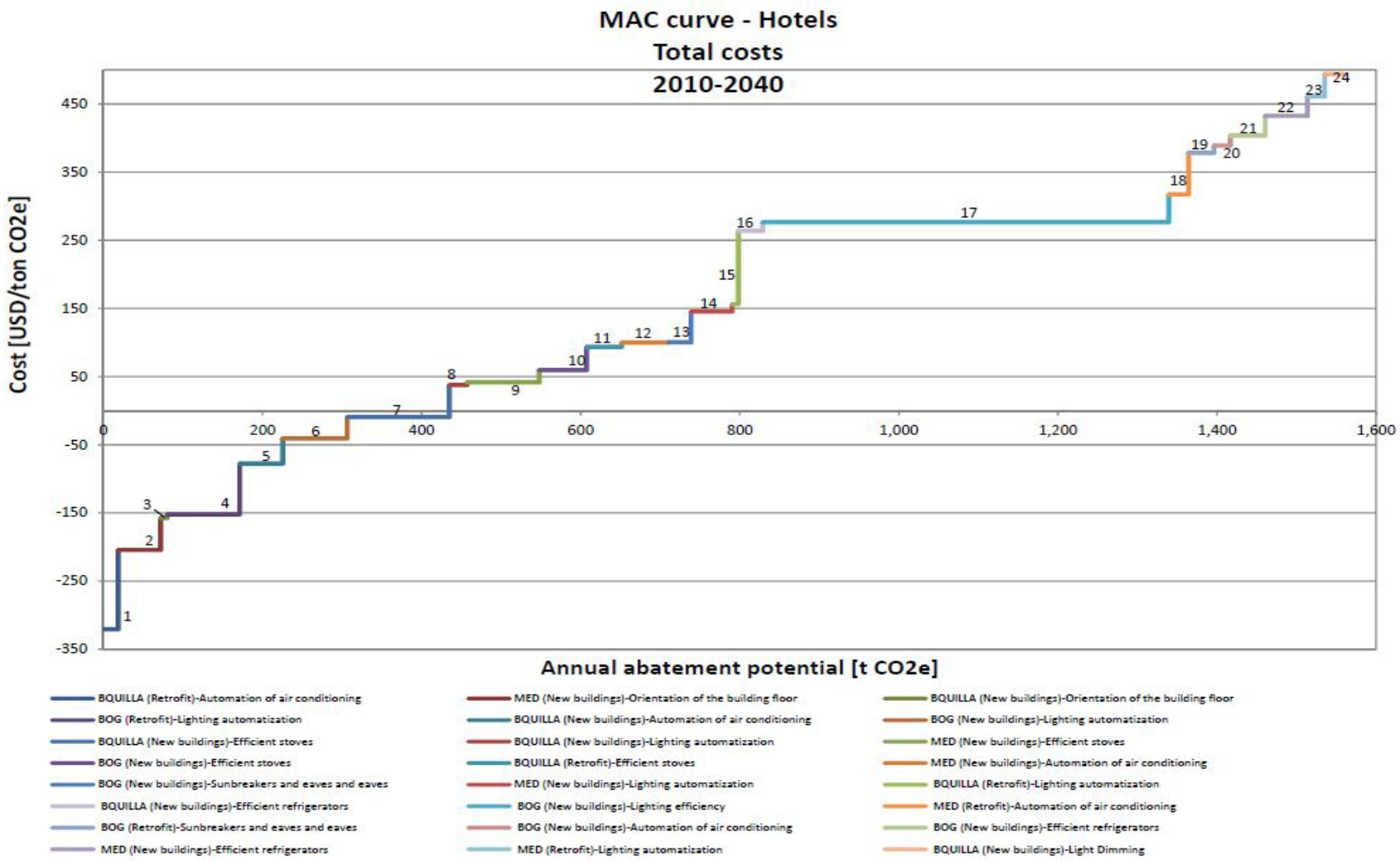
AILEG Results: GHG MACC for Hospital Energy Efficiency Options in Colombia



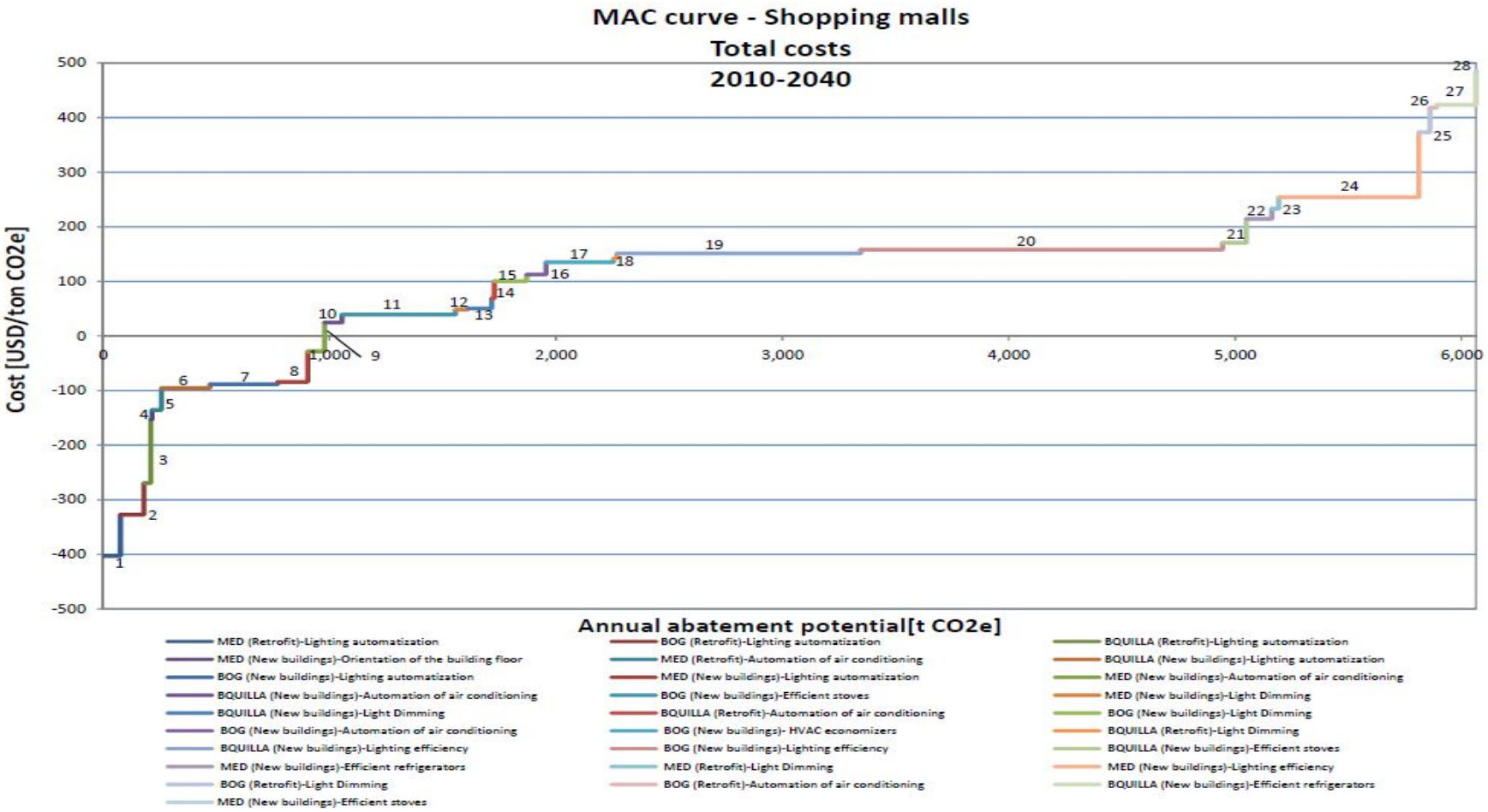
MACC Input Information for Hotels (Including Total Implementation Costs)

No.	Mitigation Measure	Annual Potential (Tons CO_2e)	Cost ($/ton CO_2e)
1	Baranquilla (Retrofit) HVAC automation	18.60	-320.57
4	Bogotá (Retrofit) Automated lighting	90.90	-152.29
5	Baranquilla (New buildings) HVAC automation	54.21	-77.54
6	Bogotá (New buildings) Automated lighting	81.18	-40.47
7	Baranquilla (New buildings) Efficient stoves	128.33	-9.24
9	Medellín (New buildings) Efficient stoves	90.73	41.79
10	Bogotá (New buildings) Efficient stoves	59.60	59.64
12	Medellín (New buildings) HVAC automation	59.16	100.02
14	Medellín (New buildings) Automated lighting	51.50	145.27
17	Bogotá (New buildings) Lighting efficiency	510.57	276.67
18	Medellín (Retrofit) HVAC automation	24.87	317.40
19	Bogotá (Retrofit) Sunbreaks and eaves	31.80	378.29
21	Bogotá (New buildings) Refrigeration efficiency	43.90	403.69
22	Medellín (New buildings) Refrigeration efficiency	53.02	432.54

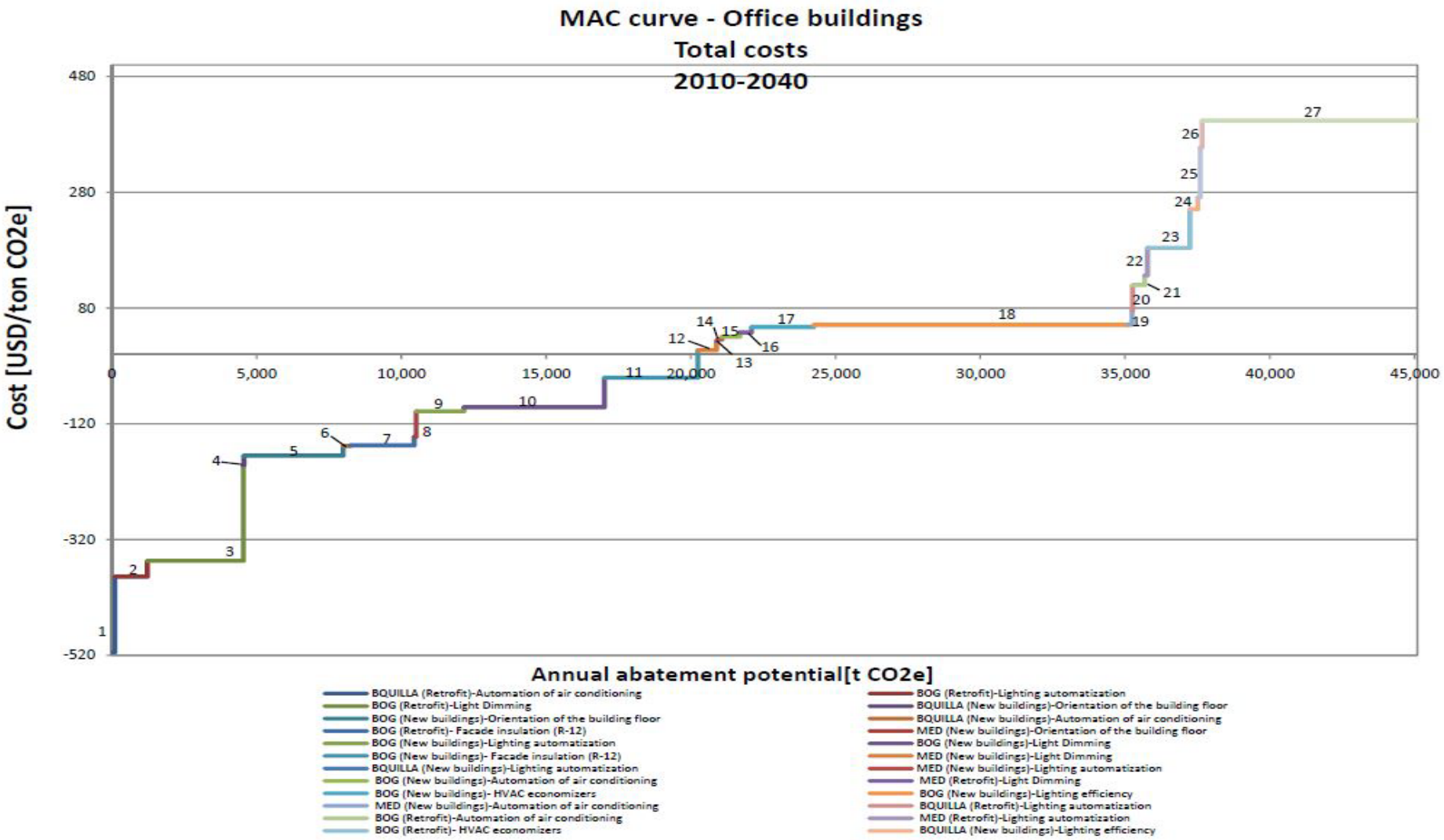
AILEG Results: GHG MACC for Hotel Energy Efficiency Options in Colombia



Step 5: AILEG Results: GHG MACC for Shopping Malls Energy Efficiency Options in Colombia



AILEG Results: GHG MACC for Office Buildings Energy Efficiency Options in Colombia



Exercise 2: Interpret GHG MACC Tables' Results

- What are the apparently least-cost options?
- What options have the most impact (GHG emission reductions)?
- What should mitigation options should the GoC promote through awareness campaigns, subsidies, or incentives?

Least-Cost High Impact Options

- **Shopping centers**
  - Lighting automation for new and existing buildings in cities
  - HVAC automation in Medellín and Barranquilla
- **Office buildings**
  - HVAC automation in Barranquilla
  - Lighting dimming and automation in Bogotá
  - Facade isolation in Bogotá
- **Hospitals**
  - HVAC automation in Bogotá and Medellín
  - Lighting automation in the three cities
  - Efficient stoves in the three cities
- **Hotels**
  - HVAC automation in Barranquilla
  - Lighting automation in Bogotá and Barranquilla
  - Efficient stoves in the three cities

GHG Emission Reduction Potential from Commercial EE Mitigation Options in Colombia

- Total potential for annual reductions in carbon emissions:
  - 6,000 tCO_2e/year in shopping centers
  - 45,000 tCO_2e /year in office buildings
  - 1,600 tCO_2e /year in hotels
  - 2,000 tCO_2e /year in hospitals

AILEG Colombia Commercial Building EE Options for GHG MACC Recommendations

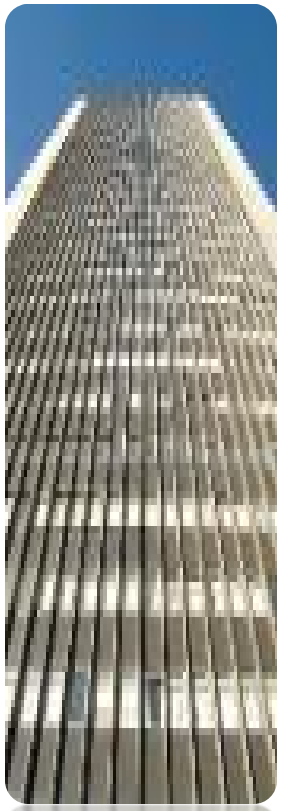
- **Lighting options** are most important mitigation measures in all subsectors—large abatement potential and negative net costs
- **Design-related measures** highest capital or operating costs per ton of carbon equivalent
- **Office building mitigation** largest in four subsectors (split incentives)
- **New construction** EE options have more GHG emission reduction impact.
- **Retro-fitting existing construction** lowest priority but important co-benefits.

AILEG Marginal Abatement Cost Curve of Demand-Side Management (DSM) Options

Philippines

Key Definitions (II)

- **Demand Side Management (DSM)**
  - The modification [lowering] of consumer demand for energy (electricity and thermal energy) through financial/economic incentives and education
- Types
  - Behavior modification (changing to CFL or LED lighting)
  - Use of more energy efficient technologies (Energy Star certified) are potential DSM mitigation options.
  - http://en.openei.org/wiki/Definition:Demand_Side_Management



Challenges: Philippines Energy DSM Issues

CONTEXT

- The Philippines has the most expensive electricity in Asia
- Electricity supply inadequate to meet growing demand which hampers economic development
- There is not enough investment to achieve the GPH's renewable energy goals or to help the GPH expand rural electricity access

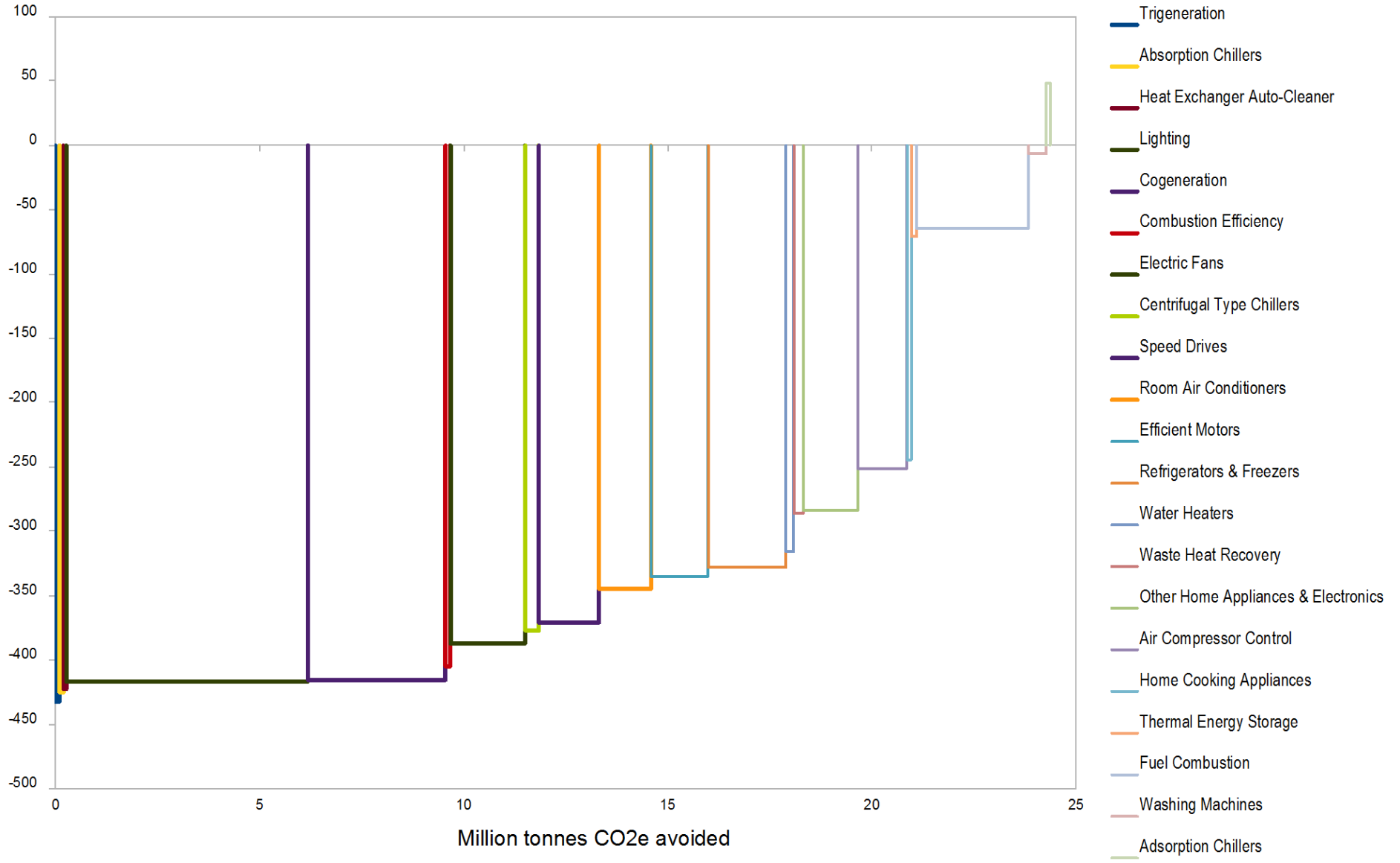
CHALLENGES

- Scarce expertise in using economic assessment models, particularly in the energy sector
- Data required for energy sector analyses is lacking and distributed in disjointed databases, with large % held by the private sector
- Many barriers to renewable energy investment, especially for small developers

AILEG Philippines DSM MACC Goals and Outputs

- **Goals and Outputs:**
  - Standard and efficient DSM technology data compiled
  - MACCs developed for 15 residential, 7 commercial and 11 industrial technologies
  - Over 30 people trained in MACCs
  - Evaluated issues hindering implementation of negative cost technologies and analyzed policy options*

Philippines DSM MACC Results



Exercise 3. Your Interpretation of Results

- What does the graph tell you?
- Why are option costs positive vs. negative?
- What should the government do to promote low emission DSM options?
- Next steps for planners?

AILEG Philippines DSM MACC Recommendations

- Build high-capability energy laboratory to support energy service company (ESCO) industry possible but low success rate around the world
- Focus on introducing DSM options into industrial sector
- Fastest emissions growth (cement, semiconductor, and food processing industries - 73%)
- **Output**
  - MOU signed by six Universities and Climate Change Commission to collaborate on LEDS data exchanges and baseline development

AILEG Colombia and Philippines Lessons Learned

- Baseline development spurs national growth and emissions dialogue
- Methodology for MACC net cost or economic assessment differs by institutional agency – standardize and consolidate the process across agencies/sectors
- “Low-Hanging Fruit” mitigation options face critical non-cost barriers
- MACCs are the start of a dialogue on action plans!

References

- University of Los Banos – National Energy Center. October 2013. AILEG Marginal Abatement Cost Curve Development for Demand-Side Management Mitigation Options in the Philippines. Prepared with Dana Kenney and Lindsay Kohlhoff (Abt Associates) for the USAID AILEG Project. Washington, D.C.
- Universidad de Los Andes. October 2013. Marginal Abatement Cost Curve Development for Buildings of the Commercial Sector in Colombia. Prepared with Abt Associates for USAID AILEG Project. Washington, D.C.
- EPA. 2014. http://www.epa.gov/greenpower/pubs/glossary.htm#e

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A Tool for Energy Planning and GHG Mitigation Assessment

Charlie Heaps

LEAP Developer and

Director, U.S. Center

SEI STOCKHOLM ENVIRONMENT INSTITUTE

Stockholm Environment Institute

- An independent international research organization conducting applied scientific research on the issue of sustainable development.
- HQ in Stockholm: Centers in the UK, US, Estonia, Thailand and Tanzania.
- 200 staff (25 in the U.S.).
- Interdisciplinary work: drawing upon engineering, economics, ecology, ethics, operations research, international relations, software design.
- Main research areas: climate mitigation and adaptation, climate finance and climate economics, energy policy, water resources planning, atmospheric pollution, sustainable futures.
- Funders include: Swedish, US and European governments, multilateral agencies, foundations, national & local governments.
- SEI's US Center is not-for-profit 501c3 research affiliate of Tufts University in Boston. Two other US offices in Seattle and Davis, CA. Apx. 30 staff in the US.
- www.sei-international.org and www.sei-us.org

What Do We Do?

- Develop and distribute LEAP at no charge to academic, non-profit and government organizations in the developing world.
- Training & capacity building activities all around the world.
  - In 2013 we conducted LEAP trainings in Albania, Argentina, Barbados, Germany, Greece, Mexico, Philippines, Thailand, Turkey, Kazakhstan
  - Support for trainings given by other organizations in places like Argentina, Indonesia, South Africa, Sweden, Thailand.
- Foster a community (COMMEND) for LEAP users and other sustainability practitioners. Now with > 21,000 members in 191 countries.
- Support LEAP users all around the world.
- Develop our own scenario studies (later slides)

A participant from NEPAL at a recent LEAP Training Workshop Explaining her energy demand analysis

SEI Support for LEDS

United Nations Framework Convention on Climate Change

Provided technical support to countries preparing National Communications to the UNFCCC. Developed the UNFCCC's training materials on GHG mitigation and conducted regional UNFCCC workshops in Asia, Latin America, the Caribbean and Africa.

National Communications Support Programme

SEI has provided technical support to the NCSP and run numerous NCSP regional training workshops over the last 10 years, teaching countries how to apply LEAP for Mitigation Assessments.

LOW EMISSION CAPACITY BUILDING PROGRAMME

Supported the UNDP LECB Program: by creating nationals-scale "starter" data sets for 22 countries, to help kick-start their LEDS analyses.

USAID LEAD LOW EMISSIONS ASIAN DEVELOPMENT PROGRAM

Supporting the USAID LEAD (Low Emissions Asian Development) and AILEG (Analysis and Investment for Low-Emission Growth) programs with LEAP trainings in Thailand, Indonesia and Philippines. Also B-LEADERS program in the Philippines in 2015.

MAPS Mitigation Action Plans & Scenarios

Supported by USAID, UNEP and others, SEI is helping the Mexican National Institute of Ecology and Climate Change (INECC) to update and strengthen its baseline and mitigation scenarios:.

A partner in EUROPEAID's CLIMACAP programs and assisting Chile's LEDS work as part of the Southern-led MAPS program.

Also partners in the Clean Air and Climate Coalition (CACC) focused on mitigation of short-lived climate pollutants (SLCPs).

Using Models for LEDS: Important Considerations

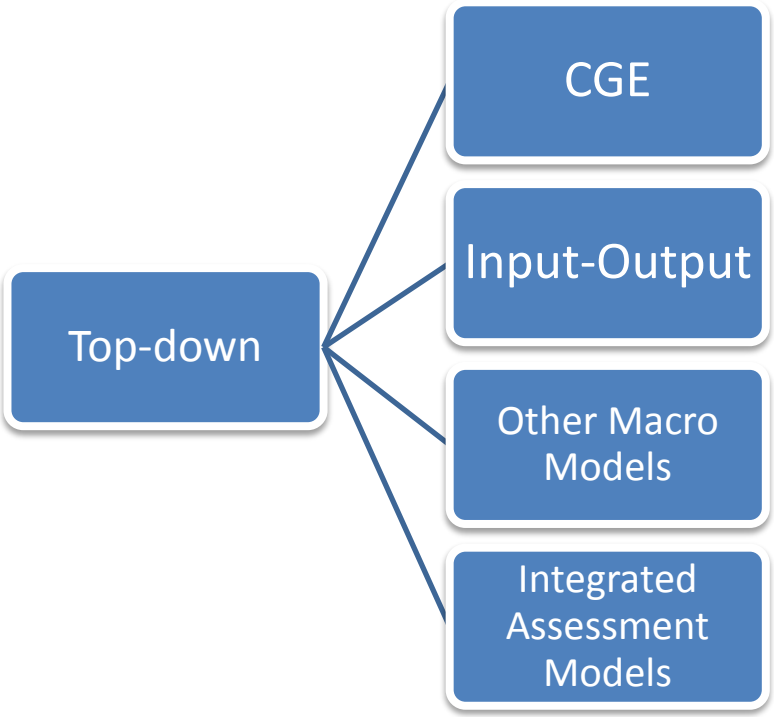
- Modeling sophistication is less important than the rigor, consistency and data quality underpinning the analysis itself.
- Consider who will undertake the analysis. Outside consultants provide ready source of expertise, but may do little to build capabilities in-country.
- Even relatively simple models require many months and a good level of expertise.
- Modeling and policy policy analysis requires strong guidance from local experts and buy-in from high level decision makers. Too important to be left to only modelers!
- Strong, coordinated and diverse team needed: economists, engineers, energy & industrial engineers, agriculture & LULUCF experts, etc.
- Ideally setup up a permanent team responsible for LEDS modeling to ensure continuity of expertise.
- Close coordination needed with other national groups: e.g. those working on GHG inventories and those doing national energy planning.

Types of Models

- Both **Top-Down** and **Bottom-up** models can yield useful complementary insights on mitigation.
  - Top-down models are most useful for studying broad macroeconomic and fiscal policies for mitigation such as carbon or other environmental taxes.
  - Bottom-up models are most useful for studying options that have specific sectoral and technological implications.
- Different models will likely be required for studying energy sector-related emissions vs. land-use change and forestry-related GHG emissions.

Types of Top-Down Models

- **CGE** (Computational General Equilibrium) models use economic data to estimate how an economy will respond to changes in policies, technologies and prices. Assumes economies approach or reach equilibrium status.
- **Input/Output models** focus on interdependencies among different sectors of an economy. Often assume static economic structures.
- **Integrated Assessment Models**: Tend to be based on physical/technological descriptions of systems and their interconnections (energy, water, land, agriculture, forestry, food, etc.).



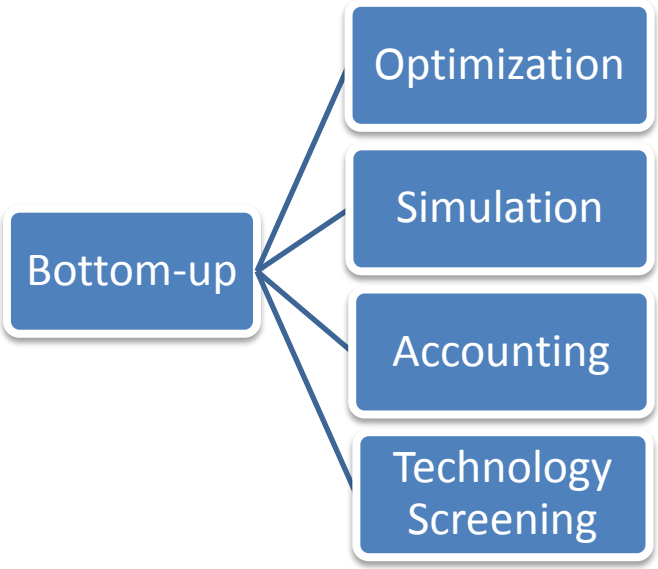
Types of Bottom-Up Energy Sector Models

Optimization: Use mathematical programming to identify configurations of energy systems that minimize the total cost of providing services.
EG: MARKAL/TIMES, LEAP, MESSAGE

Simulation: Simulate behavior of consumers and producers under various signals (e.g. price, income levels) and constraints (e.g. limits on rate of stock replacement).
EG: ENPEP-BALANCE

Accounting Frameworks: Account for physical stocks and flows in systems based primarily on engineering relationships and explicit assumptions about the future (e.g. technology improvements, market penetration rates).
EG: LEAP, EFFECT, MAED

Technology Screening: Focus on how a particular technology (or set of technologies) will perform under certain constraints and can track associated costs and emissions.
EG: RETScreen, HOMER. ClimateDesk

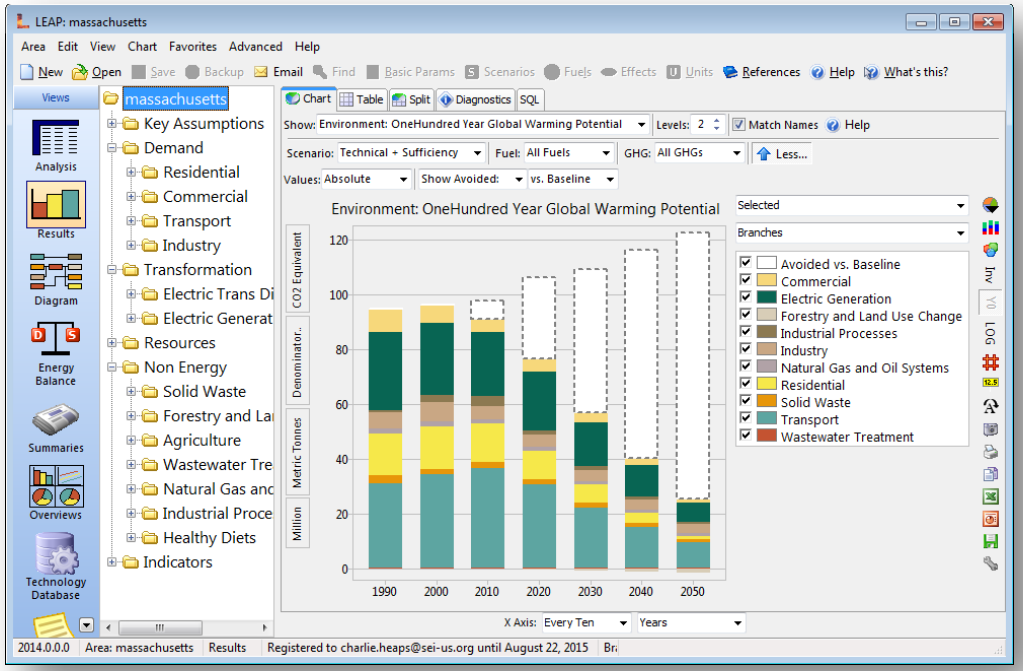


History of LEAP

- Created in 1980s as a mainframe tool for the Beijer Institute's Kenya Fuelwood Project (Funders: Sweden (Sida), Germany, Netherlands and US-AID).
- 1985: Ported to a PC environment: studies in Africa, Asia and Latin America.
- Early 1990s: Emissions modeling capabilities, first Chinese version.
- Late 1990s: Adapted for GHG mitigation assessment.
- Early 2000s: First Windows version: Major funding from Netherlands. 500 users by 2003.
- 2006: 1500 users in 130 countries
- 2011: Optimization modeling added. First global application.
- 2012: 15,000 users in 190 countries: links to WEAP for water-energy modeling.
- 2014: New scenario explorer. 21000 users worldwide.

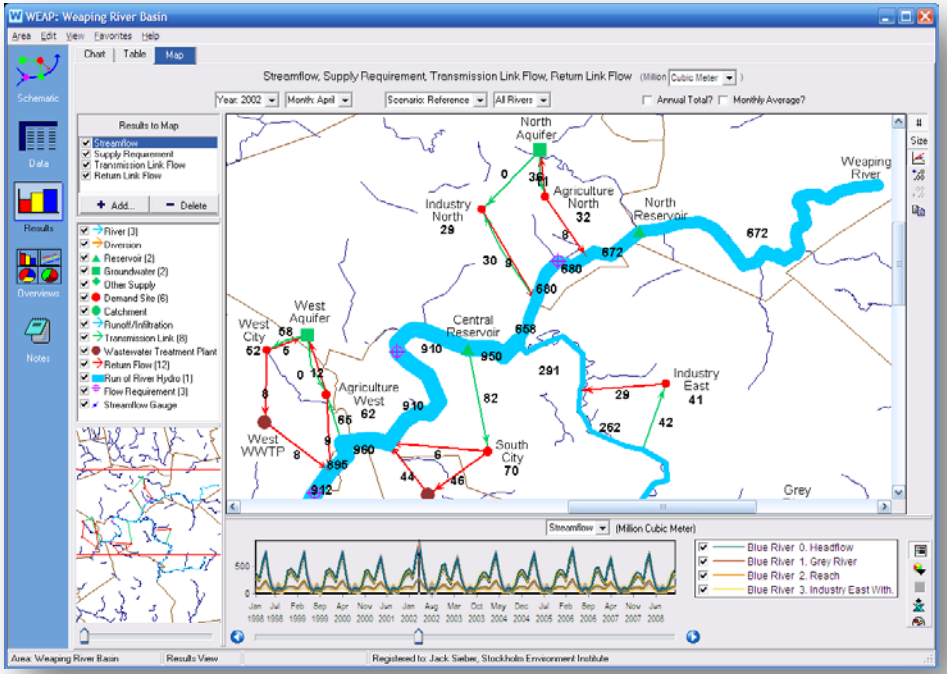
Long-range Energy Alternatives Planning System: 1982-Present

- Easy-to-use, graphical, scenario-based modeling software for energy planning and GHG mitigation assessment.
- Broad scope, low initial data requirements, flexible data structures.
- Not a model: a comprehensive decision support tool for creating models of different energy systems.
- Support for multiple methodologies including econometric, optimization and simulation models, etc.
- Becoming *de facto* standard for developing countries' energy planning, national communications, low emission development strategies (LEDS), and national action planning on SLCPs.



- Powerful API and links to MS-Office. Can be used in connection with other models (notably WEAP for nexus modeling).
- Useful at different scales: cities, states, countries, regions, globally.
- Long-range perspective, annual time step with seasonal/time-of-day details.

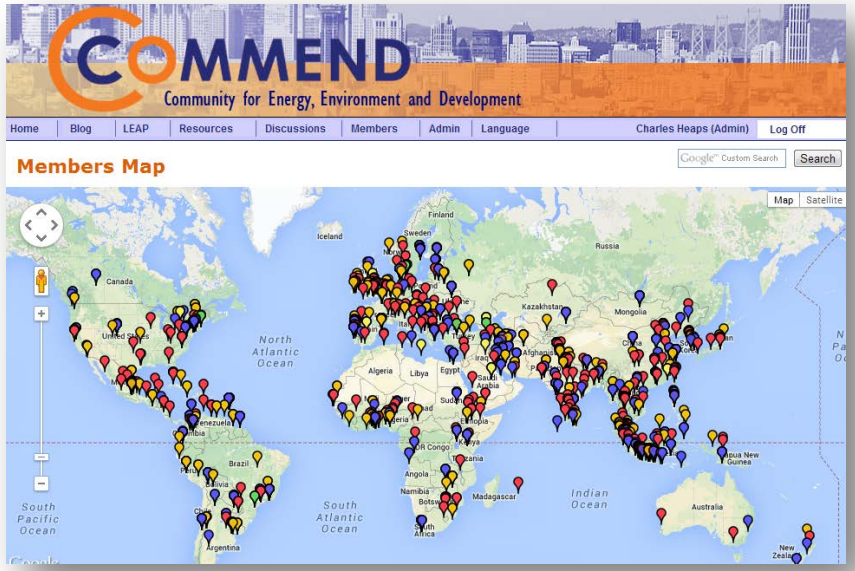
- Integrated watershed hydrology and water planning model
- GIS-based, graphical drag & drop interface
- Physical simulation of water demands and supplies
- Powerful scenario management capabilities
- Includes watershed hydrology, ground water, water quality and financial modules
- Built-in tools for data management, results reporting and model calibration.
- Works in concert with LEAP for nexus applications.
- Programming Language, components and much source code shared between LEAP, WEAP.



COMMEND

Community for Energy, Environment and Development

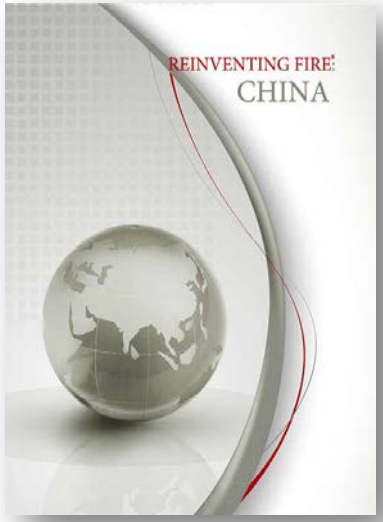
- Free online community supporting developing country sustainability planners.
- Started in 2000. Now has >20,000 members in 191 countries.
- Discussions & support forums.
- Social network connects LEAP users around the world based on their interests and location.
- Library containing useful resources for planners and modelers; lists of academic courses.
- Download LEAP and get guidance on other related models.
- Access LEAP training and reference materials.
- Free national-scale LEAP data sets for 105 countries.
- News about LEAP and trainings.
- English, Spanish, French Chinese.

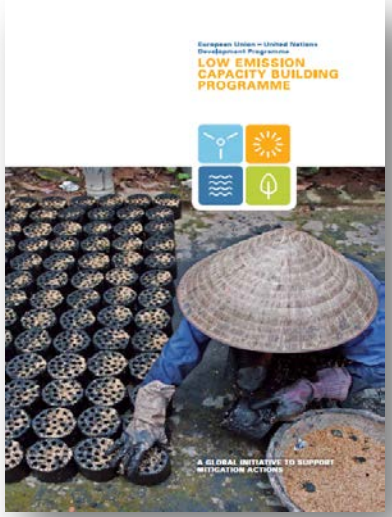


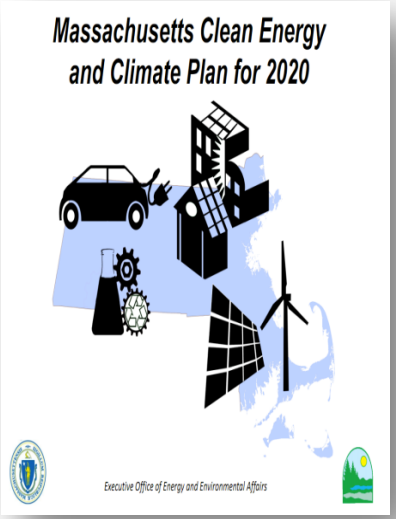
www.energycommunity.org

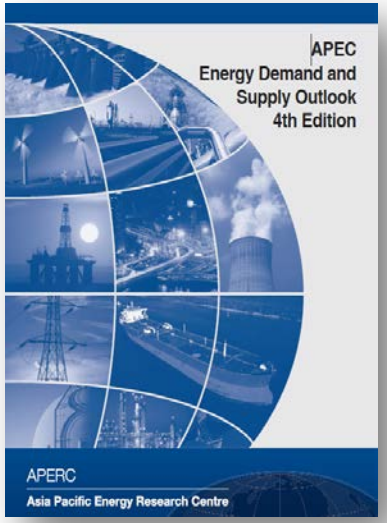
- Automatically administers LEAP licenses and downloads.
- Enables SEI to see who is using LEAP in real time (important for funders).
- Main tool for providing LEAP technical support and help desk.
- Coming soon: Support for SLCP National Action Planning.

Selected Recent Scenarios Activities









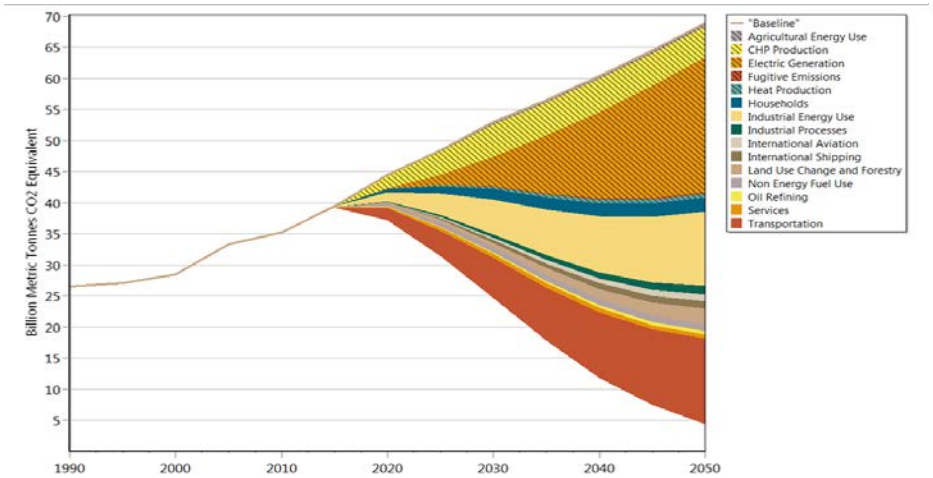
How Does LEAP Compare to Other Energy Models?

- Other tools typically have more sophisticated energy modeling capabilities, but are harder to use, more data intensive.
- LEAP's focus is on transparency of results, ease-of-use, data flexibility, adaptability to different scales, data & scenario management and reporting.
- Notable for the degree of methodological choices it provides to users.
- Ability to link to other models and software through its API.

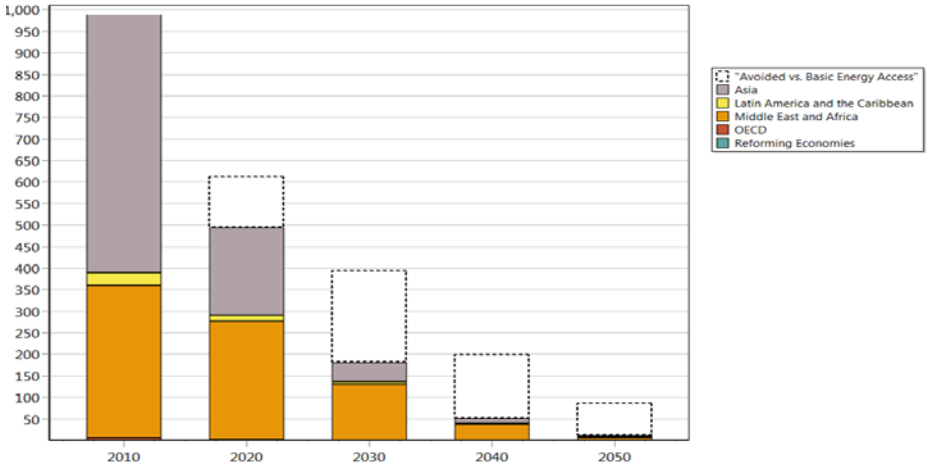
Energy for a Shared Development Agenda: A Global Assessment for Rio+20, 2012

- Explores how global energy systems can be reconfigured to address sustainability whilst also providing meaningful development and poverty alleviation.
- Conducted by SEI with IIASA, PBL, TERI and WRI.
- Energy and emissions scenarios to 2050 developed in LEAP for 20 global regions.
- Three scenarios:
  - Baseline
  - Basic Energy Access
  - Shared Development Agenda
- Report published at Rio+20

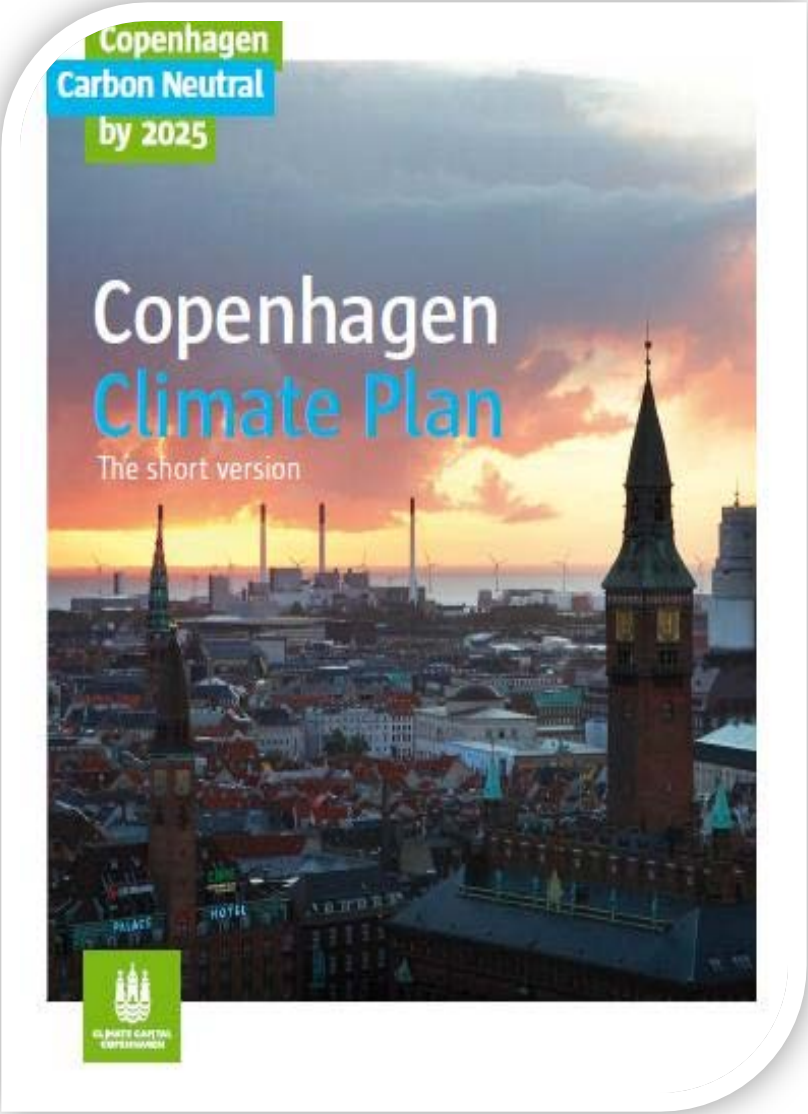
Emissions



Poverty

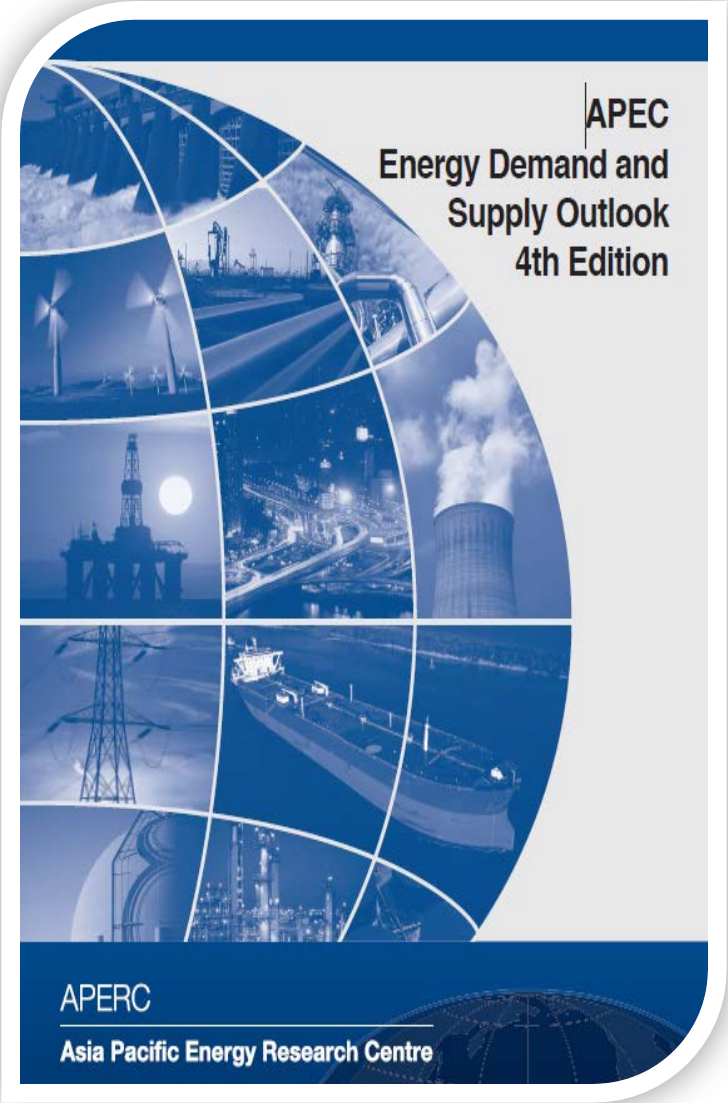


Copenhagen Climate Plan, 2009



- The Consulting Company RAMBOLL used LEAP to prepare a plan for the city of Copenhagen to become CO2 neutral by 2025.
- Copenhagen is already perhaps the most energy efficient city in the World, in part due to its widespread use of CHP systems for district heating and huge investments in wind power, and because nearly 40% of its citizens cycle to work or school every day.
- This study formed the basis for Copenhagen setting a target of 20% reduction in CO2 emissions by 2015 compared to 2005 and becoming completely CO2 neutral by 2025.

APEC: Energy Demand and Supply Outlook 2009, 2006, 2002



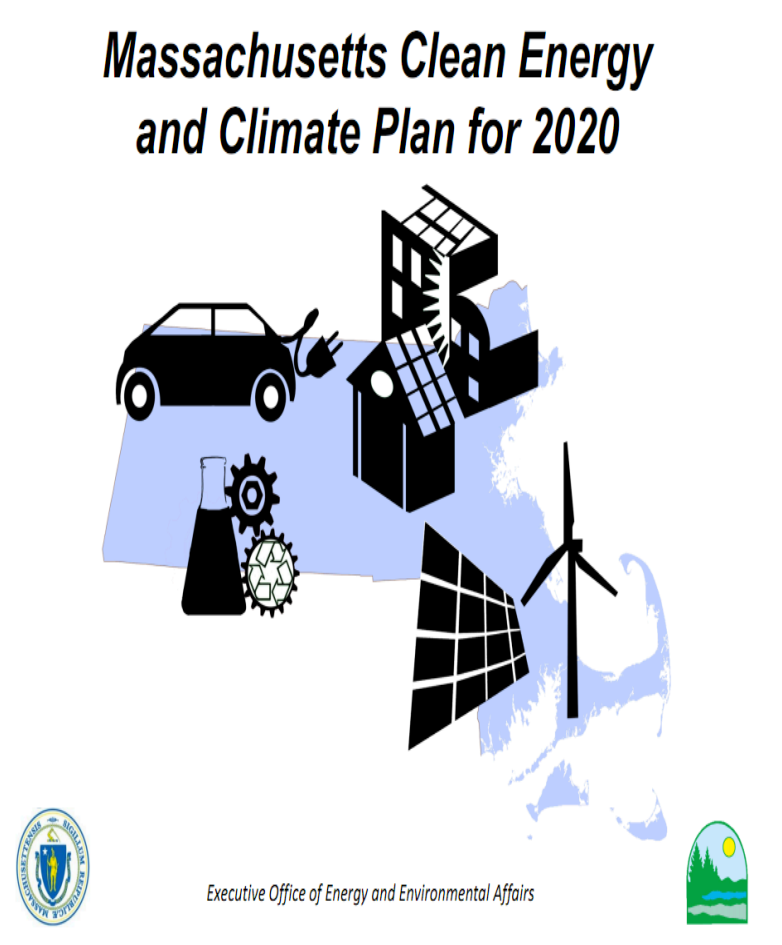
- Forecasts demand and supply for each APEC economy. Updated every 3-4 years
- Examines key technical and socio-economic drivers in APEC such as urbanization, aging of populations, relocation of industries towards less developed economies, technology development.
- Draws policy implications regarding the future energy demand and supply in the APEC region.

Data and Methods:

- Key time-series from IEA supplemented by national & APEC statistics, and World Bank indicators.
- Top-down econometric approach used to project energy demands. Microfit used to develop econometric equations, which are then entered in LEAP.
- LEAP used to model Transformation, to create scenario projections and to generate supply and demand balance tables.

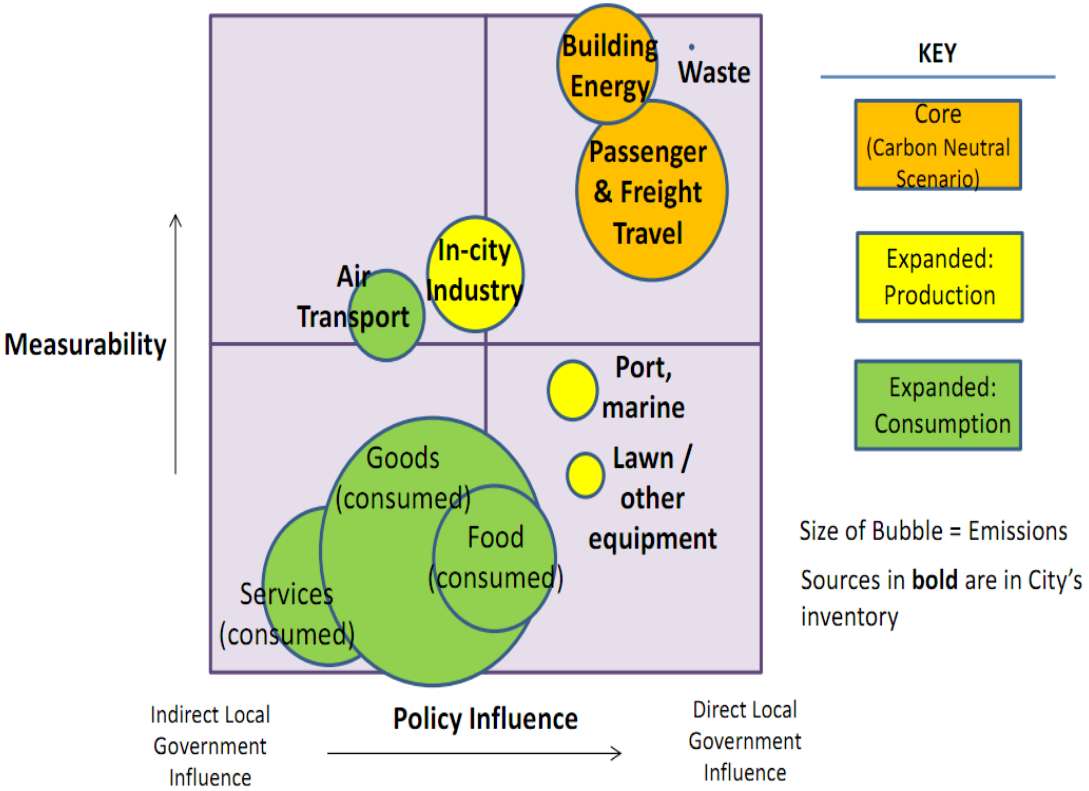
The Massachusetts Clean Energy and Climate Plan (CECP), 2010

- The Global Warming Solutions Act (GWSA) requires MA to achieve GHG reductions of 80% by 2050 vs. 1990.
- The Commonwealth of Mass asked SEI to use LEAP to model a portfolio of options capable of meeting that goal.
- For 2050, 40+ policies examined including system and end-use efficiency, electrification, low carbon fuels and lifestyles.
- Results used to inform the State Government's Clean Energy and Climate Protection plan: published in 2010.
- tinyurl.com/CECPMass



Getting to Zero: A Pathway to a Carbon Neutral Seattle, 2011

- 2010: Seattle City Council adopts vision of becoming nation's first carbon-neutral city.
- 2011: Seattle Office of Sustainability and Environment (OSE) develops a scenario showing how this might be achieved.
- In October 2011, Seattle City Council adopts zero net emissions by 2050 as the goal for its Climate Action Plan and begins to develop a detailed Climate Action Plan.
- tinyurl.com/SeattleZeroReport

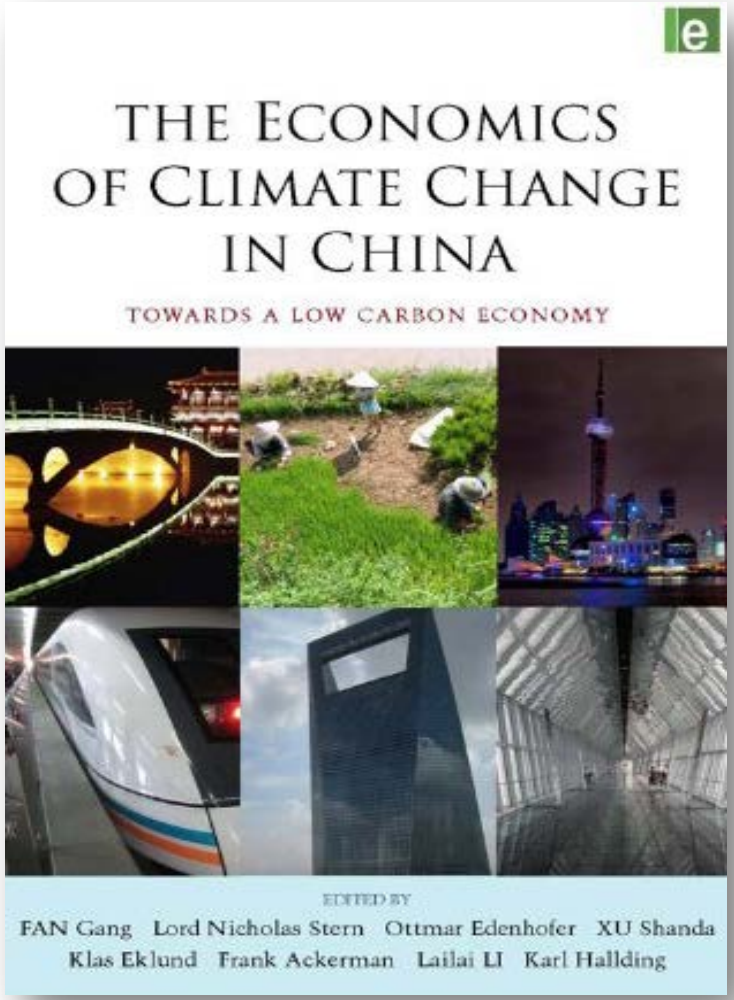


Europe's Share of the Climate Challenge, 2009

- Joint project of SEI and Friends of the Earth International, presented at COP15 in Copenhagen and at the European Parliament in 2010.
- LEAP used to create a detailed sector-by-sector mitigation scenario for all 27 EU countries, which examines how to achieve GHG reductions of
  - 40% in 2020 and
  - 90% in 2050 vs. 1990 levels.
- Examines radical improvements in energy efficiency, accelerated retirement of fossil fuels and a dramatic shift toward renewables.
- Also examines the role of sufficiency and greater equity among EU nations in helping promote a transition to a low GHG future.

The Economics of Climate Change in China, 2009

- SEI and the China Economists 50 Forum used LEAP to examine how China's energy systems might be changed to allow China to meet ambitious goals for development whilst also keeping GHG emissions within the levels required for climate protection.
- A resulting Deep Carbon Reduction Scenario examines the feasibility of massively reducing China's emissions in 2050: using efficiency, electrification of transport, renewables, CHP and CCS.
- Resulted in a chapter in the book "Economics of Climate Change in China"
- http://tinyurl.com/3pg6jst



More examples at:

www.energycommunity.org/apps

LEAP: User Interface

The main menu and toolbar give access to major options.

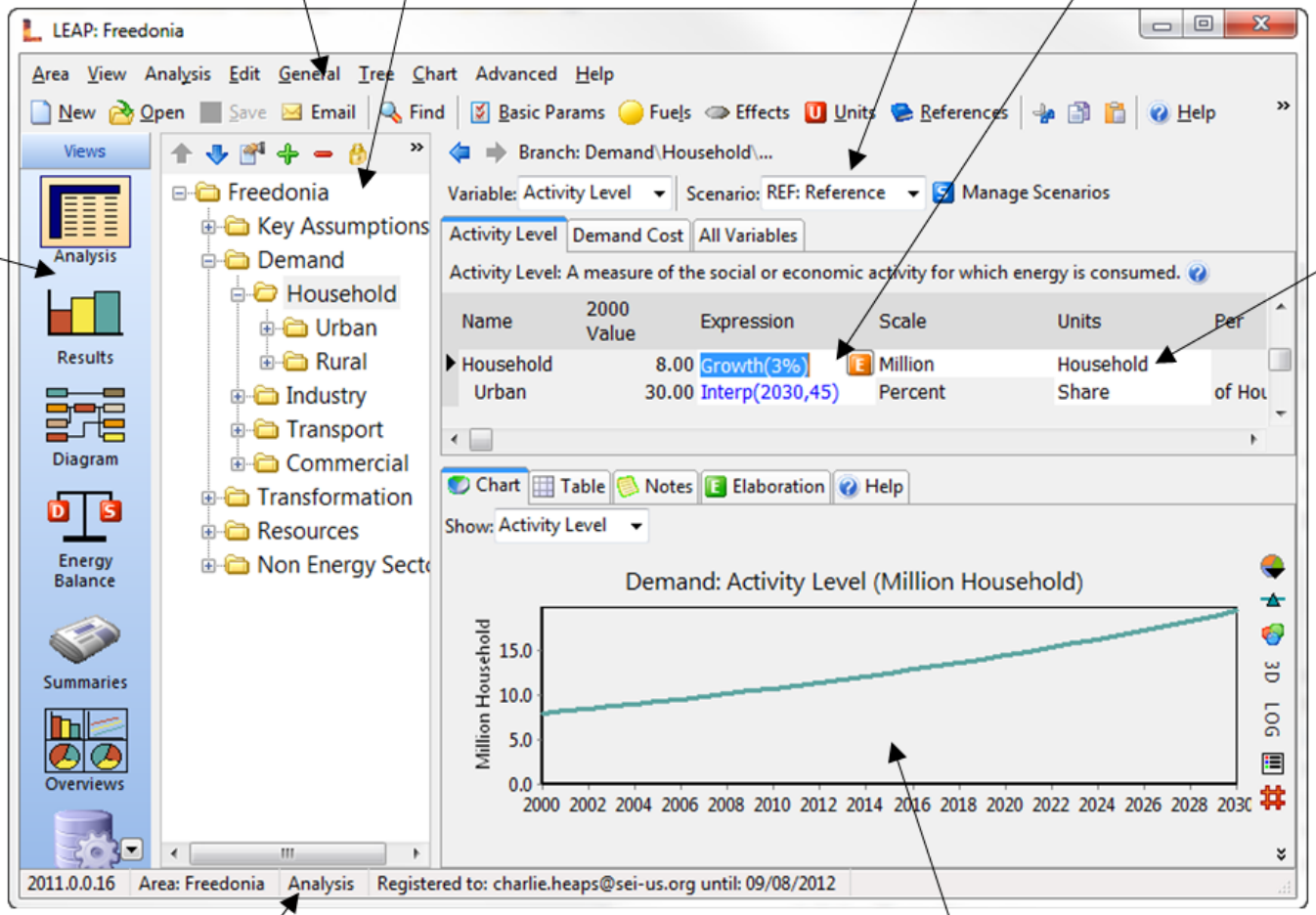
Data is organized in a tree.

Select scenarios here.

Edit data by typing here.

Switch between views of the Area here.

Select units and scaling factors here.



The status bar notes the current Area and View.

Data can be reviewed in chart or table format.

Status and Dissemination

- Available at no charge to non-profit, academic and governmental institutions based in developing countries.
- Download from: www.energycommunity.org
- Technical support from web site or leap@sei-us.org
- User name and password required to fully enable software. Available on completion of license agreement.
- Most users will need training: available through SEI or regional partner organizations.
- Check LEAP web site for news of training workshops.

Minimum Hardware & Software Requirements

Any standard modern PC:

- Windows 2000, NT, XP, Vista, 7 or 8.
  - Not compatible with Windows 95 or 98
  - Can be used on Apple or Linux PCs via WINE
    (but not recommended as does not support connections to Office in this mode).
- Minimum 1024 x 768 screen resolution.
- 128 MB RAM (more=faster)
- Optional: Internet connection, Microsoft Office

LEAP 2014

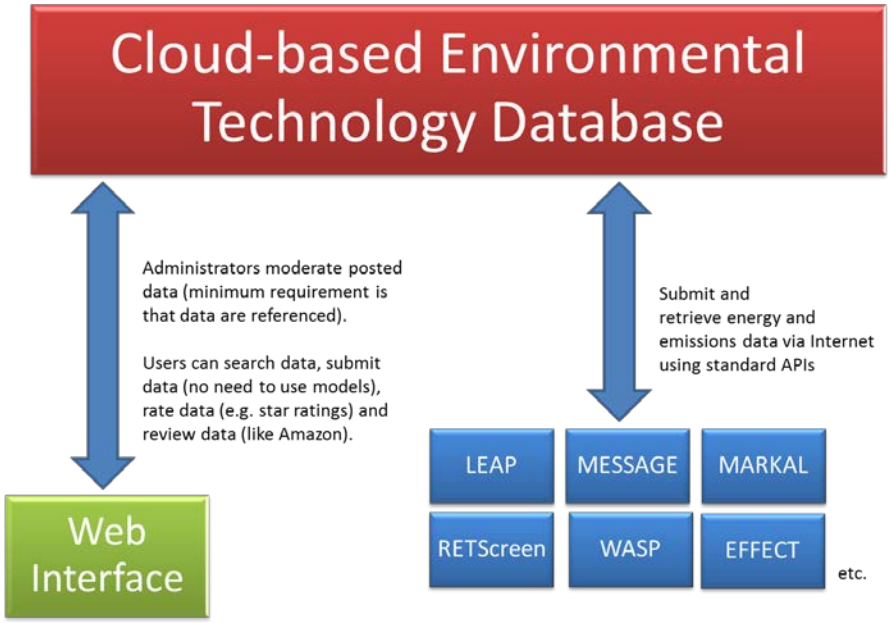
- Currently in Final Beta Testing
- Expected to be released May 2014.
- We will use LEAP 2014 today.
- Please forgive some (likely) bugs!

New Features for LEAP 2014

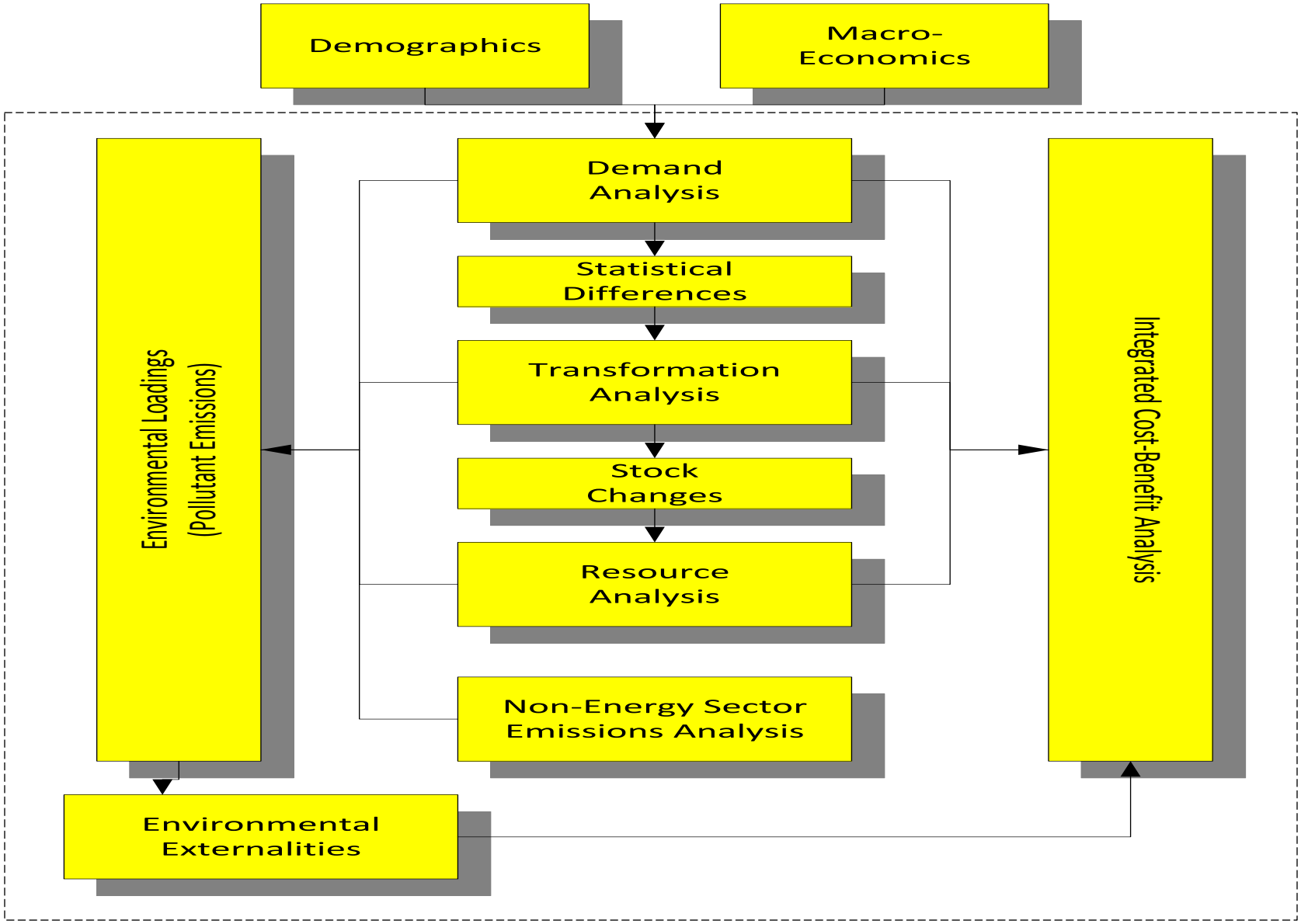
- **Faster:** 2-5 times faster calculations vs. v2012 to support more interactive workshops and Monte Carlo type analyses.
- **New Scenario Explorer:** Used for interactively exploring how key variables impact on scenario results.
- **Better Optimization:** Now supports "industrial strength" CPLEX solver. (must be purchased separately)
- **Improved Charts:** Better looking, consistent color coding of fuels, regions, scenarios and effects.
- **Improved Tables:** Multi-level subtotal tables showing sectors, subsectors, end-uses, etc.
- **Better Linking and Exporting to Excel:** more robust, faster, full precision exporting, better formatting.
- **Full-Screen View for Presentations.**
- **Primary Energy Requirements** allocated back to demands.

Plans for Future Development 2014-2015: Seeking Funding

- Easier to Use Version for City and Provincial-Scale Planning:
  - Targets planners rather than modelers
  - Better default data
- New Web Version
  - Allow LEAP Studies to be published online.
- New Cloud-based Environmental Technology Database



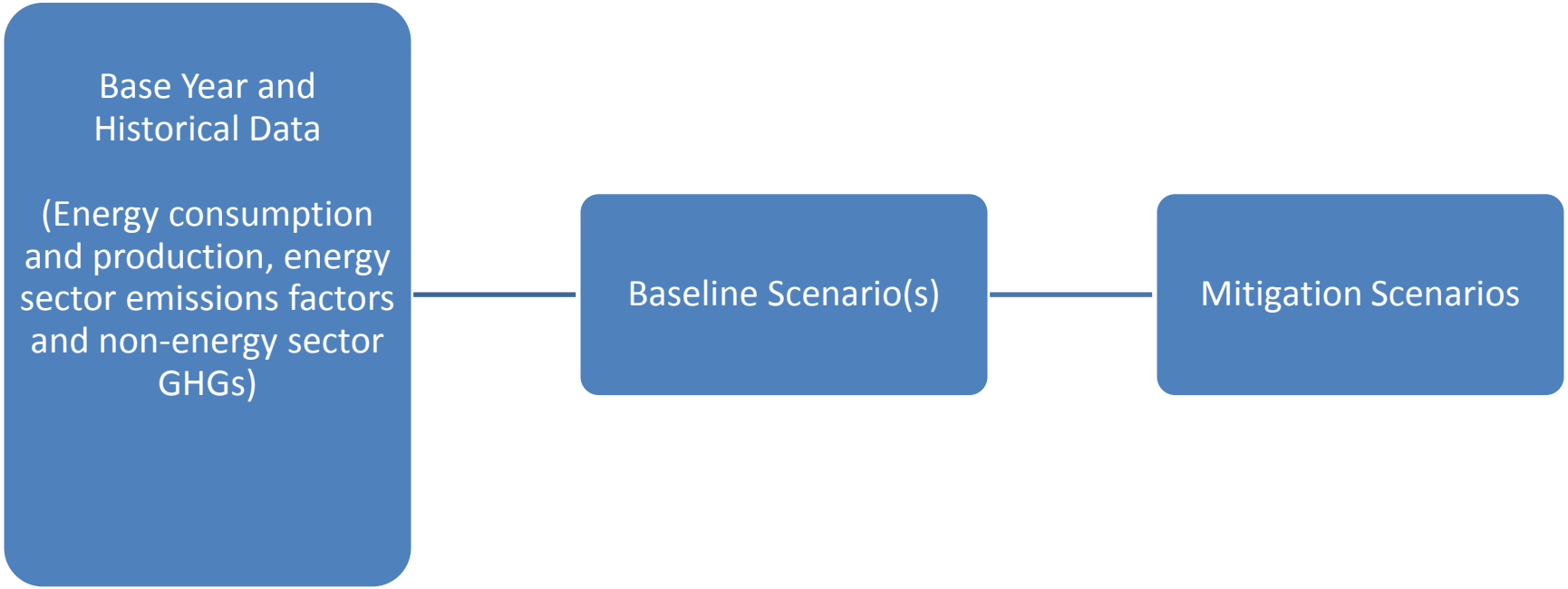
LEAP Structure & Calculation Flows



Main Components of a LEAP Analysis

- Energy Demand Analysis
- Energy Conversion and Resources (Transformation)
- Emissions (GHGs and Local Air Pollutants)
- Cost-Benefit Analysis
- Non-energy Sector Emissions

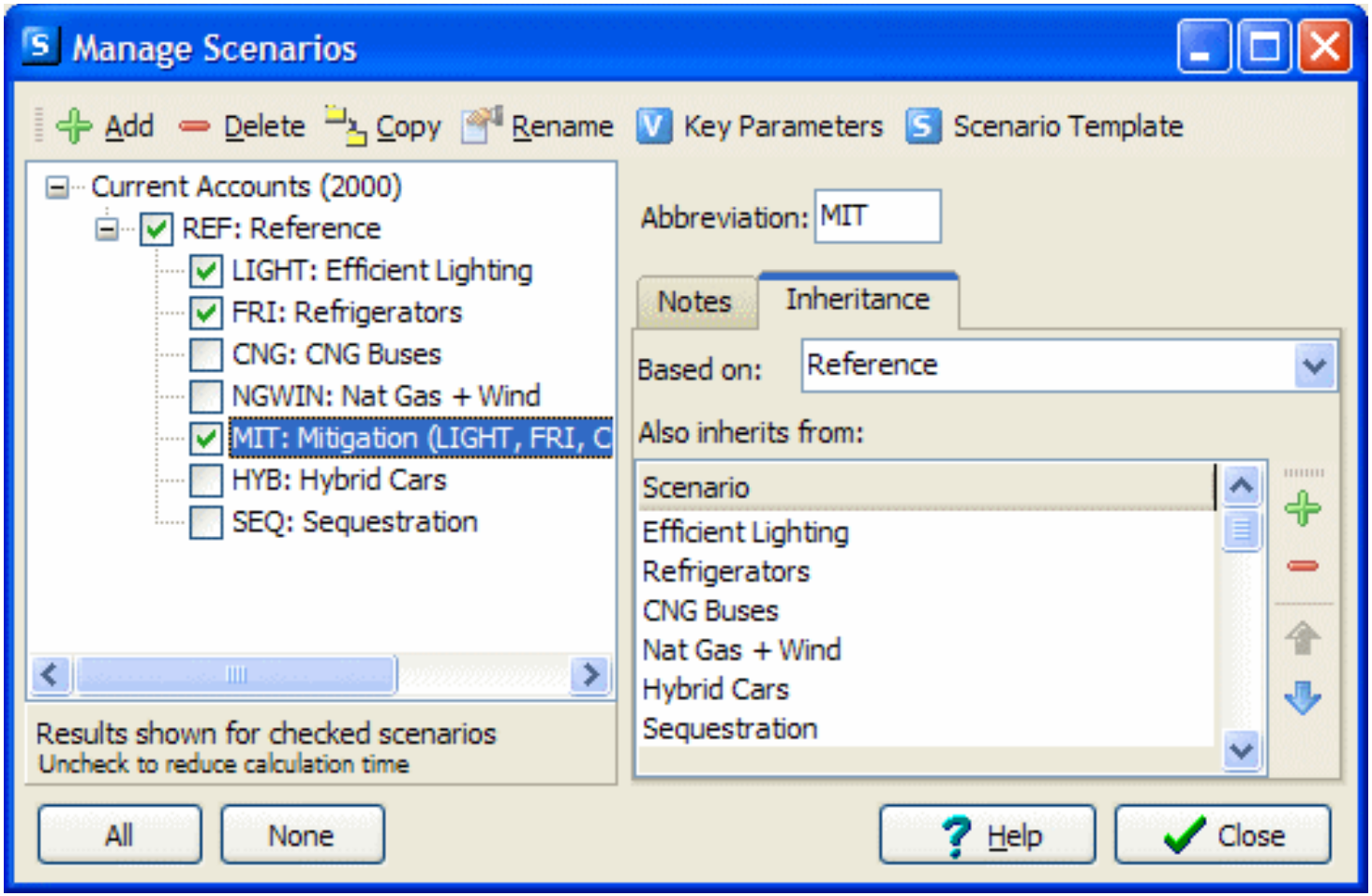
Key steps in Using LEAP



Scenarios in LEAP

- Consistent story-lines of how an energy system might evolve over time. Can be used for policy assumption and/or sensitivity analysis.
- *Inheritance* allows you to create hierarchies of scenarios that inherit default expressions from their parent scenario. All scenarios inherit from *Current Accounts* minimizing data entry and allowing common assumptions to be edited in one place.
- *Multiple inheritance* allows scenarios to inherit expressions from more than one parent scenario. Allows combining of measures to create integrated scenarios.
- The **Scenario Manager** is used to organize scenarios and specify inheritance.
- Expressions are color coded to show which expressions have been entered explicitly in a scenario (blue), and which are inherited from a parent scenario (black) or from another region (purple).

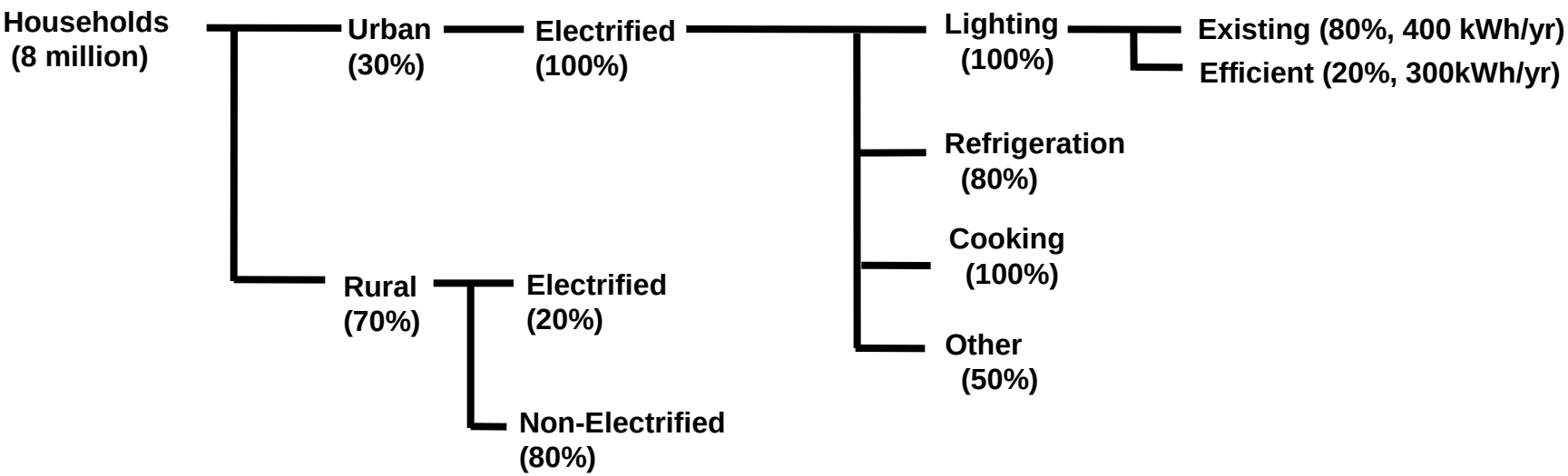
The Scenario Manager

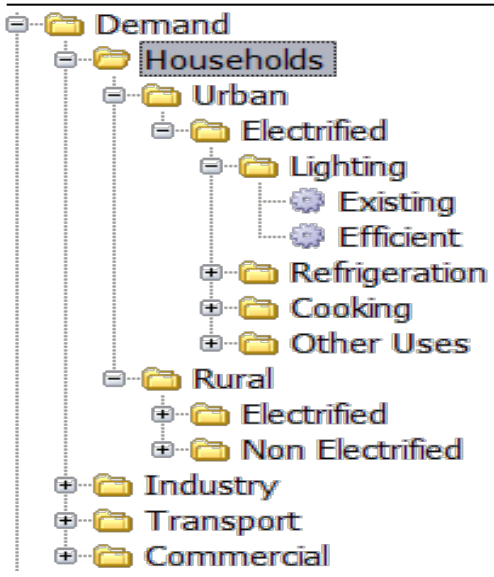


Demand Analysis in LEAP

- Analysis of energy consumption and associated costs and emissions in an area.
- Demands organized into a flexible hierarchical tree structure.
- Typically organized by sector, subsector, end-use and device.
- Supports multiple methodologies:
  - End-use analysis: energy = activity level x energy intensity
  - Econometric forecasts
  - Stock-turnover modeling

A Simple Demand Data Structure



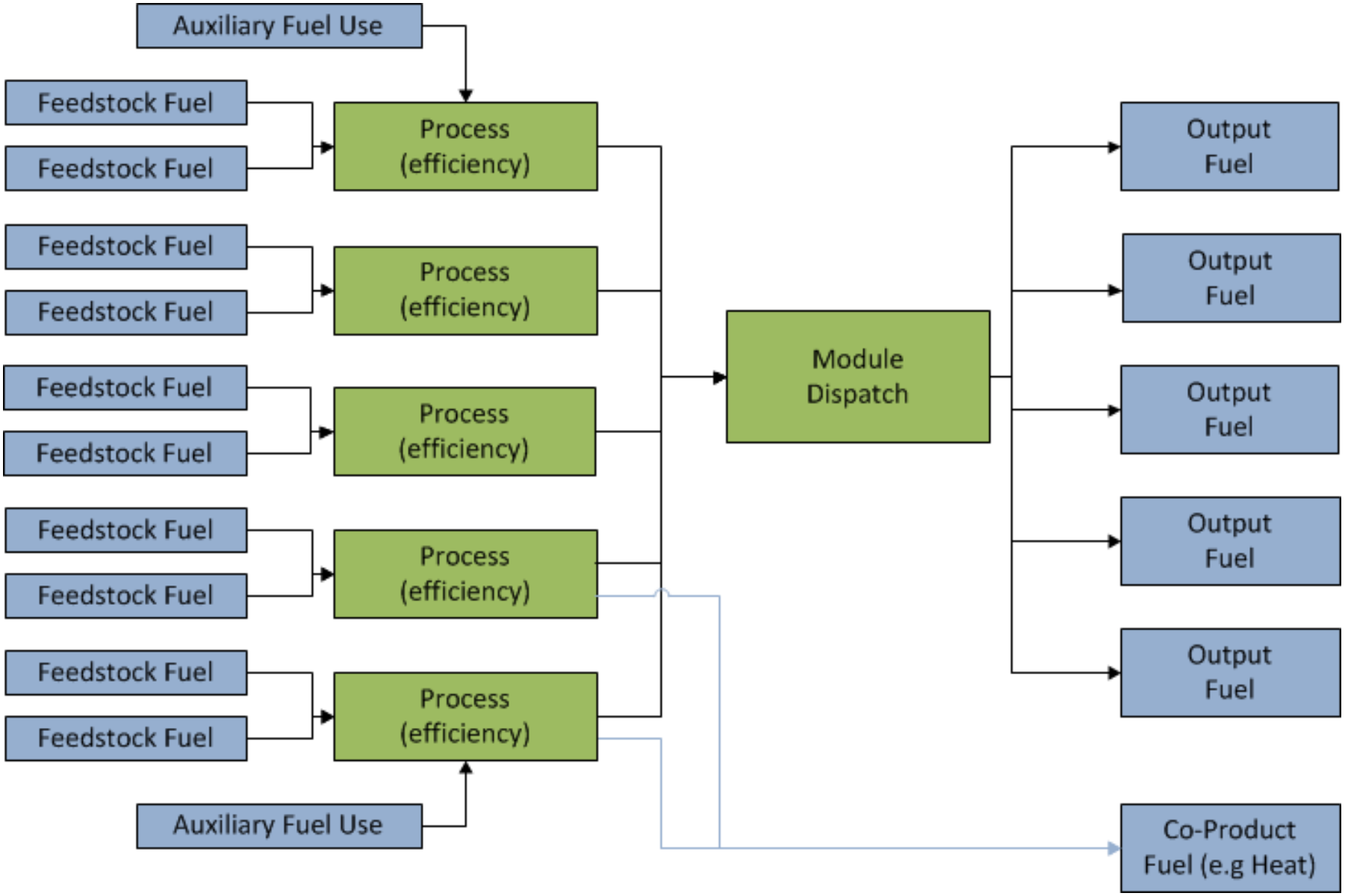


- The tree is the main data structure used for organizing data and models, and for reviewing results.
- Icons indicate the types of data (e.g., categories, technologies, fuels and environmental effects).
- Users can edit the tree on-screen using standard editing functions (copy, paste, drag & drop)
- Structure can be detailed and end-use oriented, or highly aggregate (e.g. sector by fuel).
- Detail can be varied from sector to sector.

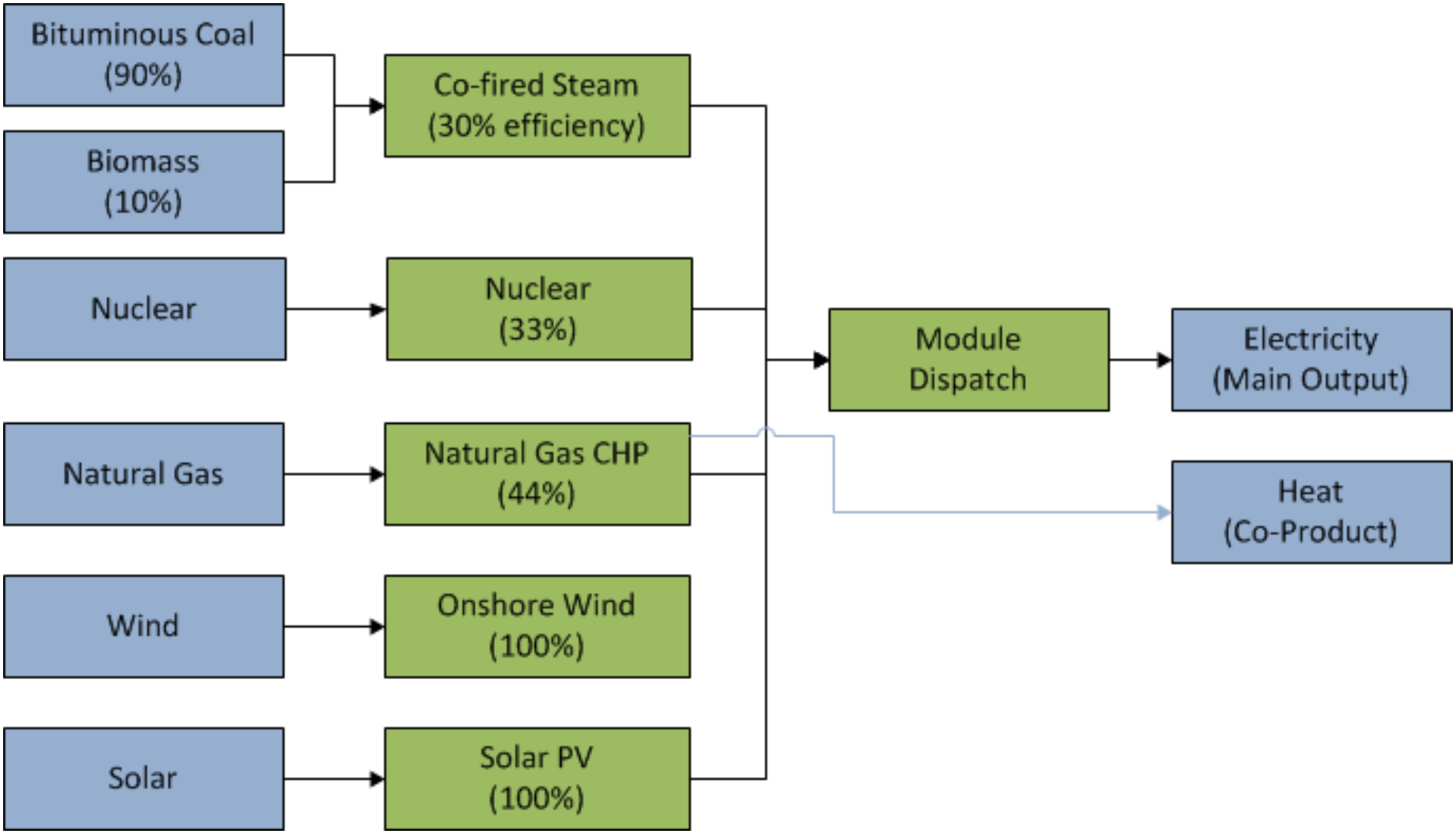
Transformation Analysis in LEAP

- Analysis of energy conversion, transmission and distribution, and resource extraction.
- Demand-driven engineering-based simulation.
- Basic hierarchy: “modules” (sectors), each containing one or more “processes”. Each process can have one or more feedstock fuels and one or more auxiliary fuels.
- Allows for simulation of both capacity expansion and process dispatch.
- Calculates imports, exports and primary resource requirements.
- Tracks costs and environmental loadings.
- Choice of two solution methodologies: **simulation** or **optimization**.

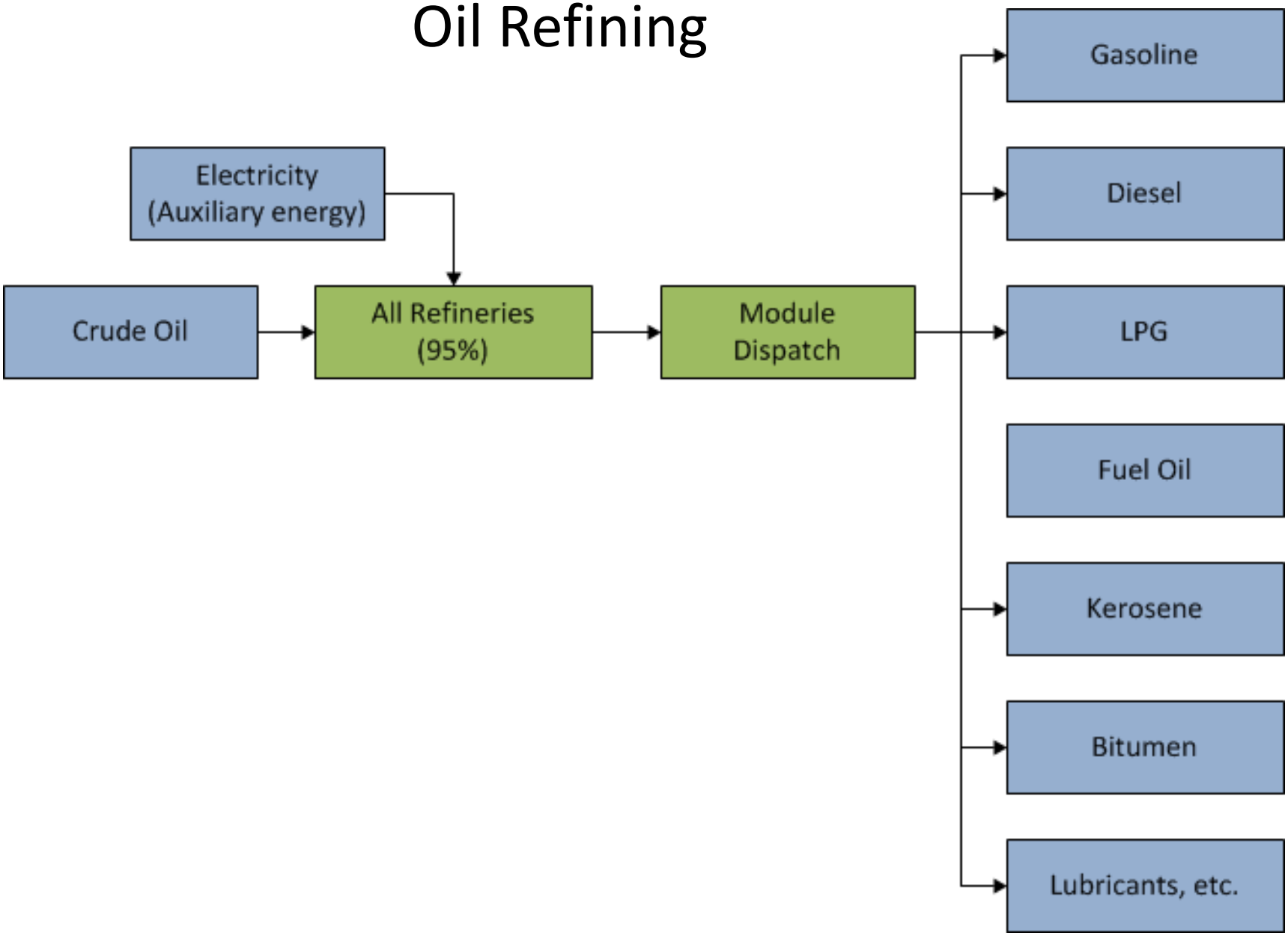
General Transformation Module Layout



A Transformation Module for Electricity Generation



A Transformation Module for Oil Refining

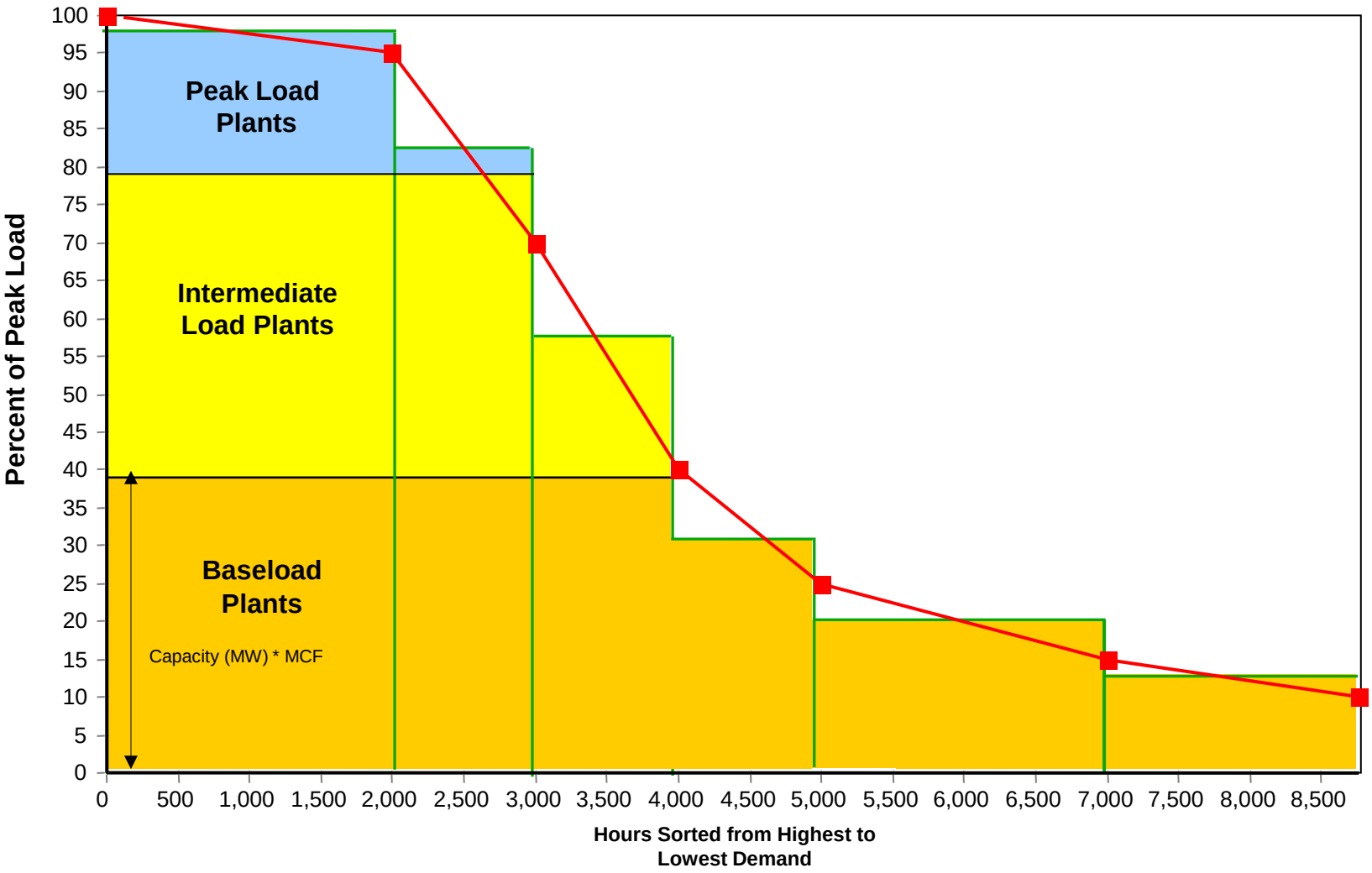


Electric Generation

Two Issues to consider:

1. **Capacity Expansion:** How much capacity to build and when? (MW)
2. **Dispatch:** Once built, how should the plants be operated? (MW-Hr)

Load-Duration Curve and System Dispatch in LEAP



Electric Generation Dispatch

- Plants are dispatched to meet both total demand (in MWh) as well as the instantaneous peak demand which varies by hour, day and season.
- User can exogenously specify a load-duration curve and LEAP will dispatch plants by merit order.
- Alternatively, load shapes be specified for each demand device so that the overall system load is calculated endogenously. Thus the effect of DSM policies on the overall load shape can then be explored in scenarios.
- Plant dispatch can also then be varied by season (e.g. to reflect how hydro dispatch may vary between wet and dry seasons).

Emissions Accounting

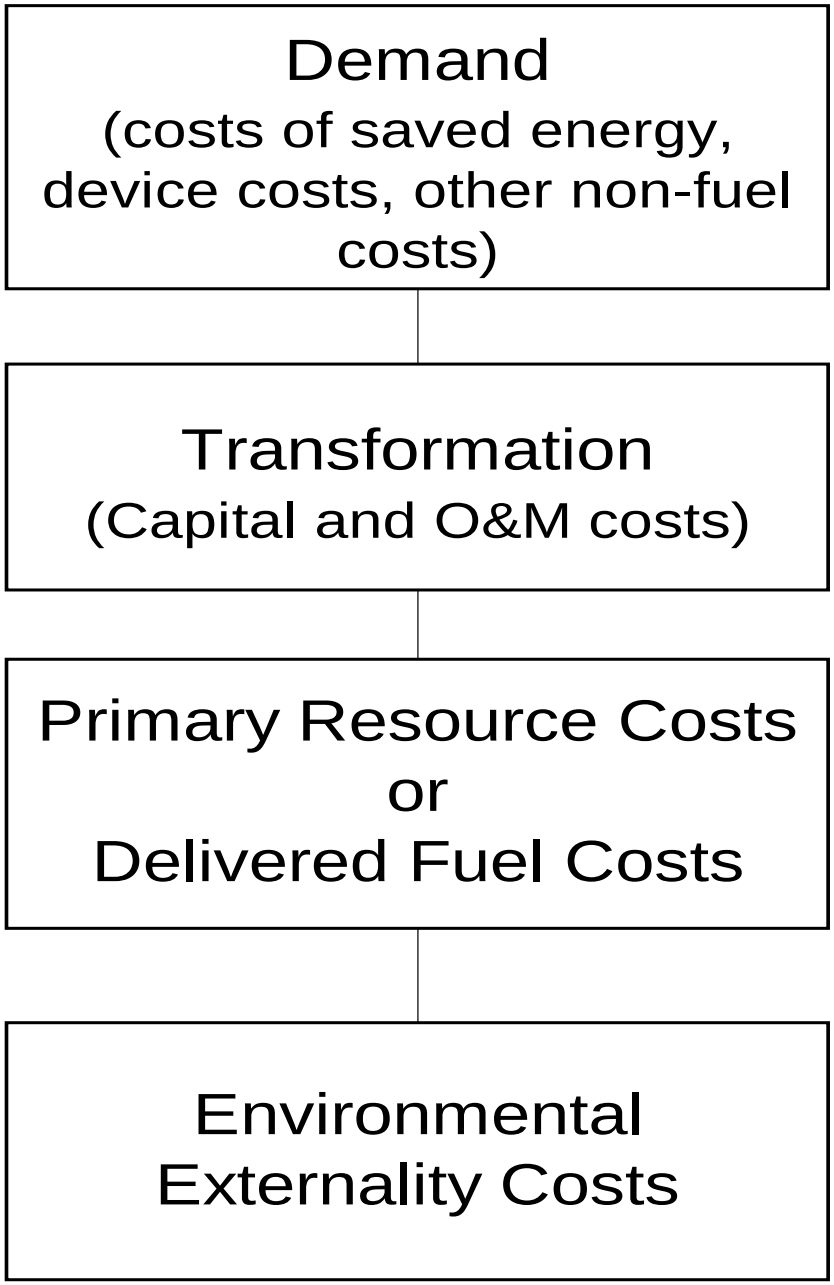
- Emission factors for any GHG or local air pollutant can be entered in LEAP and used to calculate emissions loadings.
- Can be specified in any physical unit and can be denominated by units of either energy consumption or production (e.g. kg/ton of coal) or distance driven for transport factors (e.g. grams/mile).
- Can also be specified in terms of the chemical composition of fuels (e.g. sulfur): automatically adjusts standard emission factors based on specific fuels used in the study area.
- Includes default IPCC "Tier 1" emission factors for GHG inventories.
- Results can be shown for individual pollutants or summed to show overall Global Warming Potential (GWP).

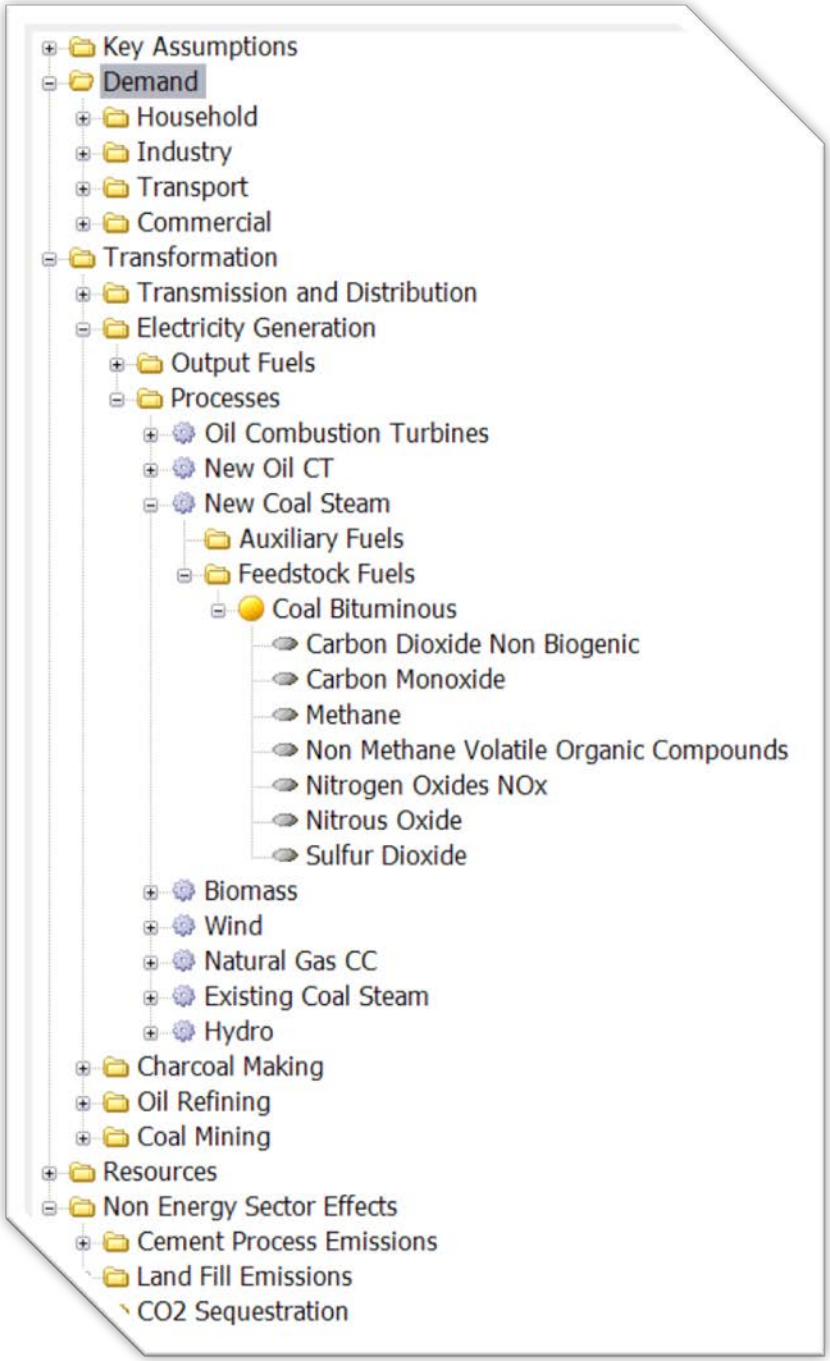
Energy Balances in LEAP

- Results automatically formatted as standard energy balance tables.
- Balances can be viewed for any year, scenario or region in different units.
- Balance columns can be switched among fuels, fuel groupings, years, and regions.
- Balance rows are the Demand and Transformation sectors. Optionally can show subsectoral results
- Displays results in any energy unit.
- Results in table, chart, or energy flow diagram formats.

Social Cost-Benefit Analysis in LEAP

- Societal perspective of costs and benefits (i.e. economic not financial analysis).
- Avoids double-counting by drawing consistent boundary around analysis (e.g. whole system including.
- Cost-benefit analysis calculates the Net Present Value (NPV) of the differences in costs between two scenarios.
- NPV sums all costs in all years of the study discounted to a common base year.
- Optionally includes externality costs, decommissioning costs and costs of unserved demands.





The Tree

- The main data structure used for organizing data and models, and reviewing results
- Icons indicate types of data (e.g., categories, technologies, fuels and effects)
- User can edit data structure.
- Supports standard editing functions (copying, pasting, drag & drop of groups of branches)

Tree Branches

- **Categories:** used mainly for organizing other branches.
- **End-Use** branches indicate situations where energy intensities are specified for an aggregate end-use, rather than with a specific fuel or device. Primarily used when conducting useful energy analysis.
- **Technology** branches represent final energy consuming devices. Three basic types:
  - **Activity Level Analysis**, in which energy consumption is calculated as the product of an activity level and an annual energy intensity (energy use per unit of activity).
  - **Stock Analysis**, in which energy consumption is calculated by analyzing the current and projected future stocks of energy-using devices, and the annual energy intensity of each device.
  - **Transport Analysis**, in which energy consumption is calculated as the product of the number of vehicles, the annual average distance traveled per vehicle and the fuel economy of the vehicles.
- **Key Assumptions:** independent variables (demographic, macroeconomic, etc.)
- **Fuels**.
- **Effect** branches: environmental loadings (emissions).

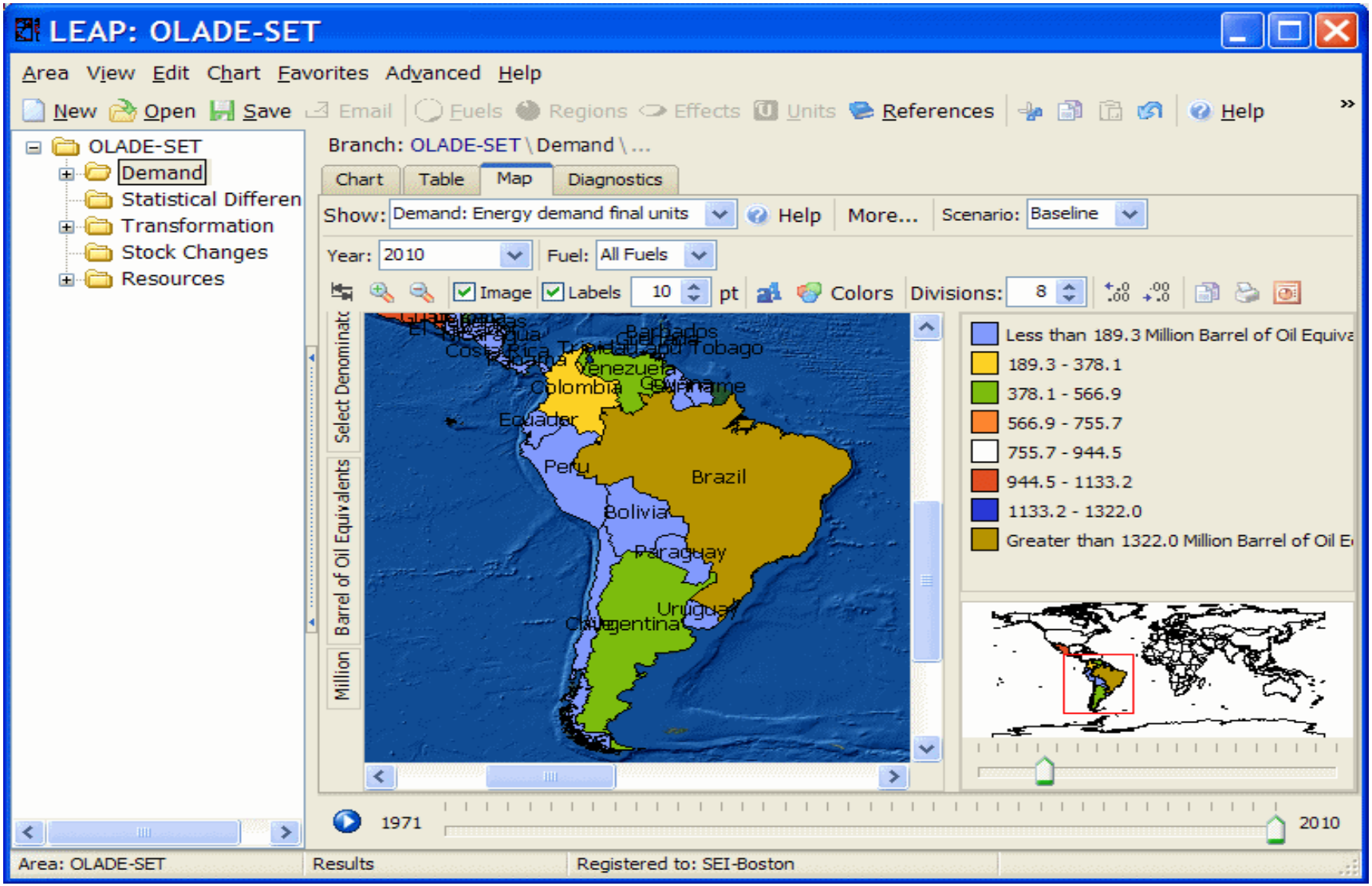
Modeling at Two levels

1. Basic physical accounting calculations handled internally within software (stock turnover, energy demand and supply, electric dispatch and capacity expansion, resource requirements, costing, pollutant emissions, etc.).
2. Additional modeling can be added by the user (e.g. user might specify market penetration as a function of prices, income level and policy variables).
   - Users can specify spreadsheet-like expressions that define data and models, describing how variables change over time in scenarios:
   - Expressions can range from simple numeric values to complex mathematical formulae. Each can make use of
     1. math functions,
     2. values of other variables,
     3. functions for specifying how a variable changes over time, or
     4. links to external spreadsheets.

Multi-Regional Analysis

- Areas can optionally be divided into multiple regions.
- Regions appear as an extra data & results dimension.
- Regions can share similar tree structures or tree branches can be selectively hidden in some regions.
- Results can be summed and displayed across regions or aggregated into groups of regions
- Supports inter-regional trade calculations so that import requirements for some regions drives production and exports in other regions.

Showing Results for a Multi-Region Data Set in LEAP



LEAP Data Requirements

- Low initial data requirements..
- LEAP itself is very flexible in terms of what data it can accept.
- Different levels of detail can be used in each different sector.
- However, serious analyses do of course require good and reasonably plentiful and up-to-date information.

Types of Data that can be Used in LEAP

Macroeconomic Variables

Sectoral driving variables	GDP/value added, population, household size
More detailed driving variables	Production of energy intensive materials (tonnes or $ steel); transport needs (pass-km, tonne-km); income distribution, etc.

Energy Demand Data

Sector and subsector totals	Fuel use by sector/subsector
End-use and technology characteristics by sector/subsector	a) Usage breakdown by end-use/device: new vs. existing buildings; vehicle stock by type, vintage; or simpler breakdowns; b) Technology cost and performance
Price and income response (optional)	Price and income elasticities

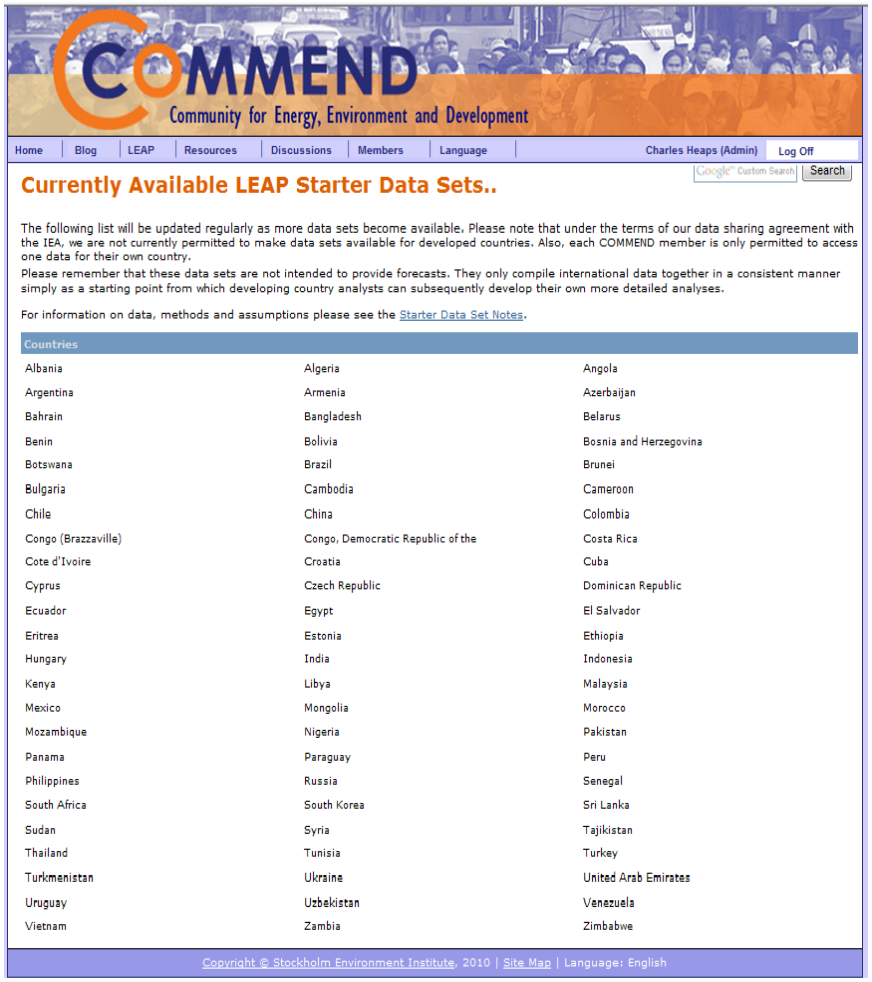
Energy Supply Data

Characteristics of energy supply, transport, and conversion facilities	Capital and O&M costs, performance (efficiencies, capacity factors, etc.)
Energy supply plans	New capacity on-line dates, costs, characteristics;
Energy resources and prices	Reserves of fossil fuels; potential for renewable resources

Technology Options

Technology costs and performance	Capital and O&M costs, foreign exchange, performance (efficiency, unit usage, capacity factor, etc.)
Penetration rates	Percent of new or existing stock replaced per year
Administrative and program costs	
Emission Factors	Emissions per unit energy consumed, produced, or transported.

“Starter” Data Sets



COMMEND
Community for Energy, Environment and Development

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Search

Currently Available LEAP Starter Data Sets..

The following list will be updated regularly as more data sets become available. Please note that under the terms of our data sharing agreement with the IEA, we are not currently permitted to make data sets available for developed countries. Also, each COMMEND member is only permitted to access one data for their own country.
Please remember that these data sets are not intended to provide forecasts. They only compile international data together in a consistent manner simply as a starting point from which developing country analysts can subsequently develop their own more detailed analyses.

For information on data, methods and assumptions please see the Starter Data Set Notes.

Countries		
Albania	Algeria	Angola
Argentina	Armenia	Azerbaijan
Bahrain	Bangladesh	Belarus
Benin	Bolivia	Bosnia and Herzegovina
Botswana	Brazil	Brunei
Bulgaria	Cambodia	Cameroon
Chile	China	Colombia
Congo (Brazzaville)	Congo, Democratic Republic of the	Costa Rica
Cote d'Ivoire	Croatia	Cuba
Cyprus	Czech Republic	Dominican Republic
Ecuador	Egypt	El Salvador
Eritrea	Estonia	Ethiopia
Hungary	India	Indonesia
Kenya	Libya	Malaysia
Mexico	Mongolia	Morocco
Mozambique	Nigeria	Pakistan
Panama	Paraguay	Peru
Philippines	Russia	Senegal
South Africa	South Korea	Sri Lanka
Sudan	Syria	Tajikistan
Thailand	Tunisia	Turkey
Turkmenistan	Ukraine	United Arab Emirates
Uruguay	Uzbekistan	Venezuela
Vietnam	Zambia	Zimbabwe

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- Now available for free download for 105 countries (1 data set per user).
- Compiles international data as a **starting point** for more detailed analyses.
- Includes IEA energy data (1971-2009), IPCC emissions factors, UN population projections, World Bank development indicators, Non-energy sector GHG emissions from the PBL EDGAR database, energy resource data from WEC.

Expressions

- Fundamental to how data is entered and managed across scenarios and regions in LEAP.
- Similar to expressions in spreadsheets.
- Used to specify the value of variables.
- Expressions can be simple numerical values, or a formula that yields different results in each year.
- Can make use of many built-in functions, or refer to the values of other variables.
- Can be linked to Excel spreadsheets.
- Inherited across scenarios and regions for efficient data management.

Expression Examples

- **Simple Number**
  - Calculates a constant value in all scenario years.
- **Simple Formula**
  - Example: 0.1 * 5970
- **Growth**
  - Example: Growth(3.2%)
  - Calculates exponential growth over time.
- **Interpolation**
  - Example: Interp(2000, 40, 2010, 65, 2020, 80)
  - Calculates gradual change between data values
- **Step**
  - Example: Step(2000, 300, 2005, 500, 2020, 700)
  - Calculates discrete changes in particular years
- **GrowthAs**
  - Example: GrowthAs(Income,elasticity)
  - Calculates future years using the base year value of the current branch and the rate of growth in another branch.

Oil Refining Simulation

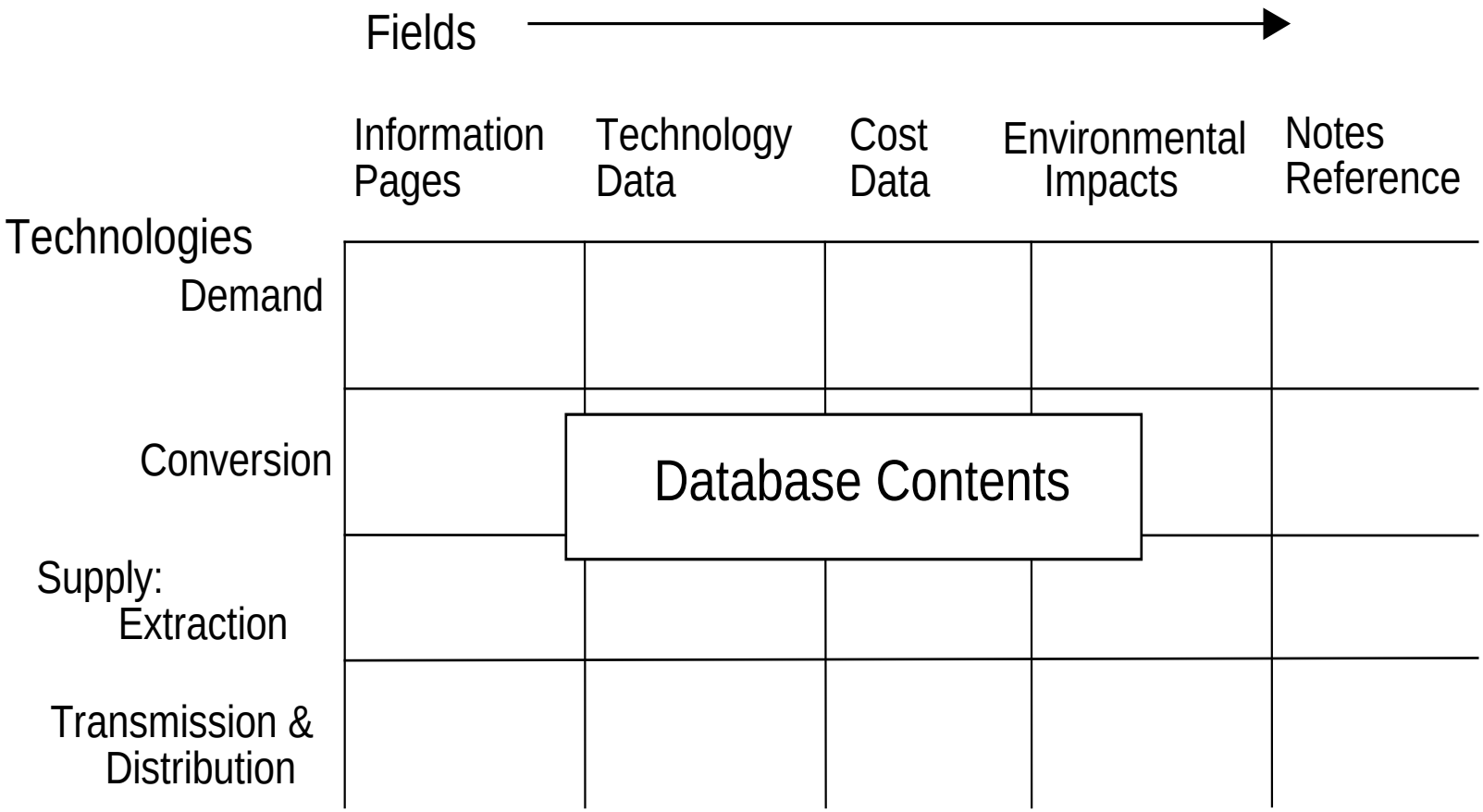
- Uses the same basic module structure as for Electric Generation, but generally has a single input fuel (crude) and multiple output fuels (gasoline, diesel, kerosene, LPG, fuel oil , etc.)
- Outputs produced in specified proportions, and the whole module is run to the point where demands for “priority products” are met (assuming module has sufficient capacity).
- Other products are considered by-products and may or may not be produced in sufficient quantities.
- User sets simulation rules to tell what LEAP to do in situations of surpluses (export or waste) and deficits (import or ignore).
- Alternatively, output fractions can be set to same proportions as requirements so all products produced without shortfalls or surpluses.

Simple Refinery Simulation Example

Fuel	Production Required	Output Energy Share	Priority Fuel?	Energy Produced	Outcome
Kerosene	400	55%	Yes	660	Surplus
Gasoline	300	25%	Yes	300	Exact
Fuel Oil	300	20%	No	240	Shortfall
Total	**1000**	**100%**		**1200**	

TED

The Technology and Environmental Database



Energy Balances

An accounting system that describes the flows of energy through an economy, during a given period.

Imports

Transformation Sectors Losses and Consumption

Non-energy consumption (e.g. petrochemical feedstock, fertilizers)

$$P + I - X = L + C_F + C_{NE} + DS$$

Total Primary Energy Produced

Exports

Total Final Energy Use in Consuming Sectors

Net Changes in Stocks

Sample IEA Energy Balance

Breakdown by Sector and Activities

Thailand Energy Balance, 1993 (Thousand TOE)

	Coal	Crude Oil	Petroleum Products	Gas	Nuclear	Hydro/ Other	Electricity	Heat	Total
Indigenous Production	4514	3948		8395		319			17175
Import	664	16425	9115				55		26259
Export		-685	-368				-4		-1057
International Marine Bunkers			-812						-812
Stock Changes	65	-304	-729						-969
TPES	5242	19383	7205	8395	0	319	51	0	40595
Returns and Transfers		-977	986						10
Statistical Differences	254		-47						207
Public Electricity	-2964		-4172	-7795		-319	5453		-9797
Autoproducers of Electricity									0
CHP Plants									0
District Heating									0
Gas Works									0
Petroleum Refineries		-18355	16892						-1463
Coal Transformation									0
Liquefaction									0
Other Transformation									0
Own Use			-34	-294			-220		-548
Distribution Losses							-444		-444
TFC	2532	51	20830	306	0	0	4840	0	28560
Industry Sector	*2532*	*51*	*3539*	*306*	*0*	*0*	*1860*	*0*	*8289*
Iron and Steel			69				172		241
Chemical		51	271	184			336		842
Non-Ferrous Metals									0
Non-Metallic Minerals	1467		933	11			293		2703
Transport Equipment									0
Machinery			300				238		539
Mining and Quarrying			43						43
Food and Tobacco	101		583				313		997
Paper, Pulp, and Printing			145				52		197
Wood and Wood Products			71				44		114
Construction			183						183
Textile and Leather			553				357		910
Non-specified Industry	965		388	111			55		1520
Transport Sector	*0*	*0*	*14236*	*0*	*0*	*0*	*0*	*0*	*14236*
Air			2423						2423
Road			11429						11429
Rail			120						120
Internal Navigation			264						264
Non-specified Transport									0
Other Sectors	*0*	*0*	*2715*	*0*	*0*	*0*	*2980*	*0*	*5695*
Agriculture			1628				11		1640
Public/Commerce							1890		1890
Residential			1086				1026		2113
Non-specified Other							52		52
Non-Energy Use			340						340

Breakdown by Energy Source

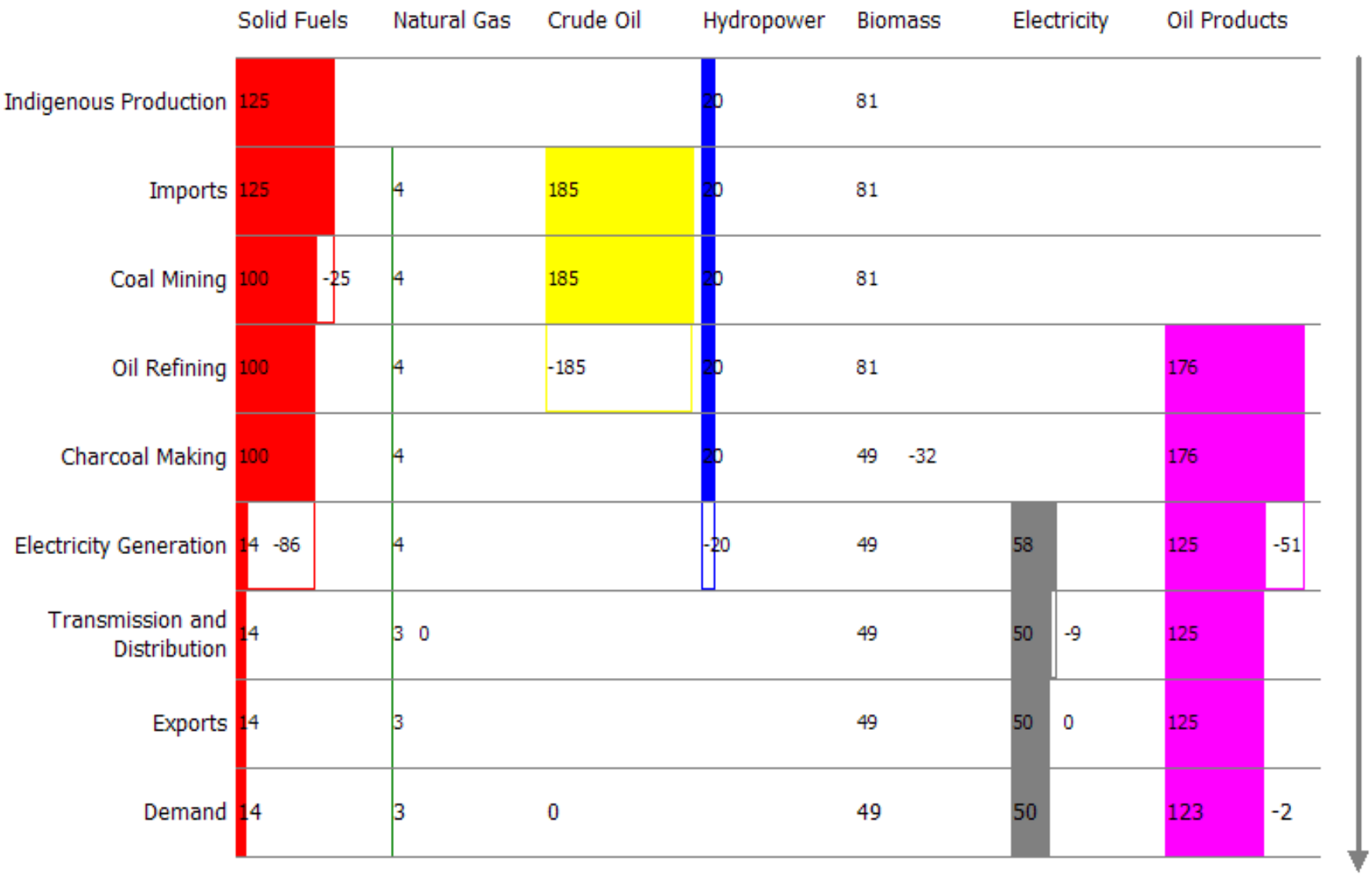
LEAP Energy Balance Table

Energy Balance for: Freedonia

Scenario: Reference. Year: 2000 (Million Gigajoule)

	Solid Fuels	Natural Gas	Crude Oil	Hydropower	Biomass	Electricity	Oil Products	Total
Production	125	0	0	20	81	0	0	226
Imports	0	4	185	0	0	0	0	189
Exports	0	0	0	0	0	0	0	0
From Stock Change	0	0	0	0	0	0	0	0
Total Primary Supply	125	4	185	20	81	0	0	415
Coal Mining	-25	0	0	0	0	0	0	-25
Oil Refining	0	0	-185	0	0	0	176	-9
Charcoal Making	0	0	0	0	-32	0	0	-32
Electricity Generation	-86	0	0	-20	0	58	-51	-98
Transmission and Distribution	0	0	0	0	0	-9	0	-9
Total Transformation	-110	0	-185	-20	-32	50	125	-174
Statistical Differences	0	0	0	0	0	0	0	0
Household	0	3	0	0	33	18	13	68
Industry	14	0	0	0	16	20	22	72
Transport	0	0	0	0	0	1	78	79
Commercial	0	0	0	0	0	10	10	20
Total Demand	14	3	0	0	49	50	123	239
Unmet Demand	0	0	0	0	0	0	-2	-2

LEAP Energy Balance Diagram



The Application Programming Interface (API)

- LEAP’s API is a standard COM Automation Server
- Other programs can control LEAP: changing data values, calculating results, and exporting them to Excel or other applications.
- For example, a script could iteratively run LEAP multiple times revising input assumptions for goal-seeking applications.
- LEAP has a built-in script editor that can be used to edit, interactively debug and run scripts that use its API.
- LEAP uses Microsoft's ActiveScript technology which supports in Visual Basic and JavaScript.

Script Editor: Export Favorite Charts.vbs

Run Script | On Top | Clear | Open | Save | Save As..

```
1   TheRegionName="Germany"
2
3   LEAP.Favorite("Population").activate
4   LEAP.ActiveRegion = TheRegionName
5   CALL LEAP.ExportResultsPPT("Population", "B
6
7   LEAP.Favorite("Income").activate
8   LEAP.ActiveRegion = TheRegionName
9   CALL LEAP.ExportResultsPPT("", "")
10
11  LEAP.Favorite("GDP").activate
12  LEAP.ActiveRegion = TheRegionName
13  CALL LEAP.ExportResultsPPT("", "")
14
15  LEAP.Favorite("Energy Demand by Fuel Baseli
16  LEAP.ActiveRegion = TheRegionName
17  CALL LEAP.ExportResultsPPT("", "")
18
19  LEAP.Favorite("Energy Demand by Fuel Mitiga
20  LEAP.ActiveRegion = TheRegionName
```

LEAP API Objects | LEAP Variables

- LEAP (Application)
  - ActiveArea
  - ActiveBranch
  - ActiveRegion
  - ActiveScenario
  - ActiveScript
  - ActiveUnit
  - ActiveVariable
  - ActiveView
  - ActiveYear
  - AddAggregateIntensity(BName, ParentID, Scale, AcUnit)
  - AddCategory(BName, ParentID, Scale, AcUnit)
  - AddFeedstock(Fuel, ParentID)
  - AddKeyAssumption(BName, ParentID, Scale, KUnit)
  - AddKeyAssumptionCategory(BName, ParentID)
  - AddModule(BName, Fuel, IsSimple, UseEfficiencies, UseCap
  - AddNonEnergySectorCategory(BName, ParentID)
  - AddNonEnergySectorEffect(BName, ParentID, Scale, KUnit,
  - AddOutput(Fuel, ParentID, ShortfallImport, SurplusExport,
  - AddProcess(BName, ParentID, Fuel)
  - AddTechnology(BName, ParentID, Scale, AcUnit, Fuel, Ener

L6 C26 Edit scripts in top pane. PRINT messages appear in lower pane.

Close | Help

Transport Stock-Turnover Modeling in LEAP

- In earlier activity level analysis we were always dealing with the average characteristics of all devices (averaged across new and old).
- In a stock-turnover analysis we want to reflect the different characteristics of vehicles of different ages (vintages).
- Vehicle characteristics will change as vehicles get older (emissions profiles, km driven, fuel economy, etc.)
- We also want to reflect how transport policies affecting new vehicles (e.g. new fuel economy standards and emissions standards) will have a gradual impact as older vehicles are retired and newer vehicles are purchased. So we need to model how long vehicles survive on the road.
- Ability to examine fuel switching and multi-fueled vehicles independently of transport stock turnover,

Key Assumptions

- **Key Assumption Variables** are used for creating additional user-defined variables such as macroeconomic, demographic and other time-series variables.
- Can hold exogenous variables (input assumptions) and can also be used to calculate intermediate results using LEAP's expressions.
- You can also add your own **User Variables** which are visible in the Demand, Transformation and Resource branches, and **Indicator Variables**: which are used to calculate additional results after all other LEAP calculations are complete.

Indicators

- Optional additional branches in the tree used to calculate user-defined results variables.
- Just like **Key Assumptions**, they are not used directly in LEAP's calculations.
- Unlike Key Assumptions, Indicators are calculated after all other LEAP calculations are complete, so they can include direct non-lagged references to all other data and results variables.
- Can make use of a series of **Indicator Functions** that calculate normalized comparisons between regions and scenarios, (e.g. scores, rankings, ratios, etc.).

Registering LEAP

Enter this in LEAP under the Help: Register screen (not the Help: Register Online)

- **User Name:** USAID Workshop
- **Password**: 967-836-014-995-226
- Software Expires: 5/30/2014
  - after this date, saving changes to data will be disabled

This green growth country assessment for FYR Macedonia aims to define the outlines of a green growth path and the initial steps along the path. Macedonia, like many countries, is already moving in a green direction. The Macedonian economy continues to evolve, with ongoing programs of structural reforms to improve growth and competitiveness and with growing alignment with Europe.

http://issuu.com/world.bank.publications/docs/fyr_macedonia_green_growth_country_

This study on Poland is part of the World Bank's series of low-carbon growth studies. It poses the question of how Poland, an EU member state, an industrialized 'Annex I' country for the purposes of international climate discussions, and an OECD member, can transition to a low emissions economy as successfully as it underwent transition to a market economy in the early 1990s.

http://issuu.com/world.bank.publications/docs/lowemissionseconomy

THE WORLD BANK

Computable General Equilibrium (CGE) Models for Climate Change Policies

Erika Jorgensen, Economic Adviser, World Bank

USAID Course on Economic Analysis and Planning for Climate Change Mitigation and Adaptation

May 2, 2014

Contents

Introduction to computable general equilibrium (CGE) modeling for energy and climate change policies

- 1. General Equilibrium Modeling for Energy and Climate Change Policies
- 2. Examples from World Bank country studies: Poland, Macedonia, Brazil, Mexico

Introduction to computable general equilibrium (CGE) modeling for energy and climate change policies

WHY IS COMPREHENSIVE MODELING NEEDED FOR CLIMATE CHANGE POLICY?

- Obligations under international agreements (Kyoto, UNFCCC) and regional agreements
  - E.g., EU obligations under Climate and Energy package and EU priority given to greening of growth
- Many sectors, significant changes expected ➔ transition and transformation of economy?
- Multi-sector economy-wide effects will shift paths of growth and employment
- Fiscal variables will be affected: revenues, public investment demands, safety nets
- Economic analysis can assess tradeoffs, price priorities, and improve policymaking

STRENGTHS OF (QUANTITATIVE) MODELS

- **Consistency:**
  - causal relationships based on sound theory (e.g. natural science or microeconomics)
- **Complexity:**
  - system boundaries (e.g. market interactions/imperfections)
  - structural policy changes
  - non-linear relationships
- **Policy relevance:**
  - magnitude of trade-offs (order of magnitudes)
  - coverage of policy options (instruments) and indicators
  - empirical foundation (e.g. micro-econometrics)
- **Robustness (sensitivity analysis):**
  - Systematic and consistent analysis of complex relationships between assumptions (inputs) and results (outputs)
  - Relative importance of uncertainties

In essence: *„Models provide a lens on data.“*

The Modeler‘s Dilemma

The dilemma:

- “Simple” theoretical analysis in a 2nd best setting already allows for wide-range of model results (order of magnitude, sign of policy impact).
- Numerical models add complexity and no longer allow for analytical solutions.

Black-box results to non-expert modelers

“Opening the black box”:

- Disclosure of model assumptions and data
- Non-technical interface to policy analysts
- Extensive sensitivity analysis and sensible policy conclusions
- Peer-reviewed publications

Complex climate change policy questions

- Long-term business-as-usual (baseline) growth path
- EU and national energy and climate policy
- GHGs emissions reduction potential by sectors
- Technical abatement potential and cost
- Economic and fiscal consequences
- Impact on income redistribution: poverty and shared prosperity

MODELING WORK

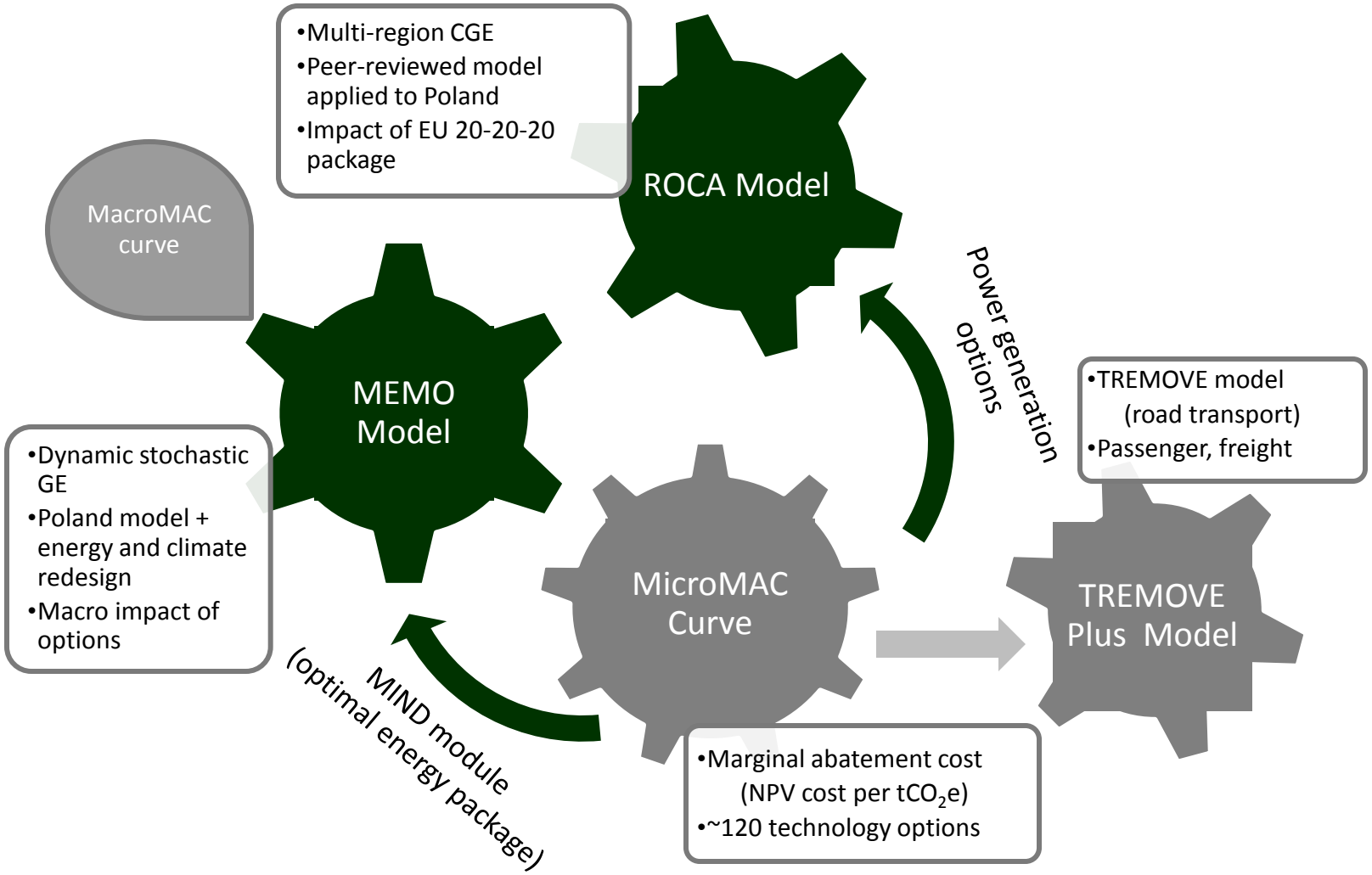
TWO DISTINCT APPROACHES AND THEIR COMBINATION

1. **Using aggregate macro data at the country or state level to analyze an energy-demand relationship**
   - *Main issue: impact on economic growth and sector output, employment, trade, production choices*

2. **Using micro-level data that reflects individual and household behavior to examine the ownership and the use of energy-consuming devices and consider efficiency scenarios from an engineering point of view**
   - *Main issue: abatement opportunities, technologies/investments, marginal abatement cost*

3. **Linking top-down and bottom-up analysis: Poland study as a good example**

Approach to macroeconomic modeling: the center of a suite of complementary and interlinked models (example from the Poland study)



Lessons and conclusions of Low Carbon analysis

- Low carbon development is a **gradual process** built on long-term relationships
- Small investments in tools and planning can have a **big payback** in terms of scaling up deployment
- **Avoid reinventing the wheel** - make use of existing models and tools
- **Be bold**, but don't underestimate the challenge of turning plans into investments and policy change
- The need to **tailor analysis to the country's needs** – sub-sectoral work can be equally valuable

1. General Equilibrium Modeling for Energy and Climate Change Policies

Policy Need: Trade-off Analysis

- **Information for rational decision making:**
  - Magnitude of costs and benefits
  - Distribution of costs and benefits
  - Conflicting objectives

  } for alternative policy options

- **Policy support:**
  - Policy-relevant robust insights
  - High priority areas for future research (“missing gaps”)

The Rationale of Policy Intervention

- **Market failures as a justification for policy interference:**
  - Competitive markets as efficiency yardstick
  - Market failures may justify collective action (policy interference) as sovereign consumers are not able to achieve overall efficiency:
    - external effects (e.g. CO2 emission from fuel combustion)
    - market power (e.g. natural monopoly in gas/power markets)
    - public goods (e.g. climate protection, R&D spillovers)
    - information asymmetries
- **Market distortions with further scope for efficiency gains:**
  - Distortionary taxes and subsidies
  - Administered price and quantity regulations e. g.:
    - Price ceilings
    - Quotas, standards

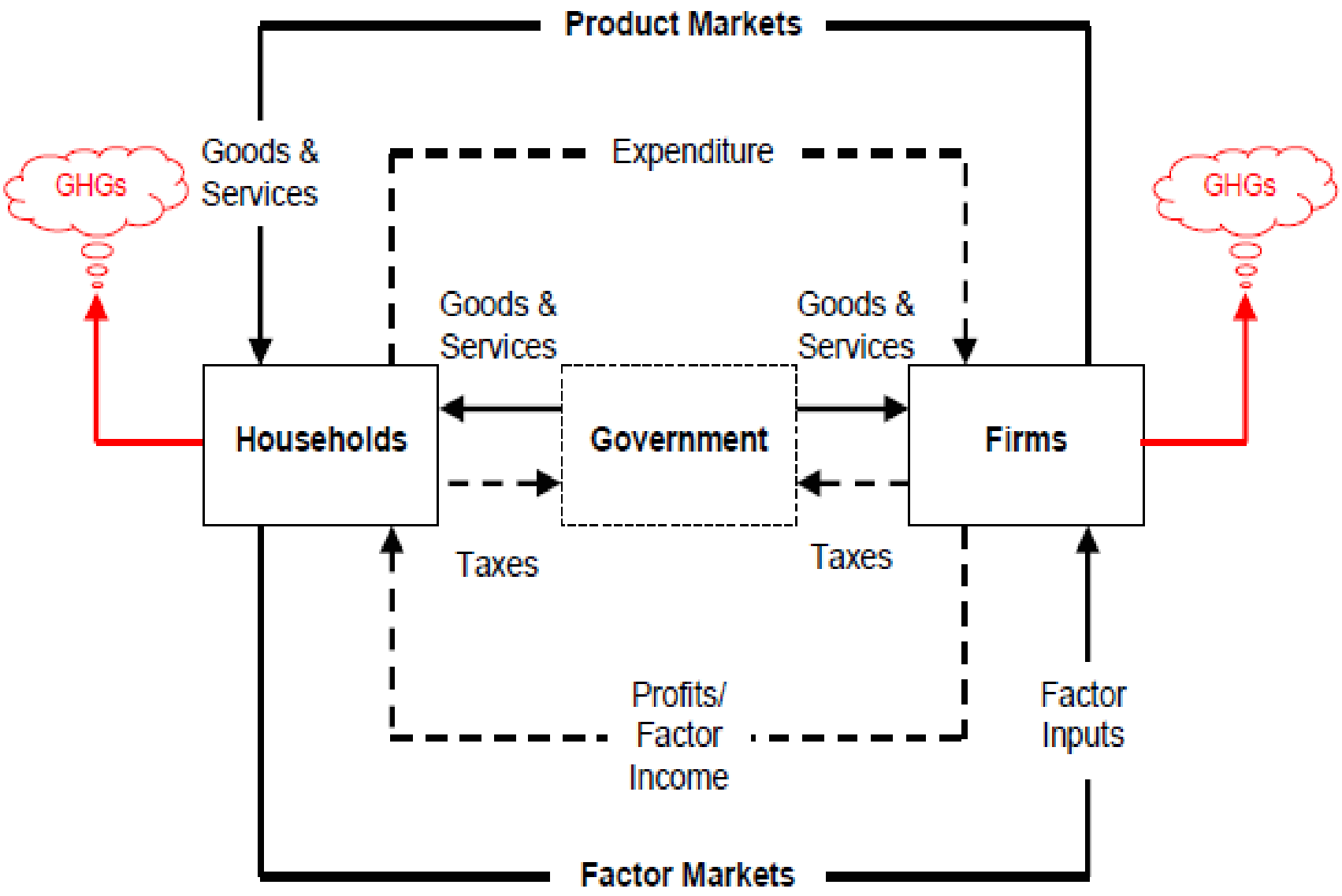
GENERAL EQUILIBRIUM MODELING

- Study of how equilibrium is determined in all markets simultaneously.
- An event in one market may have a spillover effect on other markets
- Markets are linked –through demand and –through supply
- Output in one market may be an input in another

Spillover Effect — A change in one market's equilibrium as a result of a change in another market's equilibrium.

Feedback Effect — A change in market A's equilibrium, which results from a change in another market's equilibrium, which was caused, initially, by a change in market A.

CIRCULAR FLOW

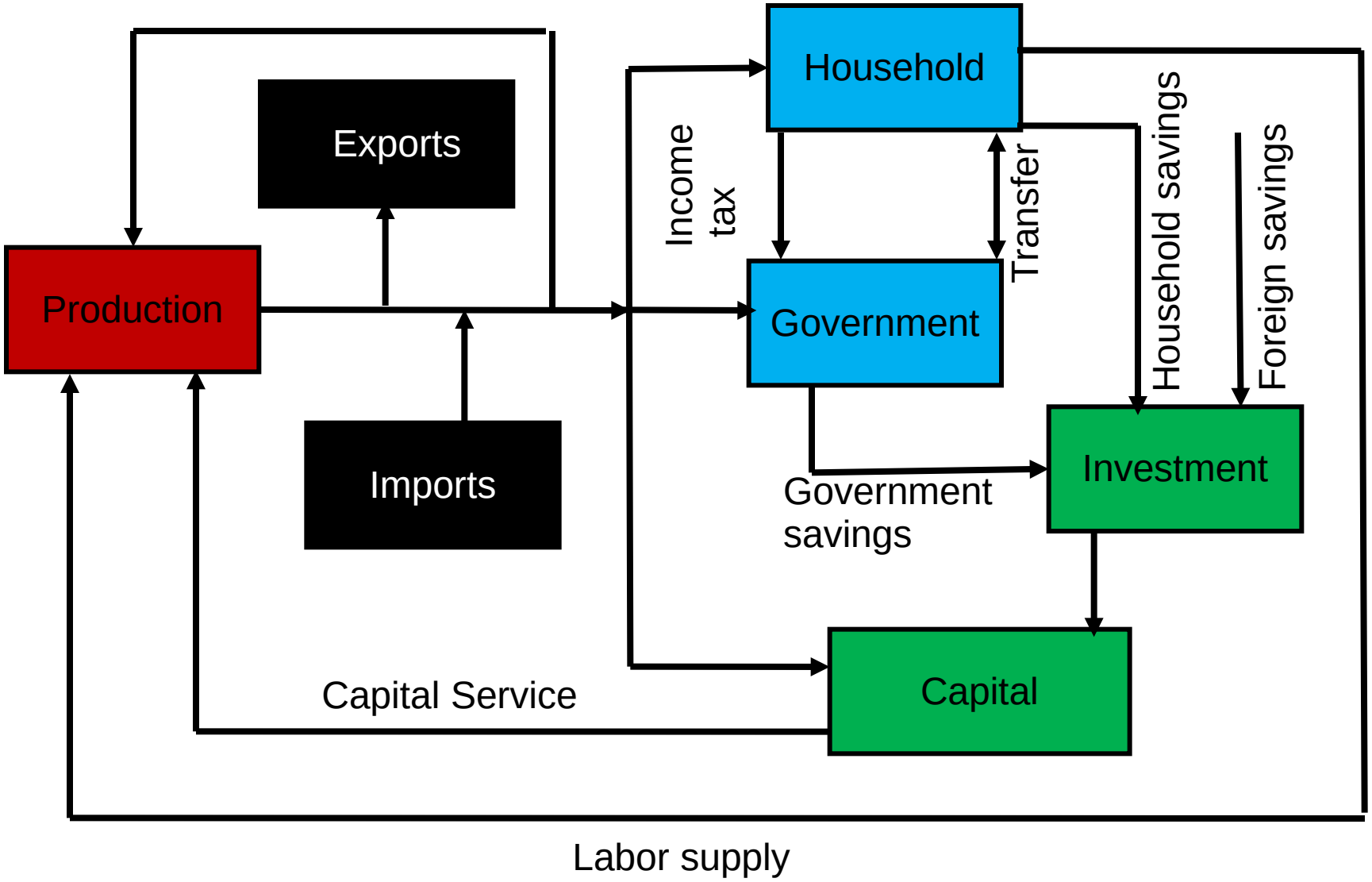


WHAT ARE CGE MODELS?

- A computable general equilibrium (CGE) model is a description of an economy using a system of simultaneous equations
- The "general equilibrium" idea implies that all the markets, sectors and industries are modelled together with corresponding inter-linkages
- This is opposed to "partial equilibrium" that only takes into account a part of the system (e.g. labor market), which neglects potential feedbacks
- This mathematical representation, coupled with a solver algorithm, ensures the "computable" nature of the model i.e. empirical results are generated

- Most CGE models rest on neo-classical economic assumptions
  - Consumers are assumed to maximise their utility subject to a budget constraint (demand-side)
  - Producers are assumed to maximise profit, given the prices of goods and factor of production costs (supply side)
  - For each good and factor of production, equilibrium price is calculated where that demand equals supply
- Can be used for "what if" simulations allowing one to obtain numerical results for endogenous variables based on assumptions about exogenous variables, functional forms, and parameter values

Schematic Diagram for a Macro Model



CGE Approach: Popular Caveats

- Idealized assumptions:
  Walras mechanism
  - price constraints (rationing)

- Lack of empirical foundation:
  calibration of functional forms
  - econometric estimation
  - maximum entropy estimation (goodness-of-fit)
  - sensitivity analysis

- Lack of technological detail:
  smooth functional forms
  - integration of bottom-up energy system models

- Lack of transparency:
  „black-box“
  - decomposition
  - visual interface

BENEFITS OF CGE

- Covers all the markets
- Consistency of data
- Deals with inter-industry linkages
- Theoretical consistency
- Takes into account trade-offs
- Financing of programs
- Captures changes in behavior
- Dynamics

AGENTS' BEHAVIOR & MARKETS

- **How do agents behave?**

–Microeconomics
–Functional forms
–Expectations
–Supply and demand functions for each agent, product, and factor.

- **How do markets operate?**

–Microeconomics (equilibrium, disequilibrium, rigidities, regulations, institutional constraints)
–Industrial economics (different types of imperfect competition, game theory, dynamics).

- **Key chains of causality in the economy**

Microfoundation of Macro-Models

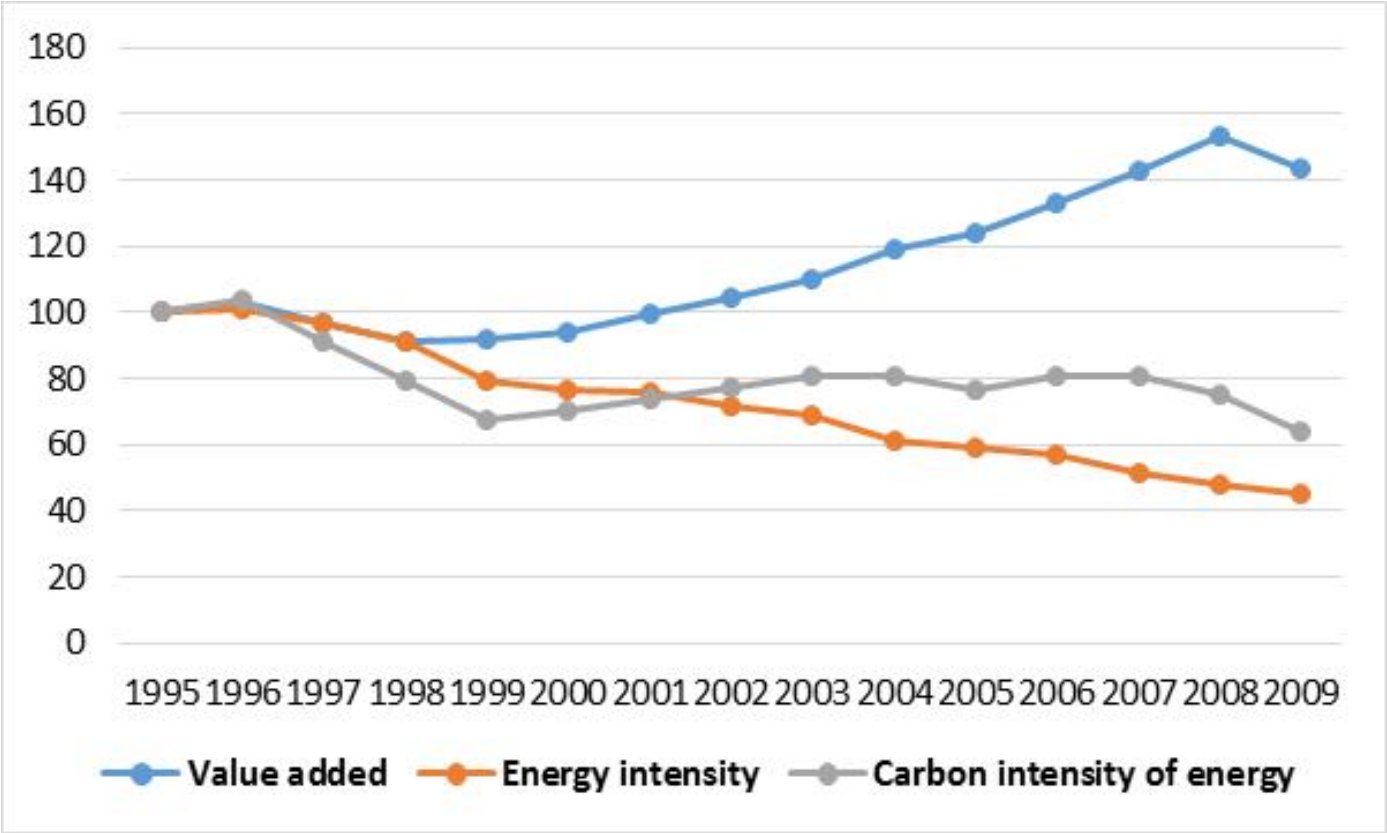
- **Microeconomic underpinning of macroeconomic relations:**
  - Economy-wide outcome as the result of optimizing behavior by individuals (households, firms – representative agent),
  - "Reconciliation" between microeconomic and macroeconomic theory: E.g. unemployment (wage curve) as a consequence of union bargaining
- **Normative basis (neoclassical economics):**
  - Individual preferences (consumer sovereignty)
  - Assumption of rationality
  - Competitive market paradigm: The allocation of scarce resources through competitive markets is pareto-efficient.
  - Separability of efficiency and distributional concerns (lump-sum transfers)

ENVIRONMENTAL FEATURES

- Energy consumption in detail
- Energy efficiency
- Renewables
- Alternative technologies
- GHG emissions
- Other pollutants
- International linkages
- Regional dimensions
- Health
- Productivity
- Environmental taxes
- Regulations
- Permits

What drives emissions

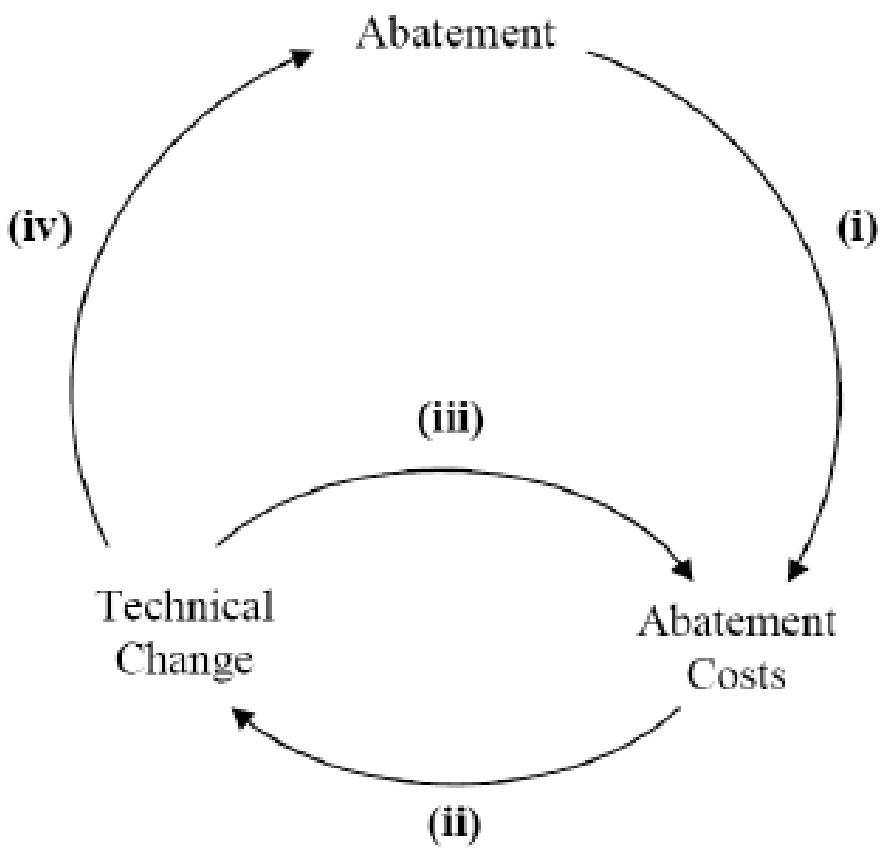
Historical perspective (Kaya decomposition of emissions)



$$Kaya\ decomposition\colon\ CO_2 = POPUL \cdot \frac{GDP}{POPUL} \cdot \frac{Energy}{GDP} \cdot \frac{CO_2}{Energy}$$

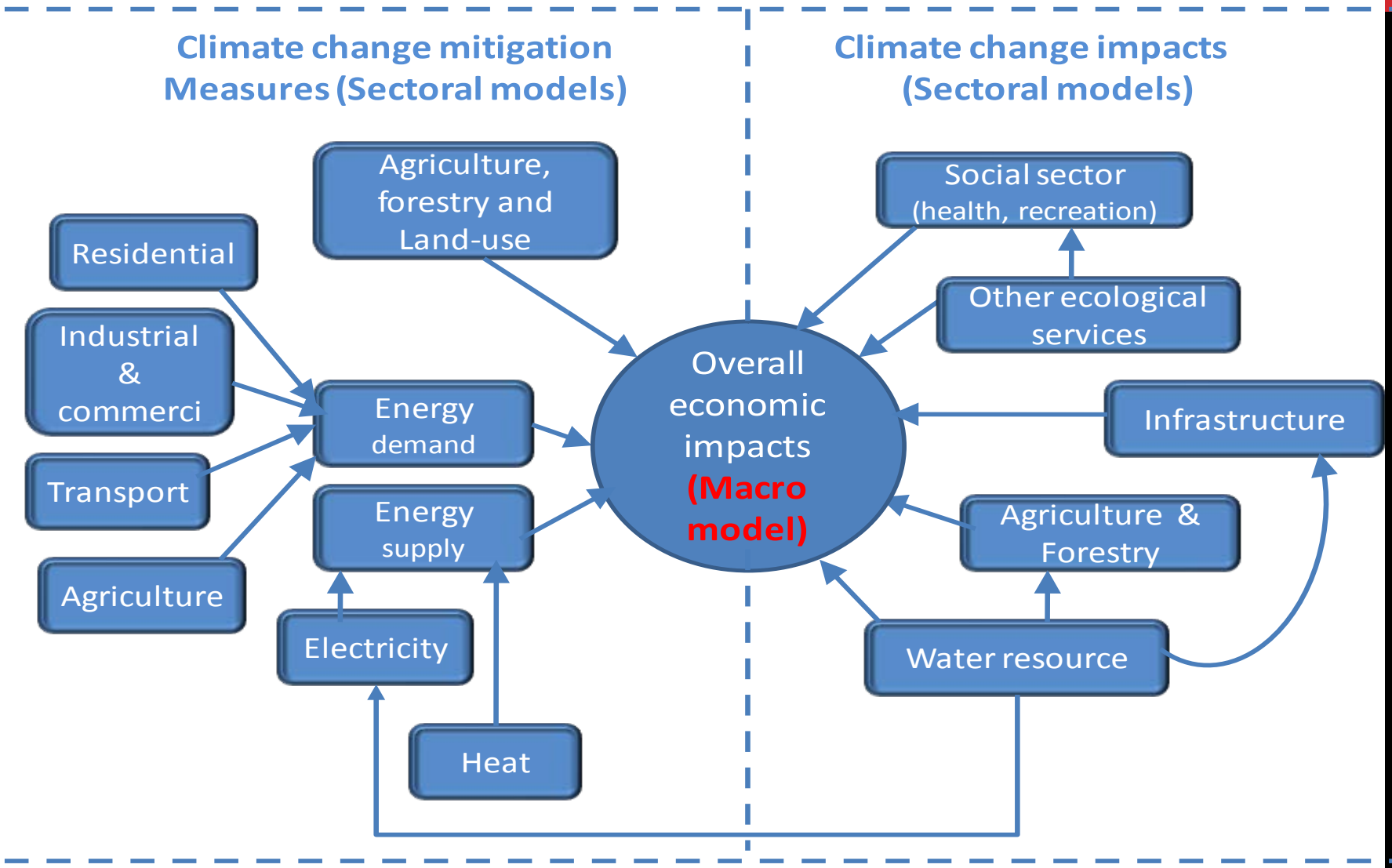
Source: World Bank staff calculations based on WIOD database.

CLIMATE-TECHNOLOGY INTERACTIONS

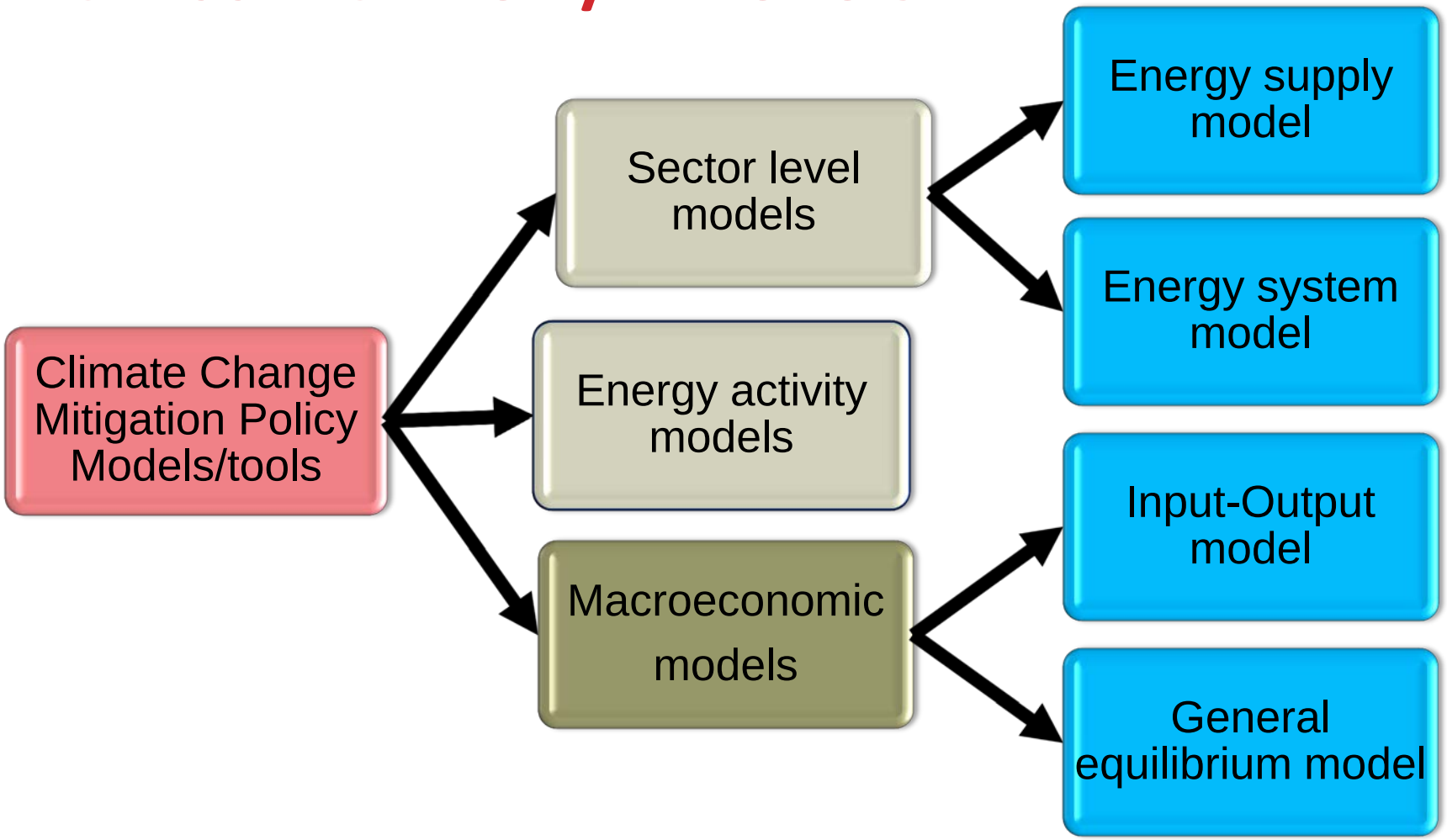


- Key processes:
  - (i) Direct effects of emission taxes/quotas on economy
  - (ii) Inducement of technological change
  - (iii) Economic and environmental consequences
  - (iv) Implications for optimal policy design
- Still need to understand mechanisms behind feedback loop (ii)-(iii)!

LOW CARBON ECONOMIC MODELING: A FRAMEWORK



MODEL CLASSIFICATION/TYPOLOGY



MODEL CLASSIFICATION/TYPOLOGY (CONT'D)

Model Type	Energy chain	Methodology	Example
Activity	Production, transformation, end-use	Benefit-cost analysis	McKinsey
Demand	Energy demand forecasting	Econometric End-use accounting	MAED, MEEDES
Supply	Energy supply analysis	Optimization Simulation	MARKAL, EFOM
System	Demand and supply	Mix of methodologies	ENPEP, NEMS, LEAP,
Economy	Linkages between energy system and rest of the economy	Input-output, macroeconomic, CGE	SGM, EPPA, MERGE,DICE

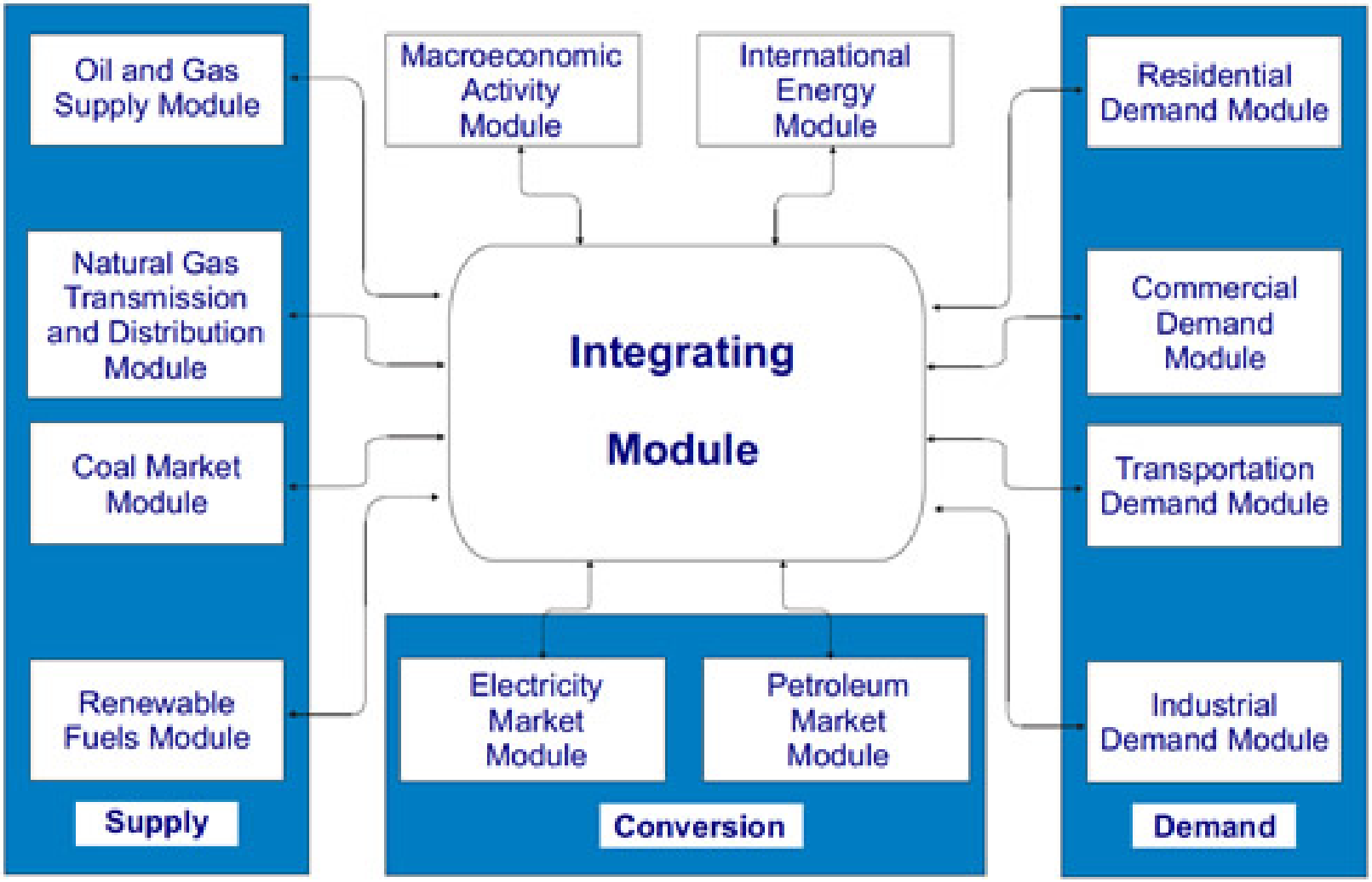
Energy System Models - Examples

Name	Developer
NEMS	US DOE
ENPEP	Argonne National Laboratory
LEAP	Stockholm Environmental Institute
TIMES	Energy Technology Systems Analysis Program (ETSAP) of the International Energy Agency (IEA),
MESSAGE	International Institute for Applied Systems Analysis, Austria
POLES	LEPII (formerly IEPE - Institute of Energy Policy and Economics), Grenoble, France
ENERGY 2020	Systematic Inc. (a US private company)

Energy System Model – US NEMS

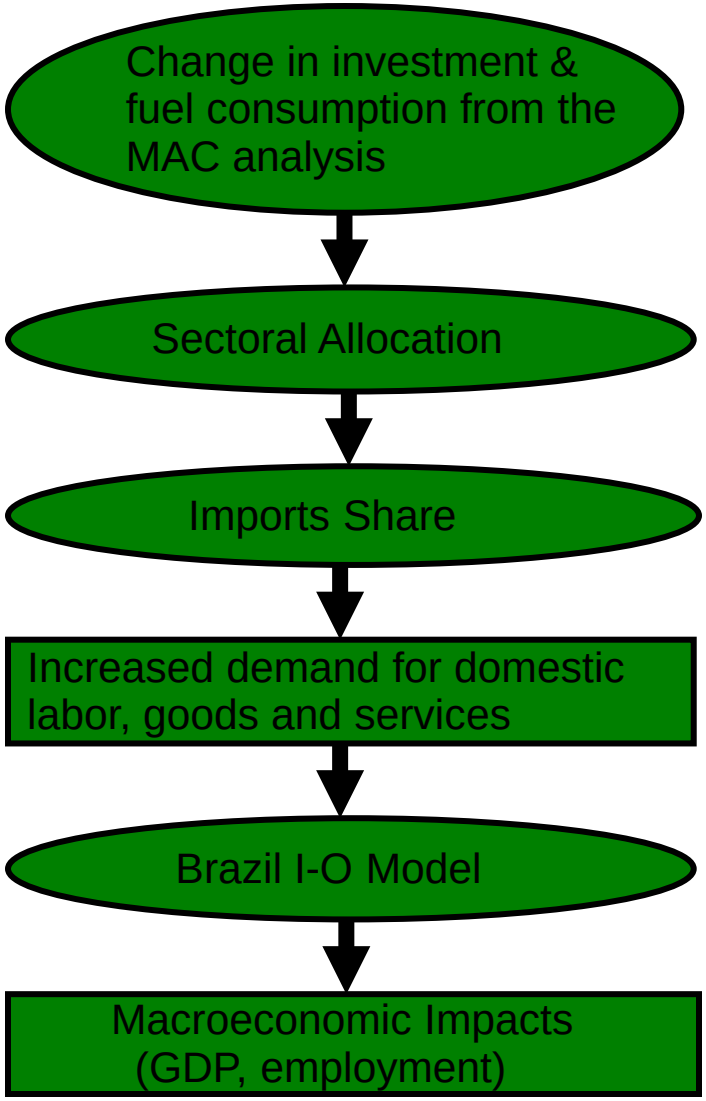
(An example of accounting model)

Figure 2. National Energy Modeling System

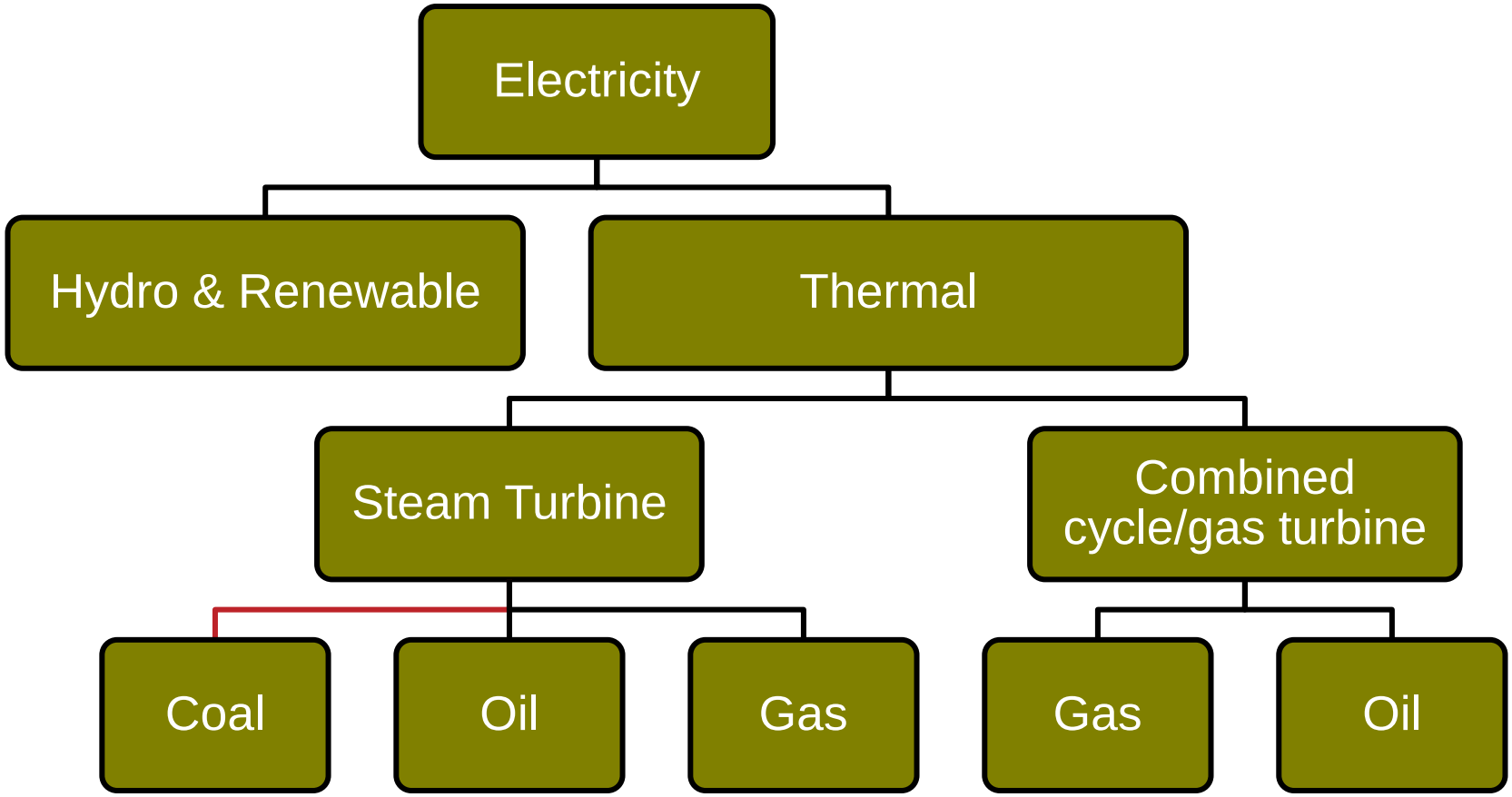


Source: EIA, USDOE (http://www.eia.doe.gov/oiaf/aeo/overview/figure_2.html)

Climate Change Mitigation Modeling
I-O Approach



REPRESENTING ELECTRICITY SECTOR IN CGE MODELS, AN EXAMPLE



2. Examples from World Bank country studies: Poland, FYR Macedonia, Brazil, Mexico

LOW CARBON studies: World Bank has piloted approaches, methodologies, tools

Pilot low carbon study program

- Brazil, China, India, Indonesia, Mexico, South Africa, and Poland
- Spanned period 2007-11, taking approximately 2 years each
- Next generation: linked to new drivers (specific WB operations, NAMAs): Macedonia, Morocco, Nigeria, Tunisia, Vietnam

Lessons

- Small investments in tools and planning can have big payback as deployment is scaled up
- Take advantage of growing number of useful models and tools
- Don’t underestimate challenge of turning plans into investments and policy change
- Tailor analysis to the country’s needs

BRAZIL

Methodology:

- Undertook a bottom-up modeling exercise with substantial amounts of original work on forestry emissions

Conclusions:

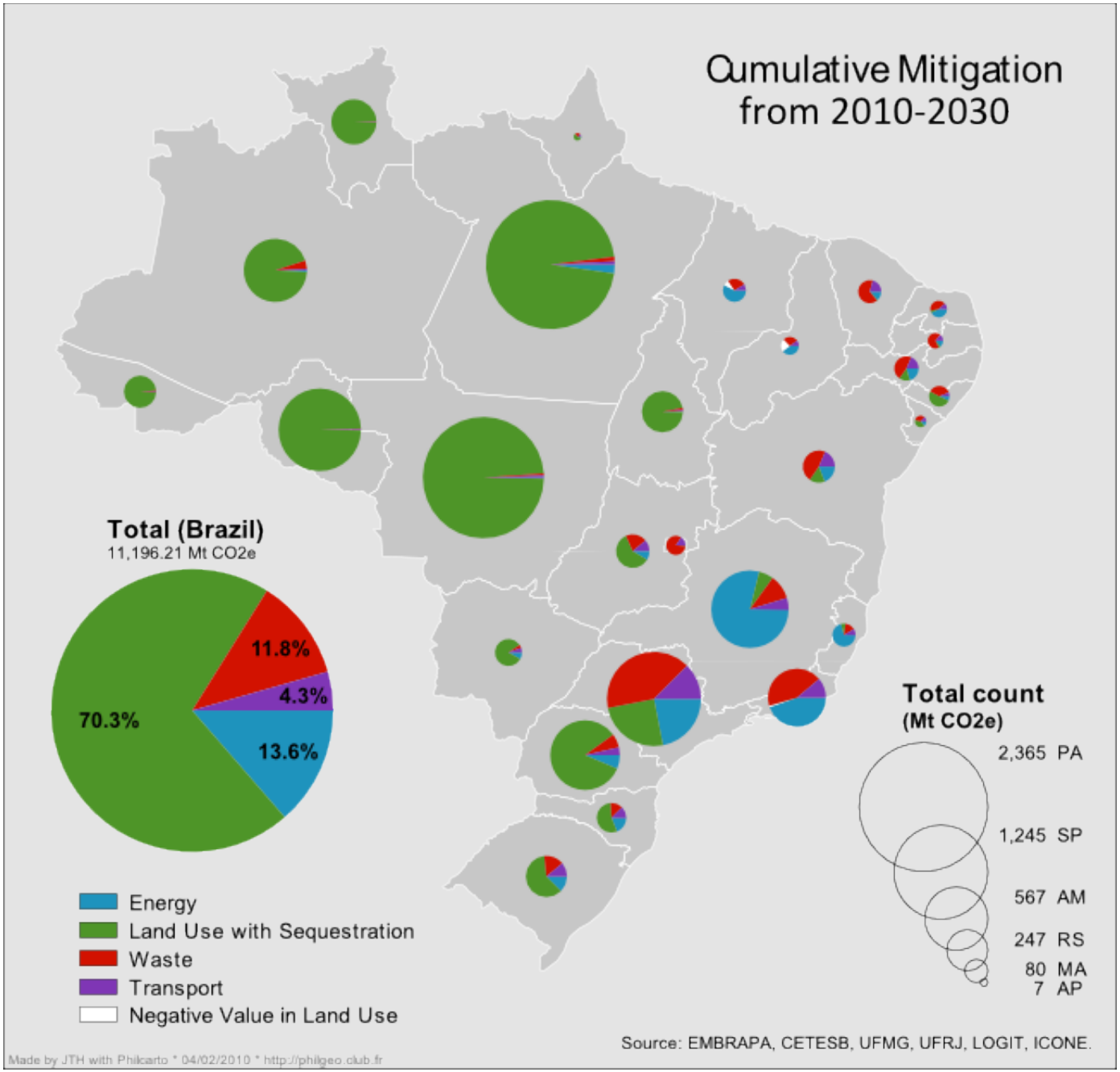
- Deforestation will remain the key driver of GHG emissions to 2030
- Energy matrix of the country is already low-carbon, but emissions from fossil fuel dependent subsectors like urban transport, thermal power generation and industrial processes could experience high emissions growth to 2030

Impact: $1.1 billion RE / EE DPL approved June 2010, on the back of…

- An ongoing and growing national debate on climate change fuelled by study, including the national consultative debate that laid out the implementation of the national climate change plan and law that contains voluntary commitments presented by Brazil in Copenhagen and Cancún
- Preparation of a new $99 million loan in the energy sector aimed at improving energy efficiency

IDENTIFY FEASIBLE MITIGATION OPTIONS …

HIGHLIGHTS FROM BRAZIL



CHINA

Context: **Government targets a reduction in energy intensity while achieving 8-10% economic growth annually**

Methodology: **World Bank asked to provide three policy notes on RE targets, power dispatch efficiency and cement sector efficiency**

Conclusions: **Lack of 'low hanging fruit' emphasizes need for detailed analysis; significant additional potential for carbon savings through RE and cement; limited potential in power dispatch due to trade-offs and compensation requirements**

Impacts:

- RE policy note helped Government refine targets in 12th Five Year plan
- Power dispatch note helped provide additional evidence to support current strategy to decommission small and medium plants
- Cement sector study helped lay groundwork for financing mechanisms that support the large up-front costs of high-efficiency motors and grinders that have significant life-cycle energy and financial savings

INDIA

Context: Government wanted to review strategies for low carbon growth to 2030

Methodology: Bottom-up modeling of specific sectors and capacity building

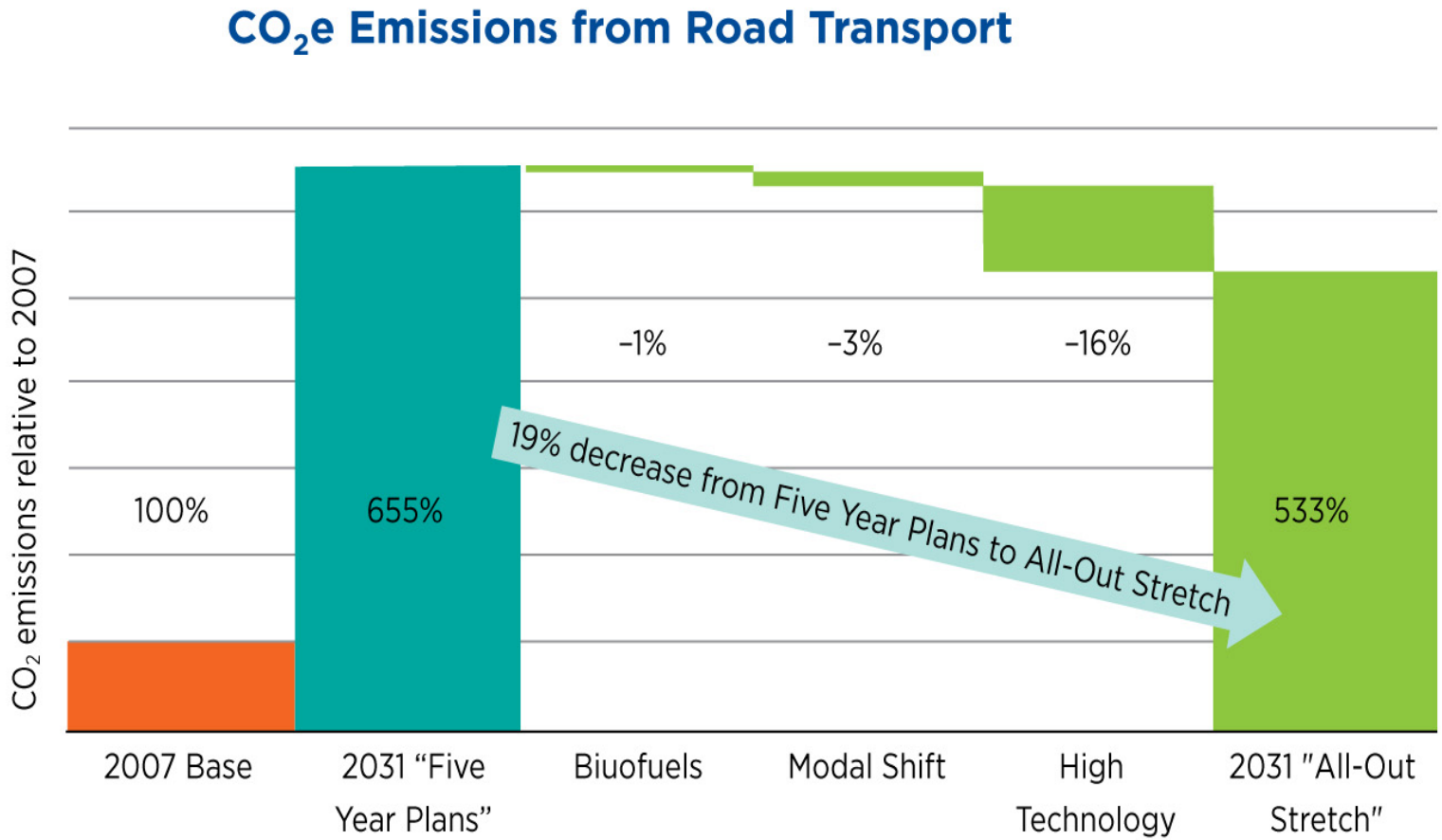
Conclusions:

- Despite efficiency improvements, expansion needs for power generation remain vast; six-fold increase to 2032
- Policies such as the solar expansion plan will require massive funding (up to $64 bn) and technology transfer to be viable
- Challenge of urbanization and increasing transport emissions

Impact:

- Study has been able to bridge the 'dialogue and knowledge gap' between national and international policymakers

INDIA



Source: World Bank staff calculations.

SOUTH AFRICA

Context: **Government request for international peer review of the Long-Term Mitigation Scenarios prior to submission to the Cabinet and the provision of substantial technical assistance on energy efficiency, demand-side management, and power rationing**

Methodology: **Peer review and technical assistance**

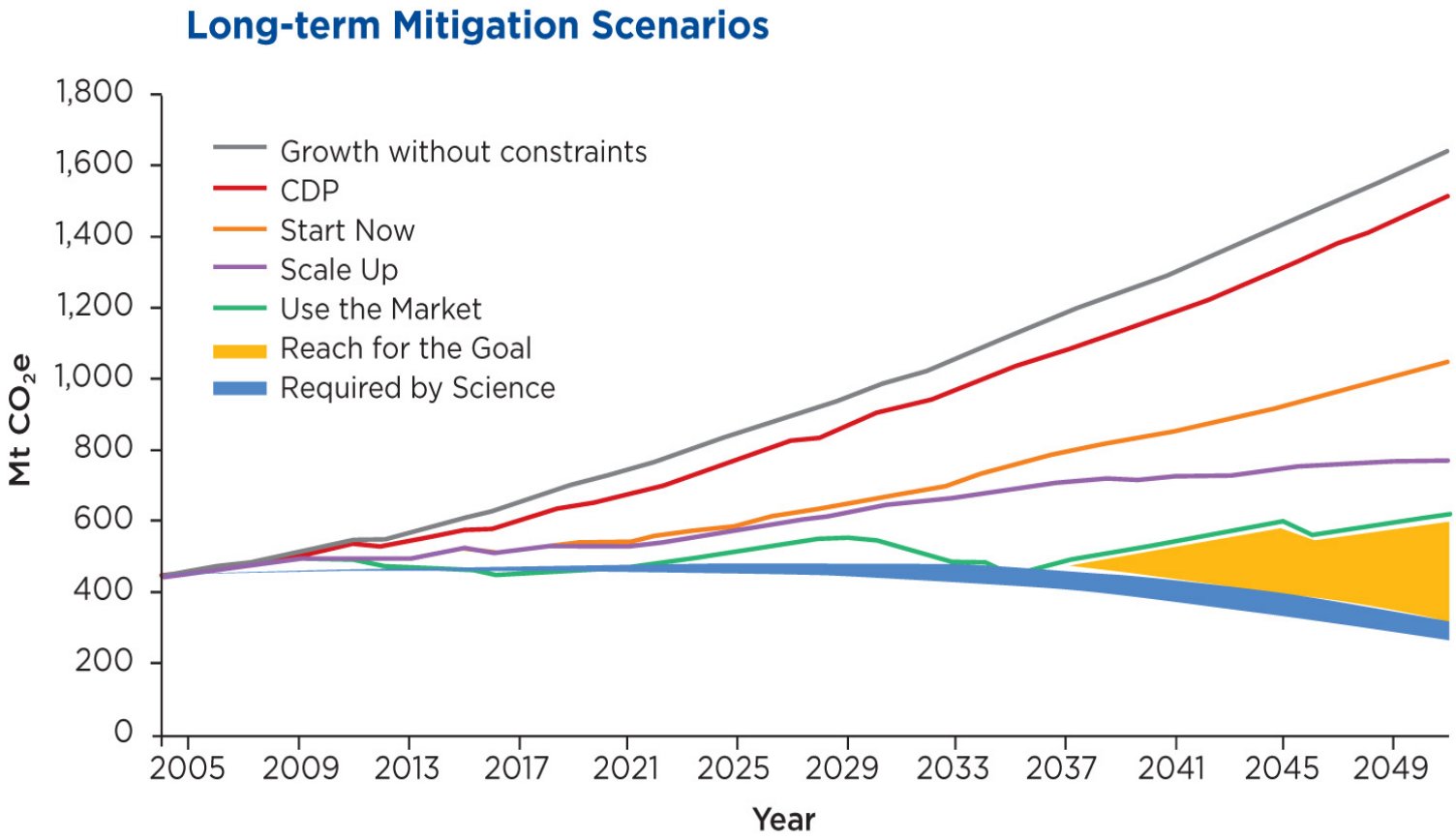
Conclusions:

- Opportunities for reductions in current levels of GHG emissions in every consuming sector: EE, DSM, solar water heating, and renewable power production

Impact:

- Standard Offer Programs recommended in the study, currently being implemented by Eskom
- Projected savings in Eskom's Integrated Resource Plan of 2009 of about 8,700 GWH by 2015 (not including solar water heaters) will be exceeded with the introduction of the Standard Offer Programs

SOUTH AFRICA



Source: Government of South Africa, Department of Environmental Affairs, 2008.

MEXICO

Context: Government had previously established a national climate change strategy; was preparing an Action Plan for specific sectoral interventions

Methodology: World Bank was asked to look at economic cost and investment requirements of alternative sectoral scenarios

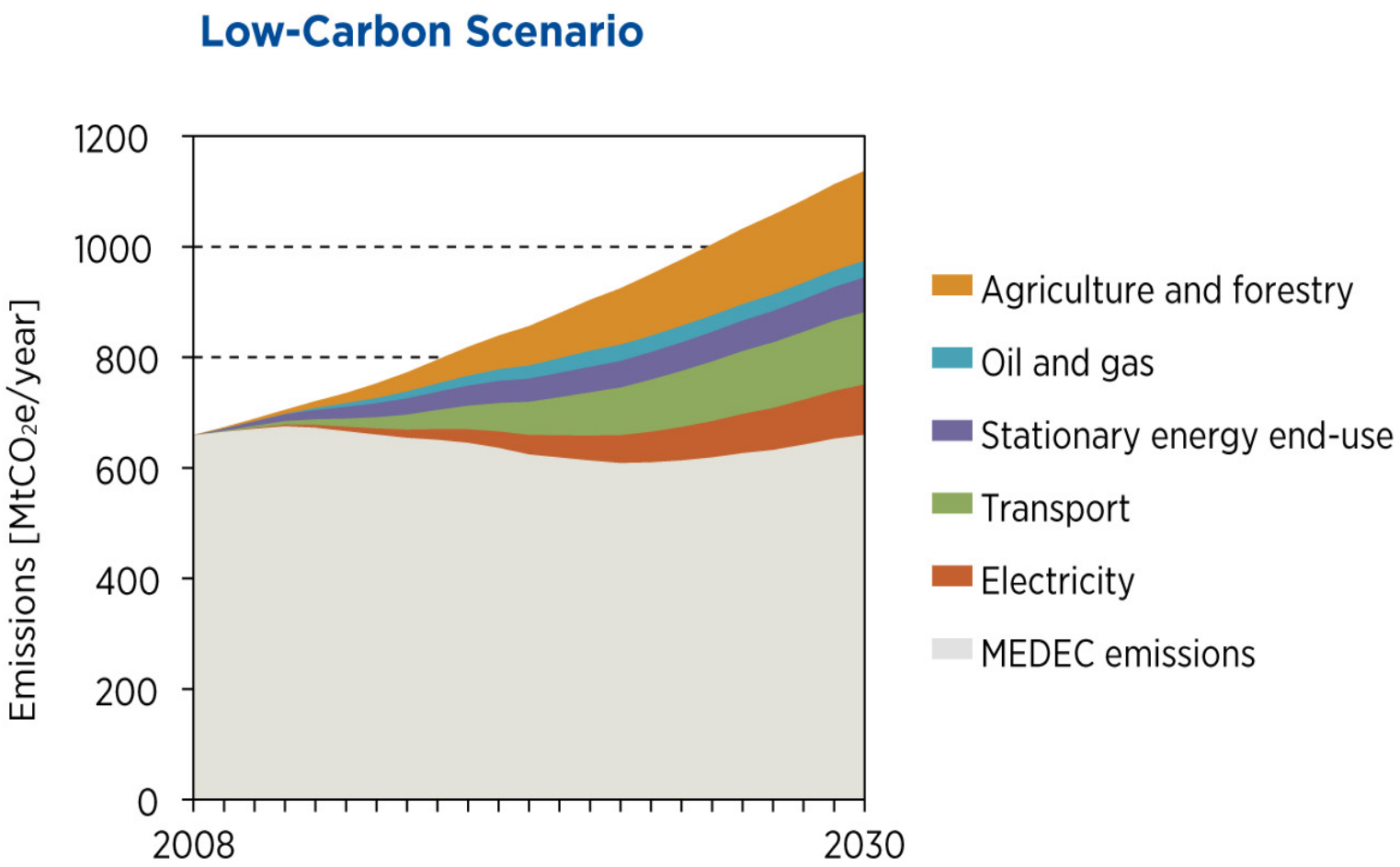
Conclusions: Estimate of $64 bn to 2030 ($3 bn/year) to adopt the 40 low-carbon measures identified by the study, including over the next five years…

- Electric Power: wind farm development
- Oil and Gas: cogeneration
- Energy end-use: efficient lighting and appliances
- Transport: bus rapid transit
- Forestry: avoided deforestation

Impacts: study directly contributed to

- Mexico's investment plan to the Clean Technology Fund
- Development Policy Loan (US$401 million) from the World Bank for 'low-carbon development'
- Two investment loans by the World Bank on urban transport and EE

MEXICO


Low-Carbon Scenario
Emissions [MtCO2e/year]
1200
1000
800
600
400
200
0
2008
2030
Agriculture and forestry
Oil and gas
Stationary energy end-use
Transport
Electricity
MEDEC emissions

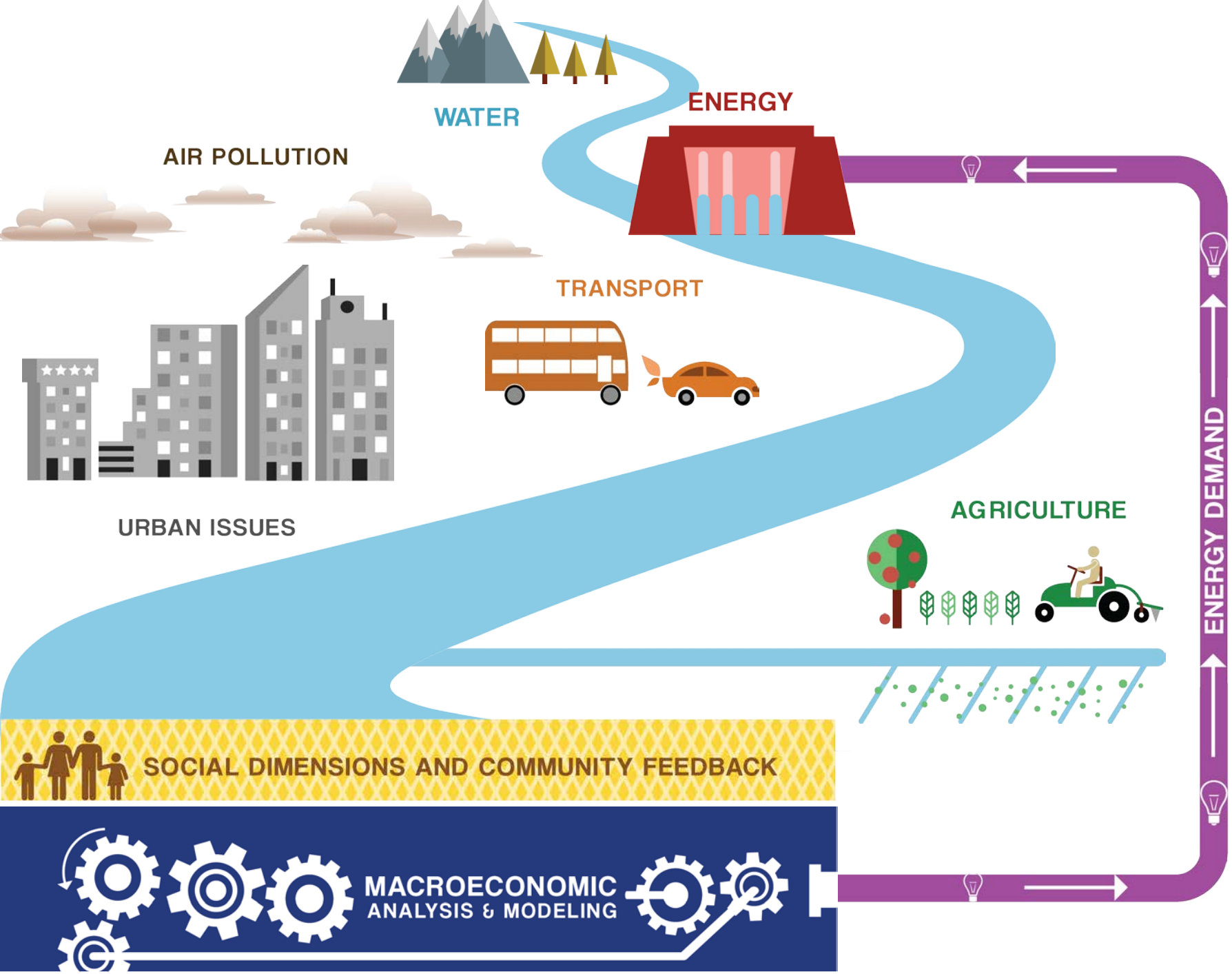
Macedonian Green Growth
and Climate Change Analytic
and Advisory Support Program

Sida

THE WORLD BANK

NORWEGIAN EMBASSY

A Country-Level Green Growth Assessment: Macedonian Green Growth & Climate Change Analytic and Advisory Support Program


WATER
ENERGY
AIR POLLUTION
TRANSPORT
URBAN ISSUES
AGRICULTURE
ENERGY DEMAND
SOCIAL DIMENSIONS AND COMMUNITY FEEDBACK
MACROECONOMIC
ANALYSIS & MODELING

Analytic Framework For Water Sector

Figure 4.3. Analytic Framework for Water Sector

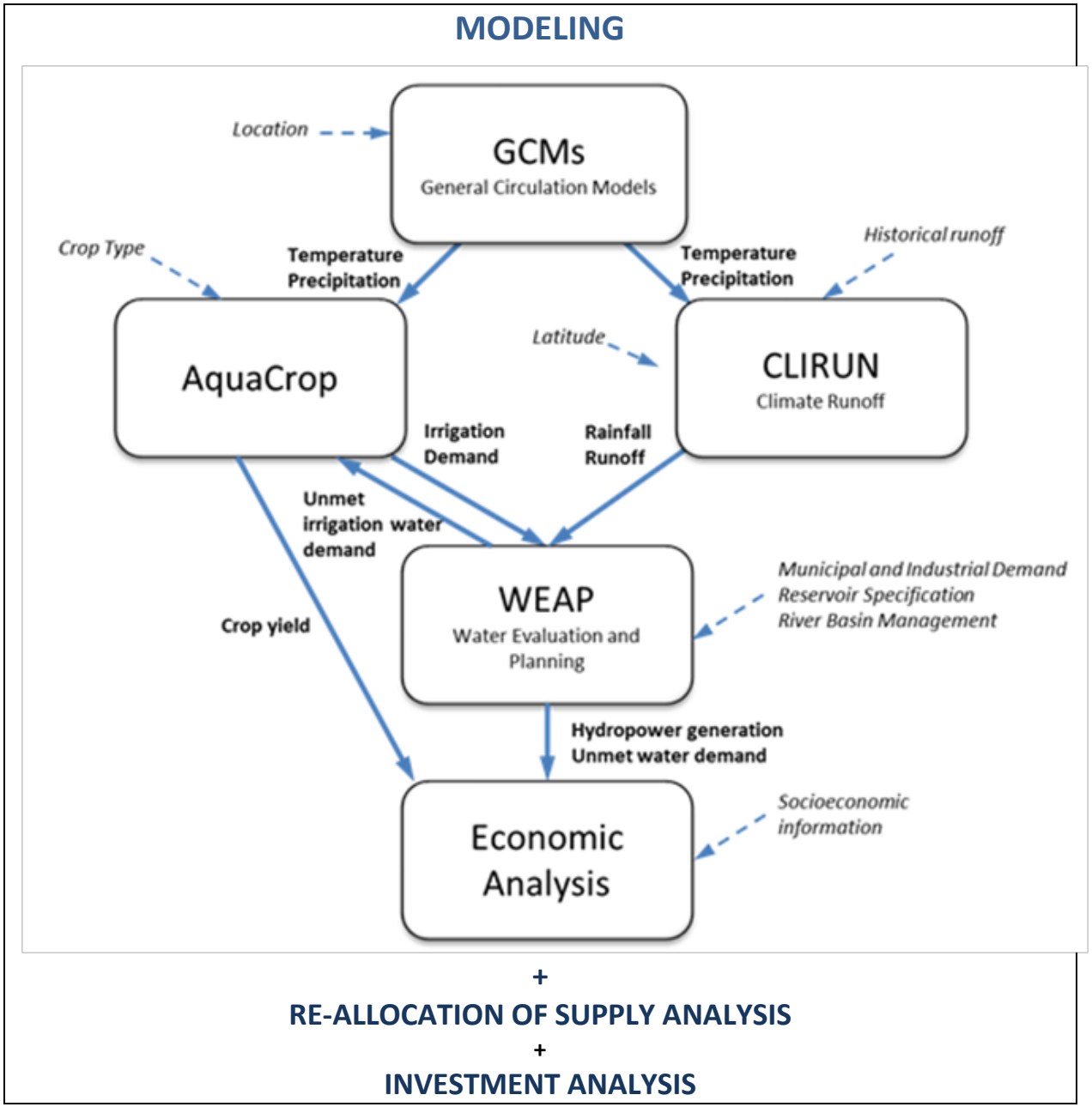
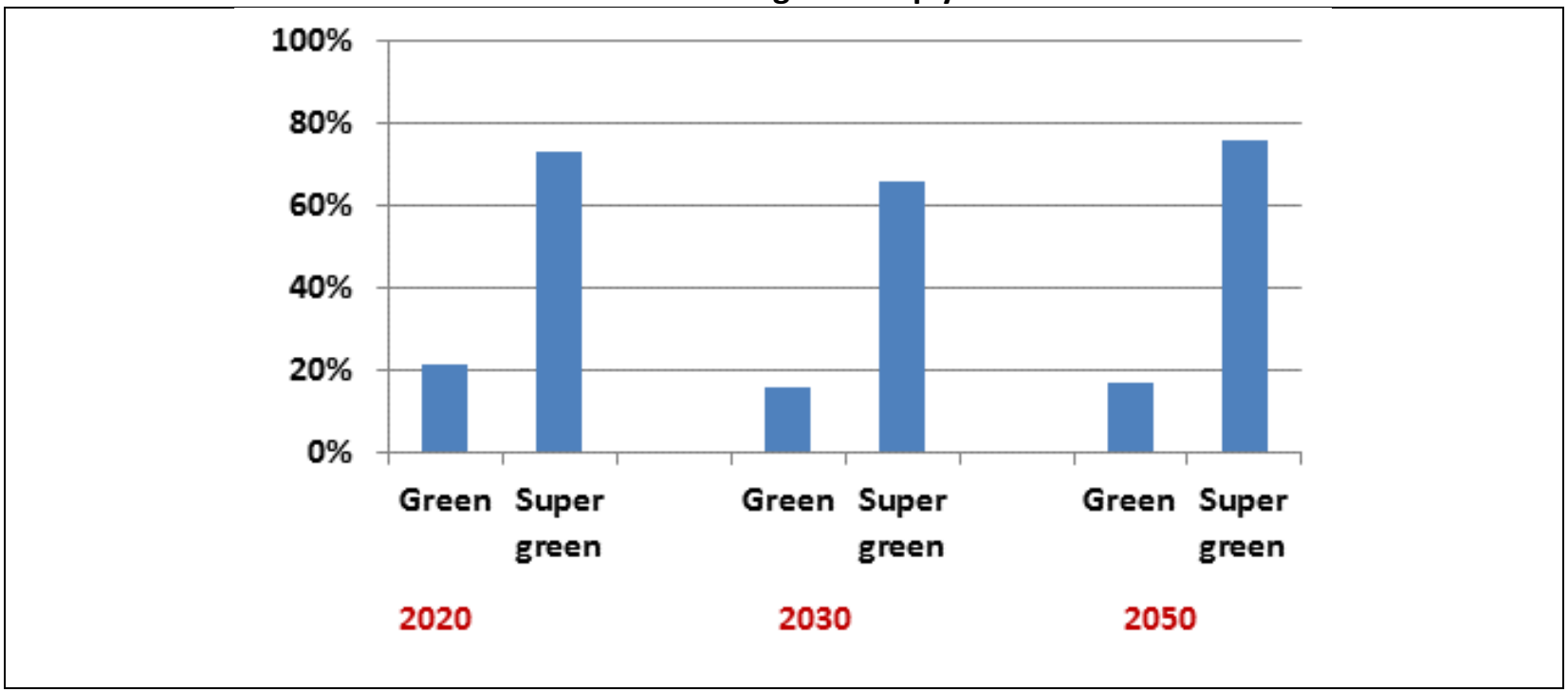


Figure 4.7. Green investments lead to increased efficiency in agriculture and hydropower

% increase in Green and Super Green scenarios as compared with BAU

a. Increased irrigated crop yields



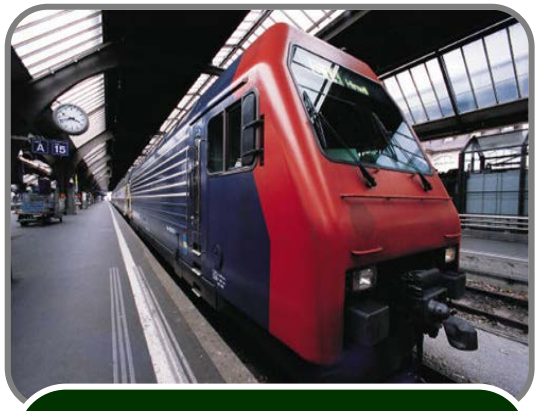
ELEMENTS OF POLAND'S LOW CARBON STUDY

Context and challenges

- Poland's greenhouse gas emissions
- Emissions abatement targets
- Business-as-usual scenarios for Poland

Suite of models

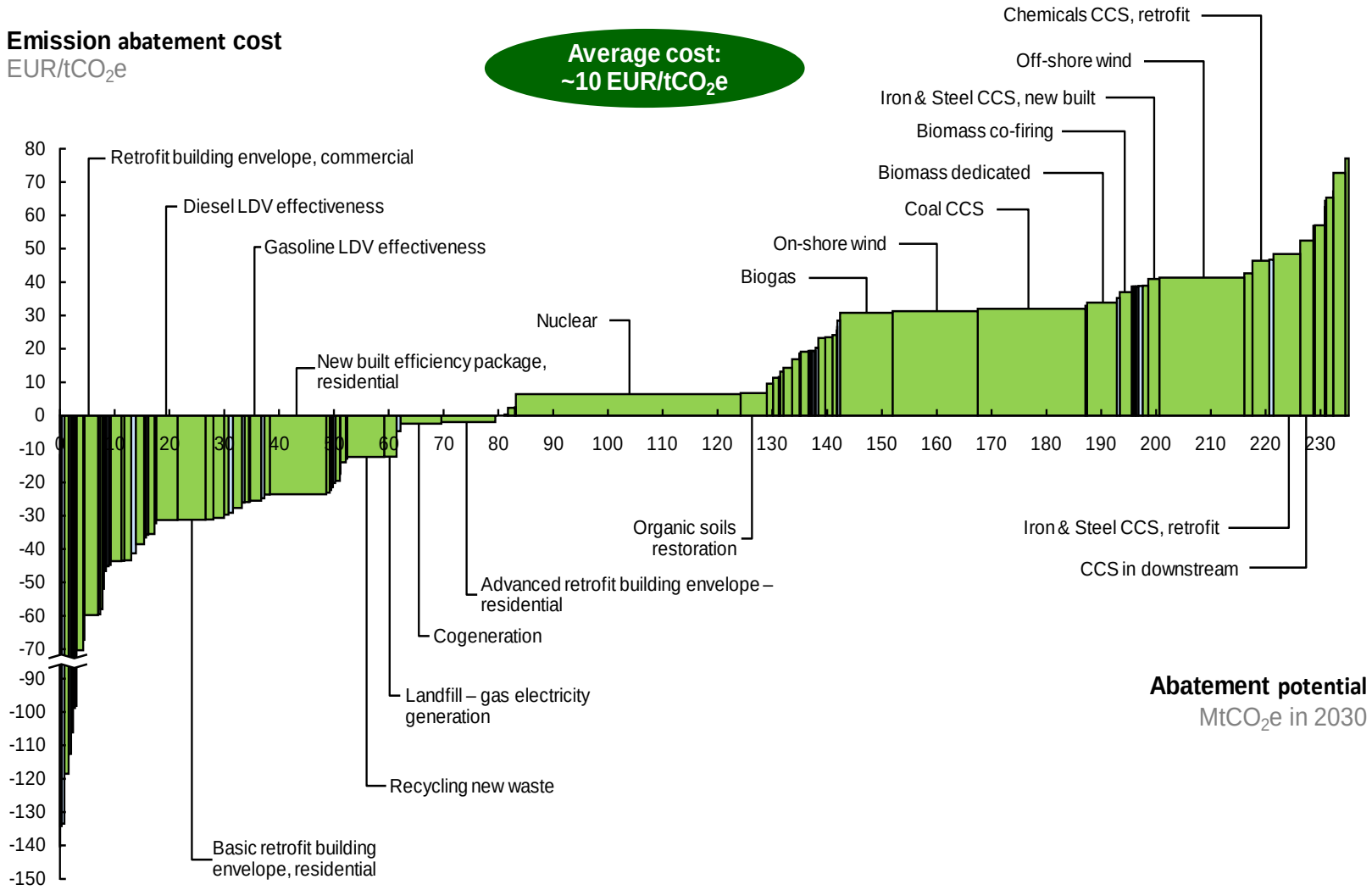
- Technical options for reducing GHG emissions
- Economic effects related to technical options
- Implementation of EU energy and



Results

- Three critical sectors for intervention
- Informing low-emissions strategy
- Readiness to analyze related issues in the future

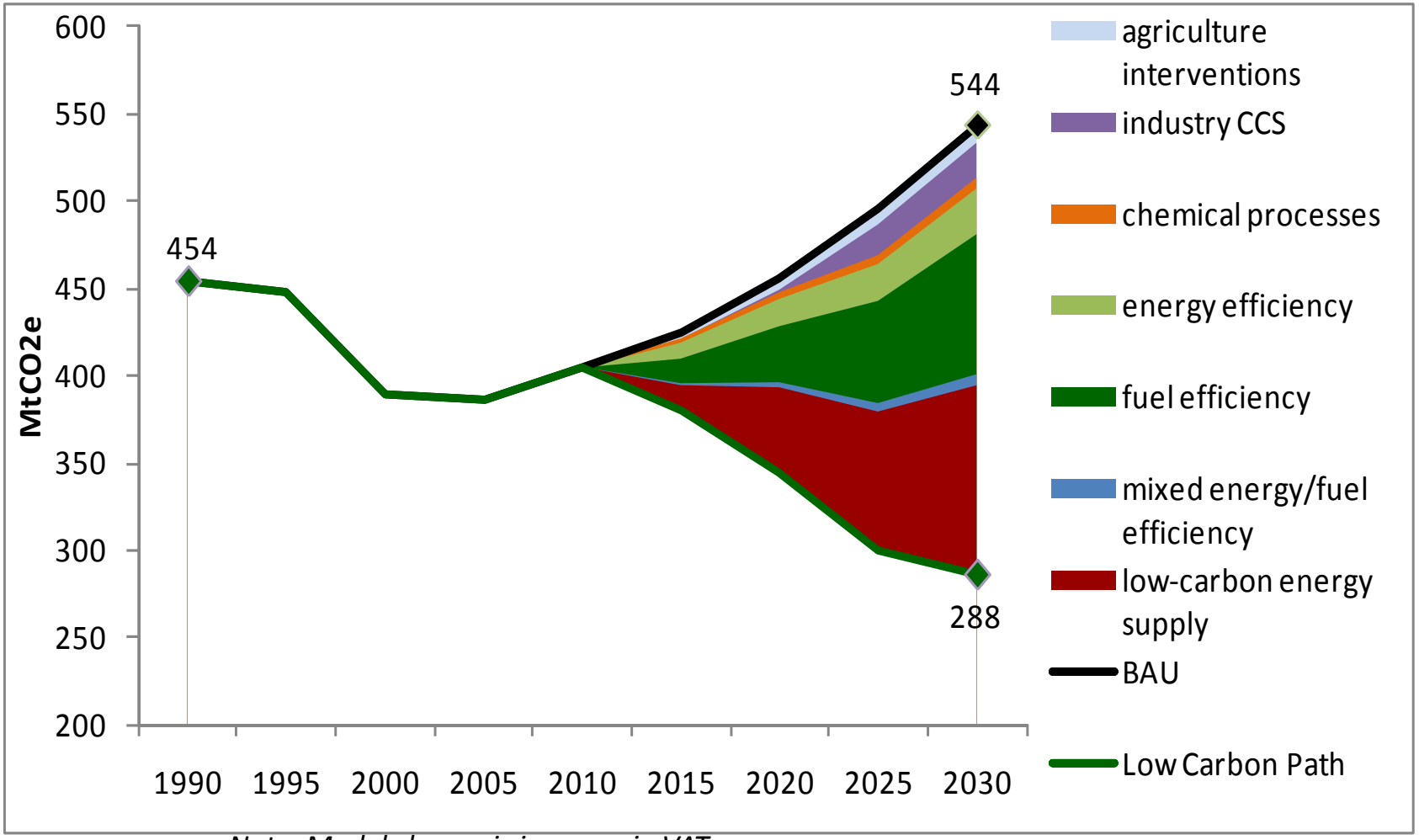
MICROECONOMIC MARGINAL ABATEMENT COST (MICROMAC) CURVE FOR POLAND, 2030



Note: Each column is one of the 120 abatement measures. The height of the columns is the cost in € per abated tCO_2e. The width is the amount emissions can be reduced against business-as-usual levels projected for 2030.

THE SWITCH TO LOW-CARBON ENERGY AND FUEL EFFICIENCY MEASURES PROVIDE THE BULK OF GHG ABATEMENT.

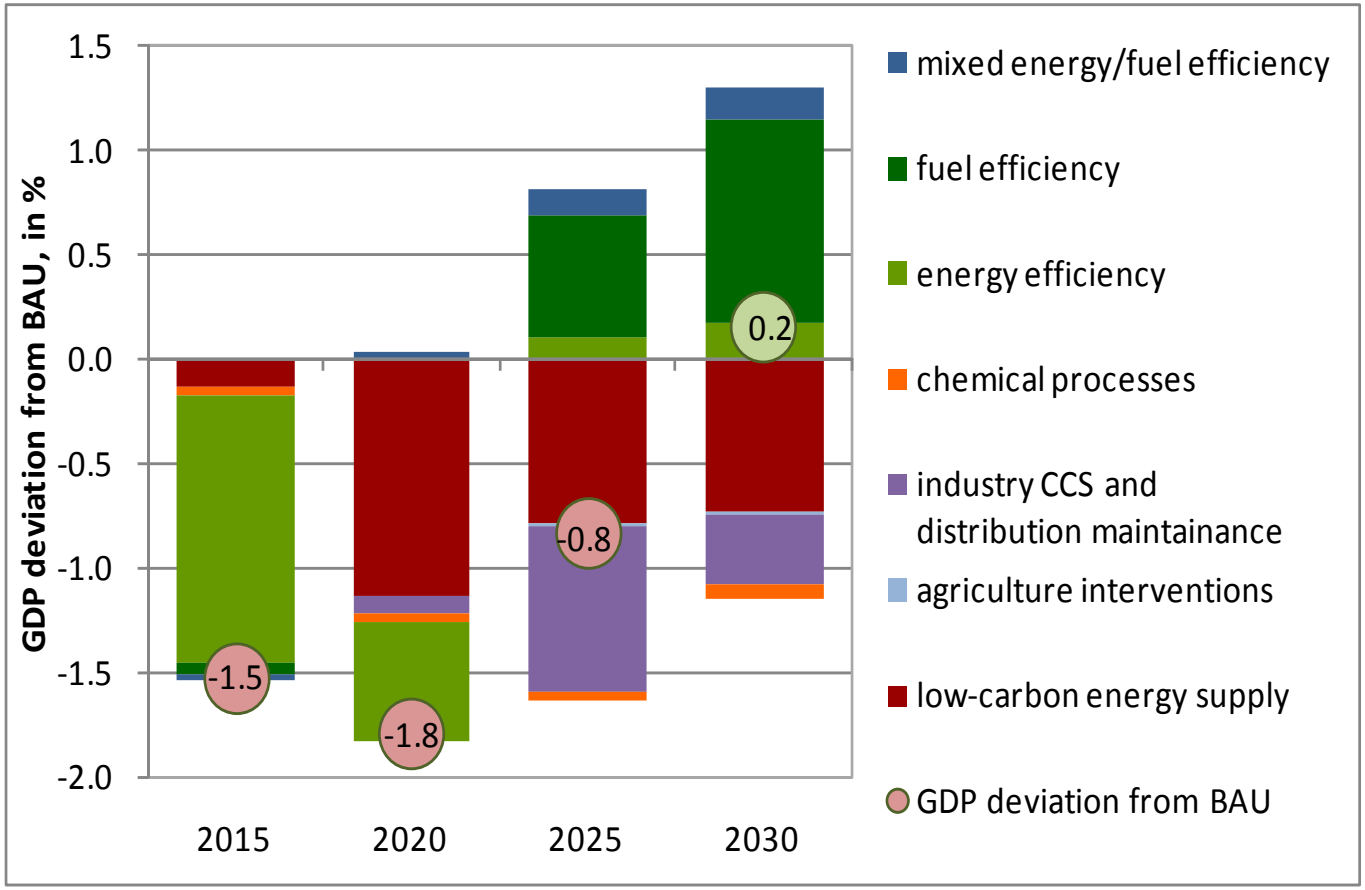
Decomposition of abatement by micro-package, $MtCO_2e$



Note: Model closure is increase in VAT.

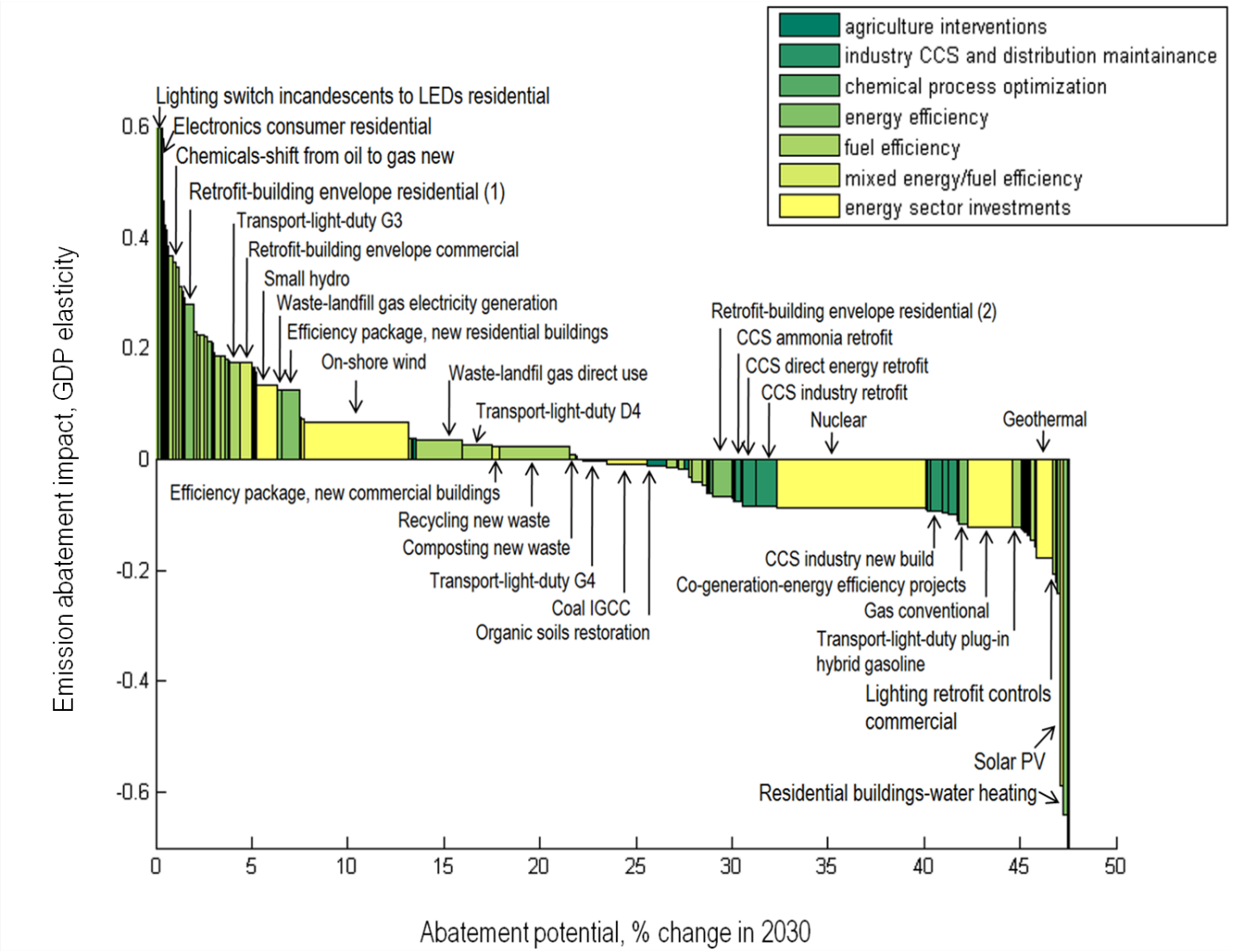
POLAND'S TRANSITION TO A LOW-EMISSIONS ECONOMY, WHILE NOT FREE OR SIMPLE, IS AFFORDABLE.

Decomposition of GDP impact of low emissions package, in %



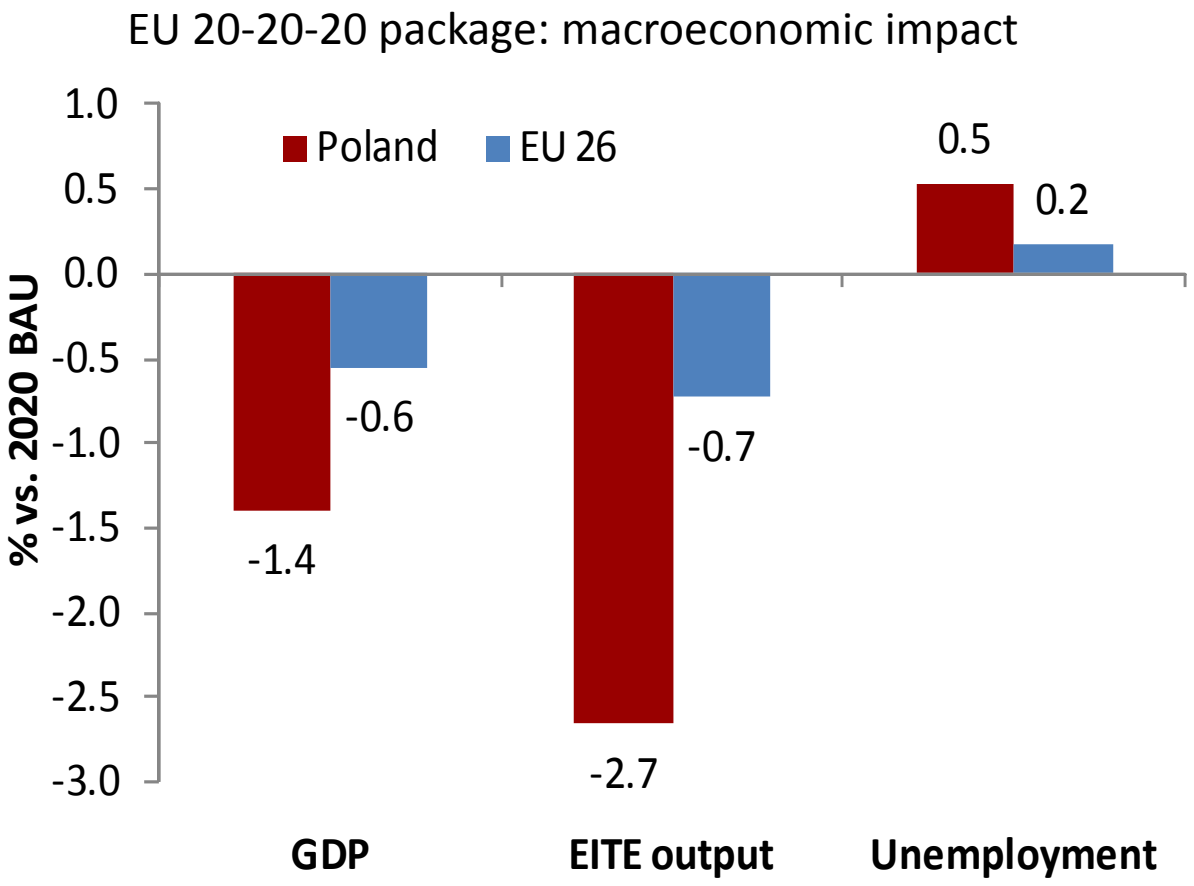
Note: Change in real GDP is measured against business-as-usual scenario. Categories are micro-packages (mitigation options grouped by economic characteristics).

MACROECONOMIC MARGINAL ABATEMENT COST (MACROMAC) CURVE, 2030



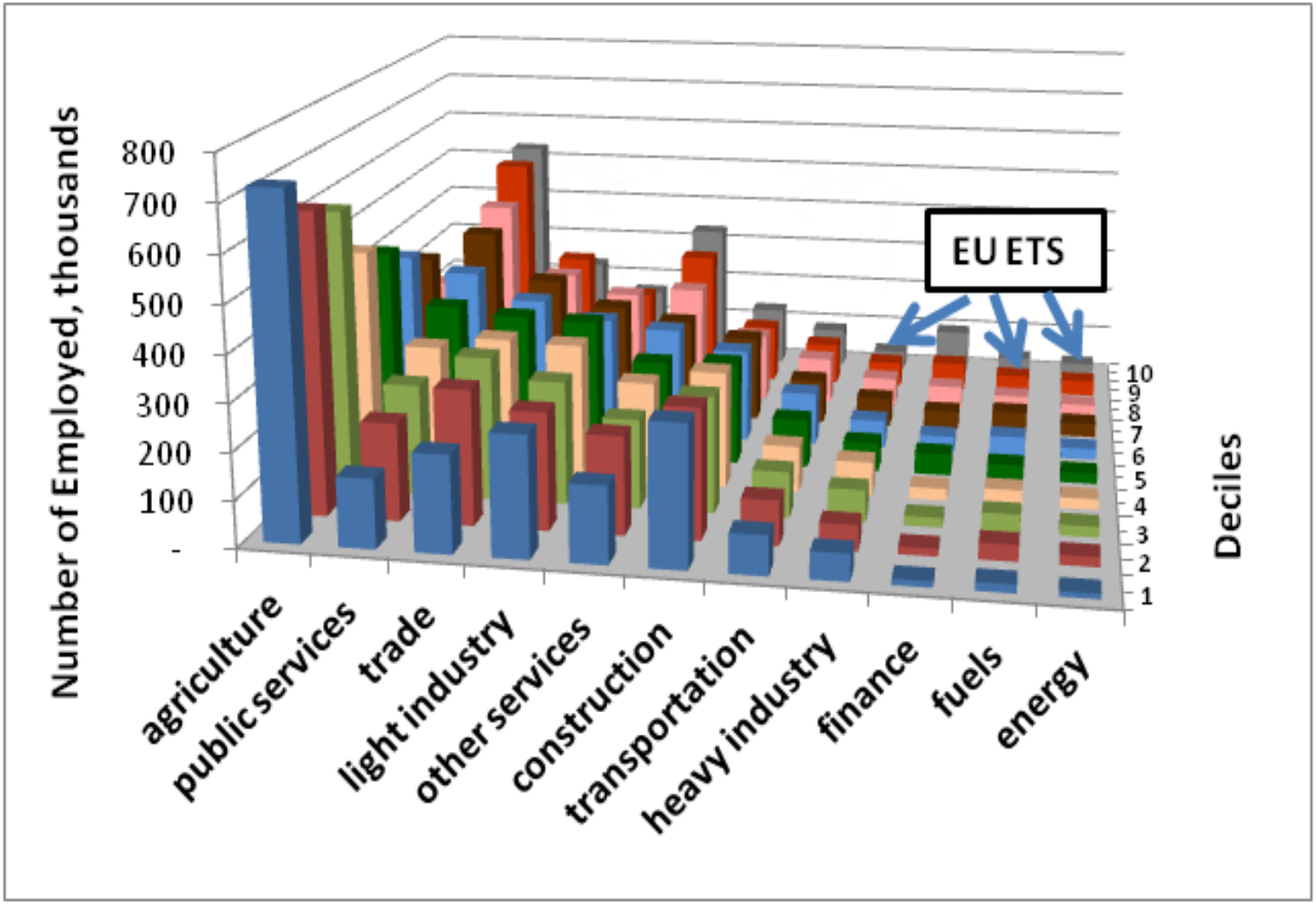
Note: Each column is one of the 120 abatement measures. The height of the columns is the marginal abatement impact in percent of GDP (for each percent of GHG abatement) compared to business-as-usual in 2030. The width is the percent emissions can be reduced. The area of any rectangle equals the GDP effect (loss or gain) of carbon abatement via any specific lever.

POLAND BEARS A MODEST ECONOMIC BURDEN DESPITE DEPENDENCE ON COAL AND EXPECTED STRONG BASELINE EMISSIONS GROWTH IN SECTORS SUCH AS TRANSPORT



Note: EU 26 is rest of the EU excluding Poland. The carbon price in non-ETS sectors is a shadow price. EITE is energy- and trade-exposed sectors. Unemployment is the change in the rate in percentage points.

DISTRIBUTIONAL EFFECTS OF CLIMATE POLICIES, BY INCOME



Source: World Bank staff calculations based on 2009 Poland HBS.

THANK YOU

QUESTIONS?

INTERNATIONAL

DEVELOPING COUNTRY ANALYSIS AND DIALOGUE

Greenhouse Gas Mitigation in Brazil, China and India: Scenarios and Opportunities through 2025

Conclusions and Recommendations

CENTER FOR CLEAN AIR POLICY

November 2006

Center for Clean Air Policy

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CCAP also acknowledges the active participation and involvement of the many government officials and other stakeholders in Brazil, India and China in the project and the in-country workshops, as well as the participants in CCAPs' *Future Actions Dialogue* (FAD), all of whom provided helpful direction, guidance and comments on the project.

About the Center for Clean Air Policy

As a recognized world leader in air quality and climate policy since 1985, the Center for Clean Air Policy, an independent non-profit entity, seeks to promote and implement innovative solutions to major environmental and energy problems which balance both environmental and economic interests. The Center's work is guided by the belief that market-based approaches to environmental problems offer the greatest potential to reach common ground between these often conflicting interests. CCAP staffs have participated in the Framework Convention on Climate Change negotiations, helping to shape the Joint Implementation provisions of the Rio Treaty and the Kyoto Protocol Mechanisms. CCAP has also developed a series of papers, the *Airlie Papers*, on domestic carbon trading in the US, the *Leiden Papers* on international emissions trading, and the *Clean Development Mechanism Papers*, on the design of the CDM, and the *Future Actions Dialogue Papers* on future international climate policy. For more information on CCAP, see: www.ccap.org

Executive Summary

SHATTERING MYTHS

This report shatters a commonly held myth among critics of the Kyoto Protocol that developing countries are not taking meaningful action to reduce greenhouse gases.

Working closely with policymakers and researchers both within and outside the governments of Brazil, China and India, the Center for Clean Air Policy (CCAP) has led an analysis of the costs and implications of policies to reduce GHG emissions. *Greenhouse Gas Mitigation In Brazil, China and India: Scenarios And Opportunities Through 2025* presents the results of that analysis. It reveals that Brazil and China have adopted "unilateral actions" since 2000 that have already reduced emissions and are expected to reduce emissions through 2020 in those nations below projected levels. Reductions in Brazil and China alone in 2010, if fully implemented, are projected to be greater than those to be achieved by the United States' voluntary carbon intensity reduction goal.[1] India is projected to achieve emissions reductions by 2020 in the transportation and iron and steel sectors below "business as usual" levels, but these reductions are projected to be offset principally by emissions increases in the electricity sector.

Most of these reductions in the three nations have been financed domestically, independent of the Kyoto Protocol's Clean Development Mechanism (CDM) under which developing countries can sell emission reductions achieved from approved projects to developed nations. While questions remain about how effective implementation of these new policies will be in each country, they nonetheless demonstrate the broad scope of policies that reduce greenhouse gases underway in key developing countries.

This revelation of unilateral action supports arguments for setting more challenging emissions reduction goals for developed countries, as it should help to allay concerns about the non-participation of developing countries in carbon reduction. China in particular has focused an important portion of its environmental effort in internationally competitive industries including iron and steel, cement, pulp and paper. This undercuts, to a degree, the argument that industries facing international competition will shift production to China and other developing countries from developed nations to avoid the costs of carbon reductions.

FUTURE CLIMATE POLICY OPPORTUNITIES

The study also details an array of additional cost-effective emission reductions that these three leading developing nations could pursue in the future -- unilaterally, under the CDM or a new international policy structure. Projected aggregate emissions reductions that could be achieved in the electricity, cement, transportation, paper, and steel industries in these nations range from 17 to 29 percent below business as usual levels in 2020. Modeling conducted for CCAP by Ecofys Consulting[2] suggests that this level of reduction by Brazil, China and India, coupled with major reductions in developed countries, a significant effort by the United States and comparable efforts by major developing countries, would keep the world on track to stabilize global carbon dioxide concentrations at 450 ppm. Also, it would keep open the possibility of achieving the European Union's goal of holding global average temperature increases due to climate change to 2 degrees Centigrade.[3]

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[1] This study estimates that Brazil and China are projected to achieve more than 210 million metric tons of CO_2 reduction in 2010 from existing unilateral policies while the U.S. voluntary target is slated to achieve 183 million metric tons of CO_2-equivalent reduction/year on average over the life of the voluntary program according to the U.S. Administration. Brazil and China were responsible for 17% of global anthropogenic greenhouse gas emissions in 1990 (not including emissions from deforestation) while the U.S. was responsible for 25% in 1990.

[2] Details on this analysis are in: Schmidt et al. (2006), available at http://www.ccap.org/international/Sector%20Straw%20Proposal%20-%20FINAL%20for%20FAD%20Working%20Paper%20%7E%208%2025%2006.pdf.

[3] Stabilizing emissions at 450ppm CO_2 is roughly equivalent to stabilizing emissions at 500 ppm CO_2 equivalent. Source: den Elzen and Meinshausen (2005), *Meeting the EU 2°C climate target: global and regional emission implications*

The study suggests there is an unprecedented opportunity for future international climate policy to:

- Recognize and encourage "unilateral actions" by developing countries
- Provide incentives for more expensive emissions reduction opportunities that are not likely to be pursued unilaterally by developing countries, and
- Establish a global policy structure coupling needed incentives for developing country action with tough emission reduction goals for developed nations that will be sufficient to protect the climate.

BACKGROUND

At the annual UNFCCC meeting in Montreal in November 2005, Parties agreed to begin formal discussions under both the Kyoto Protocol and UNFCCC on the future international climate policy structure for the post-2012 period. One of the key elements of this discussion will be what role developing countries will play in the international response to climate change. In many developing countries, discussions about concrete policy steps to reduce greenhouse gas (GHG) emissions are already underway, often motivated by concerns about energy security, air quality, and economic development. This report is intended as a contribution to that ongoing dialogue.

Greenhouse Gas Mitigation In Brazil, China and India: Scenarios And Opportunities Through 2025, summarizes the results of the first phase of the CCAP's **"Developing Country Project."** A key goal of the project is to strengthen the capacity of developing countries to take action to reduce greenhouse gases and to prepare for and participate in negotiations on the future structure of climate policy under the UNFCCC and the Kyoto Protocol. The project also will assist developing countries by identifying specific "win-win" opportunities where they can reap substantial economic and other development-related benefits through cost-effective actions that will also reduce GHG emissions.

Since the inception of the Developing Country Project in February 2005, CCAP has worked with in-country teams in Brazil, China, India and Mexico to identify technologies and approaches that are feasible and cost-effective in reducing GHG emissions and in providing co-benefits (e.g., air quality and energy security).[4] By engaging in-country teams, key government officials and stakeholders, CCAP is building each nation's capacity to continue this type of analysis following the end of the project. The partners in the research are: the Center for Integrated Studies on Climate Change and the Environment (Centro Clima) at the Federal University of Rio de Janeiro and several independent researchers in Brazil; The Institute for Environmental Systems Analysis at Tsinghua University of China; The Energy and Resources Institute (TERI) of India; and the Centro Mario Molina of Mexico.

This report—and the companion reports prepared by the teams in each country—evaluate the emissions trends and reduction opportunities in key sectors of the economies of these countries, and suggest some preliminary insights on politically practical domestic and international approaches for achieving these reductions. The next phase of the research will study in more detail the barriers to the introduction of the most promising emission reduction options identified in Phase I and will suggest domestic and international implementation strategies.

KEY RESULTS

a) Emissions Are Projected To Grow In Brazil, China, And India

Emissions of greenhouse gases in these countries are projected to more than double from 2000 levels in the electricity, industrial, transportation, and residential and commercial sectors[5] over the next two decades due to increases in population, economic activity, and urbanization.

b) Unilateral Efforts Undertaken Since 2000 Will Slow This Trend

If fully implemented, government policies and programs adopted since 2000 in China and Brazil will slow this projected growth in GHG emissions and reduce emissions by seven and 14 percent below projected levels, respectively. In India, overall emissions are expected to increase slightly on a net basis as a result of new policies.

Specific actions undertaken by these countries include:

- China's Renewable Energy Law and the Tenth Five-Year Plan are expected to reduce electricity sector emissions by five percent below BAU levels—a reduction equivalent to shutting down more than 20 large coal-fired Chinese power plants—in 2020.

[4] The analysis in Mexico began nine months later than the other three countries, and will be completed in 2007.
[5] Emissions data for China do not include residential and commercial numbers.

- China's Medium and Long Term Energy Conservation Plan is estimated to reduce cement sector emissions by 15 percent below BAU levels in 2020—a reduction equivalent to shutting down half of the shaft kiln cement facilities that existed in China in 2000. This Plan also is estimated to reduce iron and steel sector emissions by nine percent below BAU levels in 2020—a reduction equivalent to shutting down approximately 750 existing iron and steel facilities.
- China's fuel efficiency standards for passenger cars, SUVs, and multi-purpose vans are estimated to reduce transportation sector emissions by five percent below BAU levels in 2020.
- Brazil's Program for Incentive of Alternative Electric Energy Sources (PROINFA) is estimated to reduce electricity sector emissions by 14 percent below BAU levels—a reduction equivalent to closing 42 percent of Brazil's current oil-fired electricity generation—in 2020.
- Brazil's ethanol program, which has led to the development of flex fuel vehicles and cost competitive ethanol, is estimated to reduce transportation emissions by 18 percent below BAU levels in 2020—a reduction equivalent to almost 1.5 times the total emissions from light-duty vehicles in 2000.
- India's transportation policies are estimated to reduce transportation sector emissions by up to 15 percent below BAU levels—a reduction equivalent to the sector's emissions in 2000—in 2020.
- India's Electricity Act 2003 is estimated to increase electricity sector emissions by 12 percent above BAU in 2020 due to expanded electricity generation, driven in part by increased electricity access.

c) These Actions Have Been Taken Principally For Reasons Other Than Climate-Related Considerations And In Some Cases At Real Net Economic Cost:

- China's actions taken in the electricity and iron and steel sectors were aimed to increase reliability of the power network, enhance economic productivity and competitiveness, and improve air and water quality. Many of the renewable opportunities in China are estimated to cost more than $10 per ton, and a number of the mitigation options in the iron and steel sector being pursued today are priced in the $5 to $10 per ton range.
- The Chinese vehicle standards and the Brazilian ethanol and flex fuel vehicle programs primarily have been driven by the goal of reducing the use of imported oil.
- Brazil's flex fuel vehicle program is estimated to achieve its reductions at greater than $30 per ton, yet has been pursued aggressively.

d) Many Of The Emissions Reductions Achieved Through These Policies Are Not Being Developed As Clean Development Mechanism (CDM) Projects And Thus Represent These Countries' "Contribution To The Protection Of The Atmosphere":

- China currently has around 14 $MMTCO_2$ per year in the CDM pipeline from hydro and wind generation projects—and around 5 $MMTCO_2$ in industrial energy efficiency projects—both of which are significantly below the level of reductions estimated to be achieved as a result of China's post-2000 policy initiatives.
- China's vehicle efficiency standard and Brazil's flex-fuel vehicles are not being developed into CDM projects.
- While India only has one transportation CDM project in the pipeline, it does have a number of industrial energy efficiency and carbon reduction projects pending approval as CDM projects.

e) Opportunities Exist To Make Significant Additional Emission Reductions To Help Slow The Rapid Increase In GHG Emissions Projected In These Countries

- On an aggregate basis, the study projects cost-effective reductions (below $10/ton CO_2) of four percent in India, four percent in Brazil and 10 percent in China below BAU levels in 2020 totaling more than 625 million tons of CO_2 per year – the equivalent of avoiding the construction of more than 150 coal-fired power plants.[6]
- In China, major potential targets include nearly 200 million tons of CO_2 reductions in each of the transport and cement sectors
- In India and Brazil, transport, cement and electricity options stand out as top targets for further cost-effective action.
- This year, China also has adopted several new policies (thus beyond the scope of this study) that promise to produce significant additional reductions:

[6] These aggregate estimates include both reductions due to existing policies and reductions due to potential new measures.

- Eleventh Five Year Plan requires the 1000 highest energy-consuming enterprises to install equipment to attain a 20 percent efficiency improvement by 2010.
- Vehicle excise taxes are now based on vehicle engine size and have increased significantly (e.g., the SUV tax has quadrupled to about $8,000 per vehicle).
- The National Development and Reform Commission has set new goals for the cement industry: increase the share of cement produced by dry kilns from 40 to 70 percent, close more than 250 million tons of inefficient capacity and reduce energy intensity 15 percent by 2010.

f) If China, Brazil And India Chose To Make The Reductions Outlined In This Study By 2020, Their Efforts, Coupled With Other Countries' Efforts, Could Be Sufficient To Stay On Track To Stabilize Global Atmospheric Carbon Dioxide Concentrations At 450 ppm.

To meet this concentration goal, other nations would need to make reductions along the lines of:

- EU and other developed nations cutting their emissions to 30 percent below 1990 levels by 2020
- The U.S. cutting its emissions to 1990 levels by 2020, and
- The other major developing countries making efforts similar to China, India and Brazil.

This proposed combination of emission reductions is simply illustrative. Any combination of reductions from developed and developing nations that achieves the same aggregate reduction can keep the achievement of a 450 ppm global atmospheric carbon dioxide concentration in play. Even given the huge projected growth in emissions in these three developing countries through 2020, the key point here is that the potential, largely cost-effective reductions identified in this study are significant – their achievement would mark important progress toward achieving the goal of limiting global increases in temperature to 2 degrees Centigrade.

ROLE OF INTERNATIONAL POLICY

A future international policy that recognizes and encourages further "unilateral actions" is needed. Countries could be encouraged to "pledge" GHG policies and reductions. The future international policy also needs to provide incentives for action to implement the more expensive emissions reductions options available in these countries. These options could benefit from financial support, technology development and transfer assistance, and capacity building. A variety of international policy options under discussion for developing countries could achieve this, including: voluntary pledges to take action on sustainable development policies and measures (SD-PAMs), pledges to achieve no-lose sector-based intensity levels with countries able to sell reductions achieved in excess of these targets, and new sectoral approaches to the CDM which could encourage greater unilateral emission reductions.[7]

[7] See CCAP paper, "Sector-based Approach to the Post-2012 Climate Change Policy Architecture", August 2006.

GREENHOUSE GAS MITIGATION IN BRAZIL, CHINA AND INDIA: SCENARIOS AND OPPORTUNITIES THROUGH 2025

I.A Conclusions and Recommendations

This report shatters a commonly held myth among critics of the Kyoto Protocol that developing countries are not taking meaningful action to reduce greenhouse gases.

Working closely with policymakers and researchers both within and outside the governments of Brazil, China and India, the Center for Clean Air Policy (CCAP) has led an analysis of the costs and implications of policies to reduce GHG emissions. *Greenhouse Gas Mitigation In Brazil, China and India: Scenarios And Opportunities Through 2025* presents the results of that analysis. It reveals that Brazil and China have adopted "unilateral actions" since 2000 that have already reduced emissions and are expected to reduce emissions through 2020 in those nations below projected levels. Reductions in Brazil and China alone in 2010, if fully implemented, are projected to be greater than those to be achieved by the United States' voluntary carbon intensity reduction goal. India is projected to achieve emissions reductions by 2020 in the transportation and iron and steel sectors below "business as usual" levels, but these reductions are projected to be offset principally by emissions increases in the electricity sector.

Most of these reductions in the three nations have been financed domestically, independent of the Kyoto Protocol's Clean Development Mechanism (CDM) under which developing countries can sell emission reductions achieved from approved projects to developed nations. While questions remain about how effective implementation of these new policies will be in each country, they nonetheless demonstrate the broad scope of policies that reduce greenhouse gases underway in key developing countries.

This revelation of unilateral action supports arguments for setting more challenging emissions reduction goals for developed countries, as it should help to allay concerns about the non-participation of developing countries in carbon reduction. China in particular has focused an important portion of its environmental effort in internationally competitive industries including iron and steel, cement, pulp and paper. This undercuts, to a degree, the argument that industries facing international competition will shift production to China and other developing countries from developed nations to avoid the costs of carbon reductions.

The study also details an array of additional cost-effective emission reductions that these three leading developing nations could pursue in the future—unilaterally, under the CDM or a new international policy structure. Projected aggregate emissions reductions that could be achieved in the electricity, cement, transportation, paper, and steel industries and the residential and commercial sectors in these nations range from 17 to 29 percent below business as usual levels in 2020. Modeling conducted for CCAP by Ecofys Consulting suggests that this level of reduction by Brazil, China and India, coupled with major reductions in developed countries, a significant effort by the United States and comparable efforts by major developing countries, would keep the world on track to stabilize global CO_2 concentrations at 450 ppm. Also, it would keep open

the possibility of achieving the European Union's goal of holding global average temperature increases due to climate change to 2 degrees Centigrade.

The study suggests there is an unprecedented opportunity for future international climate policy to:

- Recognize and encourage "unilateral actions" by developing countries
- Provide incentives for more expensive emissions reduction opportunities that are not likely to be pursued unilaterally by developing countries, and
- Establish a global policy structure coupling needed incentives for developing country action with tough emission reduction goals for developed nations that will be sufficient to protect the climate.

Background

Greenhouse Gas Mitigation In Brazil, China and India: Scenarios And Opportunities Through 2025, summarizes the results of the first phase of the CCAP's "Developing Country Project. This project was financed by the United Kingdom's Department for International Development (DFID), the Tinker Foundation, and the Hewlett Foundation. The project developed comprehensive analysis of greenhouse gas (GHG) projections and potential mitigation options, costs, co-benefits, and implementation policies in Brazil, China, India, and Mexico, led by the Center for Clean Air Policy and eading partner organizations in these four countries:

The in-country partners in this project consist of:

- a team at the Center for Integrated Studies on Climate Change and the Environment (Centro Clima) at the Institute for Research and Postgraduate Studies of Engineering at the Federal University of Rio de Janeiro (COPPE/UFRJ), Haroldo Machado Filho, Thelma Krug, Magda Aparecida de Lima, Luiz Gustavo Barioni, and Geraldo Martha;
- a team from the Institute for Environmental Systems Analysis within the Department of Environmental Science and Engineering at Tsinghua University of China;
- The Energy and Resources Institute (TERI) of India; and
- the Centro Mario Molina of Mexico.

The project is conducted in two phases. In Phase I of this project, the teams conducted individual GHG emission mitigation analyses for major economic sectors. The results of Phase I have been presented in a series of reports. The reports for Brazil, China and India will be released in conjunction with this report, while the report for Mexico will be released in 2007. This integrated report presents the results of Phase I (GHG Mitigation Option and Cost Analysis) of the project analysis for Brazil, China and India. In the next phase of the project, the teams will build upon Phase I by: evaluating the implications of specific international climate change policy options for GHG mitigation in these four countries; development of a suite of potential policies and approaches for implementation of each option; and comprehensive and in-depth analysis of the key actors, barriers and co-benefits associated with each.

Methodology

The GHG mitigation analysis was conducted using country-specific scenarios for annual population and gross domestic product (GDP). The teams developed two alternative GHG reference case scenarios for each sector, partly based on the A2 and B2 scenarios in the

Intergovernmental Panel on Climate Change (IPCC) *Special Report on Emissions Scenarios* (in this integrated report, we refer only to the B2 scenario data[8]).

Three different scenarios were developed:

- **"Pre-2000 Policy" scenario** which considered only policies and programs adopted prior to 2000. For the analysis of mitigation options this scenario was used as the "business as usual" (BAU) scenario.
- **"Recent Policy" scenario** (also called "unilateral actions") which considered the impact with implementation of all policies announced before 2006.
- "**Advanced Options" scenarios**. Where appropriate, each country analysis conducted up to four variations of the Advanced Options scenario, based on the potential cost effectiveness (measured in $/metric ton CO_2e reduced) of the mitigation measures analyzed. The first three Advanced Options scenarios assumed implementation of all measures costing, respectively, less than $0 per ton (<$0 per ton), less than $5 per ton (<$5/ton), and less than $10 per ton (<$10/ton). The fourth scenario was the most aggressive and considered all feasible (in the team's judgment) mitigation options.

I.B Emissions are projected to grow in all three countries

Brazil, China, and India combined account for 40% of the world's population, 7% of world economy, and an estimated 23% of current global GHG emissions (Schmidt et al., 2006).[9]
As the powerful developing economies of China, India and Brazil continue to grow and develop, production and consumption of energy will all rise as well. This analysis considered emissions projections and reduction opportunities in key sectors of the economy: China included electricity, iron and steel, cement, pulp and paper, and on-road vehicles; Brazil considered electricity, iron and steel, cement, pulp and paper, residential, commercial, transportation, methane from enteric fermentation, and land-use change and forestry (this analysis includes discussion of projected future deforestation rates in Brazil, but these were not included in Brazilian emission estimates discussed below); and India included electricity, iron and steel, cement, pulp and paper, residential, commercial, transportation, and agriculture pumping. While not economy-wide, emissions from these sectors account for a sizeable share of each country's CO_2 emissions from fuel combustion in 2000: 74% in China, 77% in India, and 71% in Brazil[10].

Under business-as-usual conditions considered in this analysis, **emissions of greenhouse gases in these countries are projected to increase significantly in the electricity, industrial,**

[8] While analysis of an "A2-like" scenario was calculated, the team's and the in-country reviewers considered the "B2-like" scenario a more realistic representation of emissions projections. The "A2-like" scenario produces significantly larger growth in emissions as it is "dirtier" scenario.
[9] This excludes emissions from land-use change. Including these would increase the share to 22% (Schmidt et al., 2006).
[10] Note that values for China and Brazil include emissions from electricity, iron and steel, cement, pulp and paper, and transportation; share for India includes commercial and residential. It should also be noted that Brazil share does not include emissions from deforestation, which are a significant share of the country's overall greenhouse gas emissions.

transportation, and residential and commercial sectors[11] over the next two decades (see Figure 1)**.**

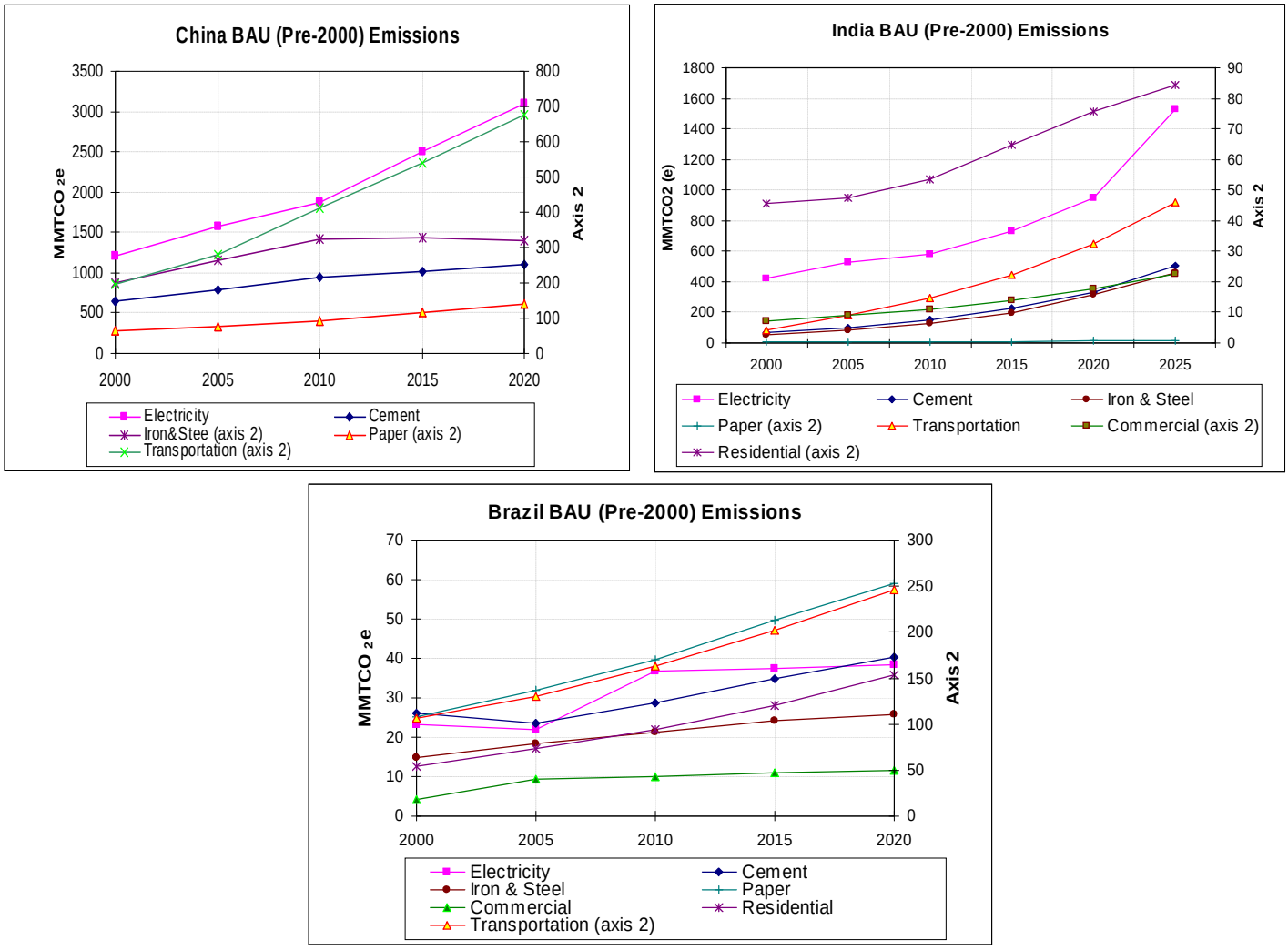

Figure 1. Sector CO_2 Emissions Under the Pre-2000 Policy and Recent Policy Scenarios

As Figure 1 demonstrates, when considering only policies adopted before year 2000, emissions from these sectors are projected to increase over the period in all three countries due to increases in economic activity, population, and urbanization. As a result, compared to 2000 levels the combined emissions from the sectors analyzed in China and Brazil are projected to more than double by 2020 as GDP and population increase in both countries. In China, GDP and population increase by 285% and 14%, respectively, between 2000 and 2020. Likewise, Brazilian GDP and population are projected to grow significantly by 118% and 29%, respectively, over this timeframe. Indian emissions will rise even faster, increasing by almost 3.5 times, due to a larger projected increase in GDP and population of over 360% and 30%, respectively. It should be noted, however, that this is based on the assumption of a relatively

[11] Emissions data for China do not include residential and commercial numbers.

high rate of national economic growth—8% per year through 2026—compared to that in other studies.[12] The actual estimated emissions growth in India may thus be significantly lower than the projected levels in this analysis if the Indian economy should fail to maintain this level of growth over the time period.

In the BAU scenario, transportation emissions in China are projected to increase by 250%— due to a more than four times increase in the number of cars, trucks, and buses—and electricity emissions by 160%—driven by an almost doubling of electricity production—from 2000 to 2020, with large increases expected in the other sectors as well. As a result, compared to 2000 levels the combined emissions from these sectors in China are projected to more than double by 2020. Electricity is expected to be a sizeable share of these emissions in the future—accounting on average for over one-half of total annual emissions from the sectors analyzed in the 2000 to 2020 period—with cement accounting for about 30% in 2000 but only one-fifth in 2020.

The increases are equally dramatic in India, with transportation emissions rising by a factor of 6.5—due to an increase in the number vehicles and the usage per vehicle—electricity emissions more than doubling—driven by a 255% increase in electricity production—and cement and iron and steel emissions rising by about 5 times in both sectors. As a result, electricity accounts for about one-half of emissions from the sectors analyzed in India in 2010, but only about two-fifths in 2020, while the share of transportation emissions is projected to increase from 14% in 2000 to more than one-quarter in 2020. The Indian iron and steel and cement sectors will also increase significantly over the period, and combined will account for the same share of emissions (28%) as transportation in 2020.

In Brazil, the projected increases are significant as well, with transportation emissions rising by 130%—largely driven by an increase in emissions from freight trucks. In Brazil, transportation accounts for about one-half of total emissions throughout the period.

Taken together, sector emissions from these countries would increase by 150% – almost 5,000 $MMTCO_2$. From the pre-2000 perspective, the outlook from these countries is therefore one of rapidly increasing fuel consumption and GHG emissions in all sectors, and a corresponding increase in their contribution to global greenhouse gas emissions.

I.C "Unilateral" Efforts Will Slow This Trend and Reduce Emissions

While emissions will likely continue to expand in many sectors in the near term, **fully implemented government policies and programs adopted since 2000 in these countries will slow this projected growth in GHG emissions and reduce emissions below projected levels.** It is important to note that these emissions reductions are not necessarily guaranteed as achieving these levels of reduction will require full enforcement of existing policies and programs. For this reason, the teams and the in-country reviewers felt it was more appropriate to use the pre-2000 scenario (which does not include policies adopted since 2000) as the basis of the "business as

[12] The growth rates assumed were based on government plans detailed in the Tenth Five Year Plan prepared by the Planning Commission, Government of India. Other studies, however, have projected lower rates of growth for the Indian economy, some on the order of 5% or less.

usual" case. These efforts have been undertaken for reasons other than climate change mitigation, such as energy security, air quality, competitiveness, and sustainable development. Figure 2 shows the impact of these policies and programs.

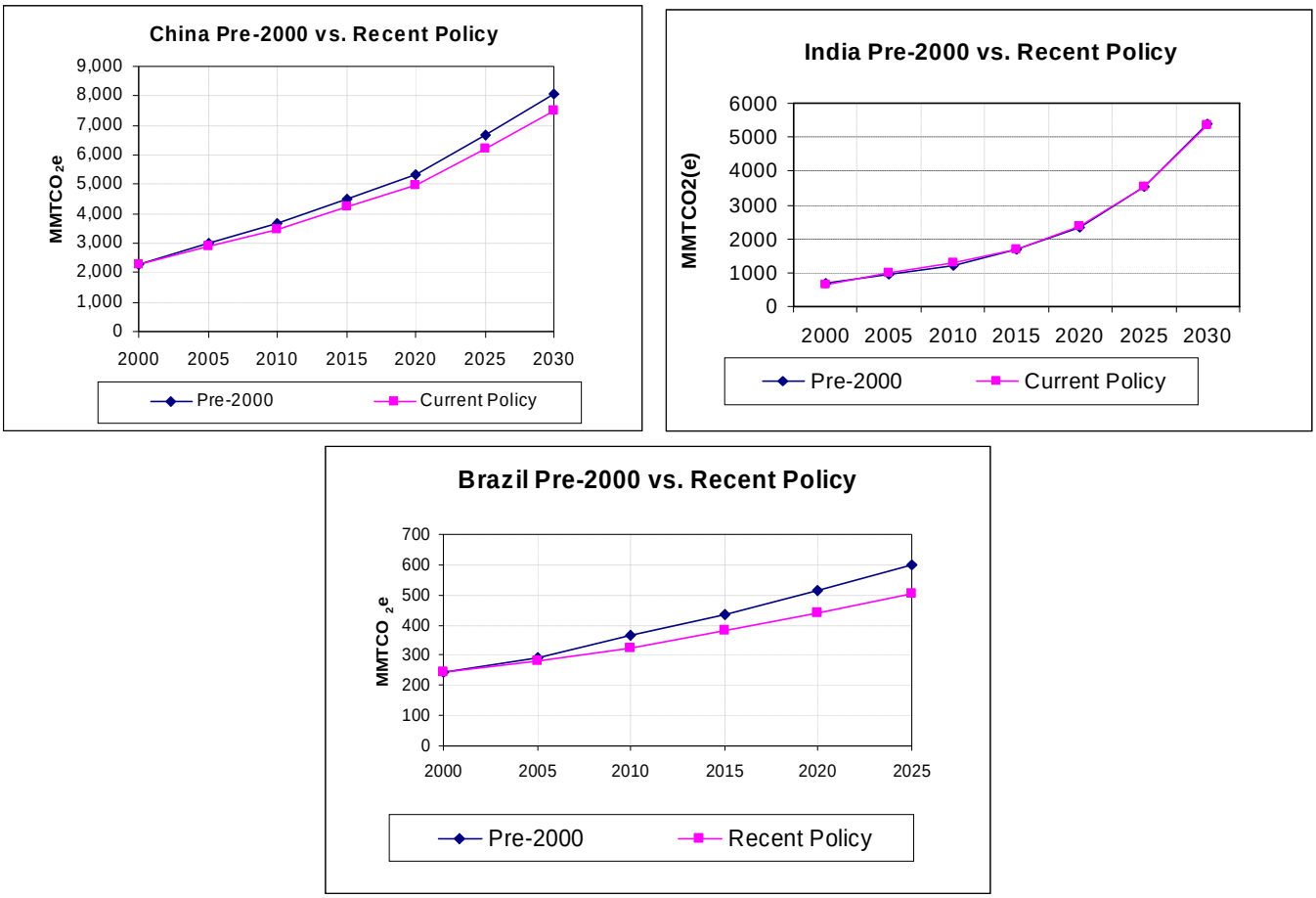

Figure 2. GHG Emissions Under Pre-2000 Policy and Recent Policy Scenarios

Overall, the policies and actions already undertaken and underway in these three countries, if full implemented, are estimated to lower GHG emissions by about 460 $MMTCO_2$ below BAU levels in 2020, a fall of 6%—equivalent to offsetting the emissions of over 120 coal-fired power plants[13]. In China and Brazil, these measures are estimated to reduce emissions by 7 and 14 percent below projected levels, respectively, while in India overall emissions are expected to increase slightly on a net basis as a result of new policies. Thus, while the current outlook in China, India and Brazil is for a significant growth in emissions, unilateral actions already undertaken through government policies and programs in these three countries driven primarily for non-climate change reasons will have a positive impact in lowering this trend. This development represents an important "first step" for developing countries, as they have already begun to make important contributions to the global effort to reduce GHG emissions and combat climate change.

[13] Assumes a new 600 MW facility with 85% capacity factor and 9,000 Btu/kWh heat rate using sub-bituminous coal, which equals 3.74 $MMTCO_2$ per year in emissions. This value is used in the conclusions for the "rule of thumb" comparisons.

These actions have in some cases been taken at real net economic cost and principally for reasons other than climate-related considerations, including: energy security with growing demand and limited domestic supply, reliability of the power network, enhanced economic productivity and competitiveness, and improved air and water quality.

Many of the emissions reductions achieved through these policies are not being developed as Clean Development Mechanism (CDM) projects and thus represent these countries' "contribution to protection of the atmosphere." Overall, these countries have over 823, with average annual reductions of 144 $MMTCO_2$, in the CDM pipeline.[14] The majority of these reductions in China and Brazil are in sectors not covered by this analysis (e.g., landfill gas or HFCs) or in sectors where these "unilateral actions" are being undertaken: over 70% of the average annual reductions in China and Brazil are in sectors not covered by this analysis.[15] The opposite is true in India where the majority of average annual emissions reductions in the CDM pipeline—69%—are in sectors covered by this analysis.[16]

The level of reduction achieved in China and Brazil through these actions is equal to or better than the level of reduction projected to be achieved by the U.S. under its voluntary emissions intensity target and around 30% of the level of reduction estimated for the EU-15 to meet its Kyoto target. Accounting for only the domestic reductions in the EU-15 to meet the Kyoto target (excluding the expected use of the Kyoto Mechanisms for compliance) would increase the value to 37%. This study estimates that Brazil and China are projected to achieve more than 210 million tons of CO_2 reduction in 2010 from existing unilateral policies, while the U.S. voluntary target is slated to achieve 183 million tons of CO_2e reduction per year on average over the life of the voluntary program according US Administration[17]. Brazil and China were responsible for 17% of global anthropogenic CO_2 emissions in 1990 while the U.S. was responsible for 25% in 1990.[18] To meet the EU-15 emissions target under the Kyoto Protocol requires an estimated emissions reduction from the business as usual level of around 682 $MMTCO_2e$ in 2010. Taking out the use of Kyoto Mechanisms would mean that EU domestic emissions reductions below the BAU would be 573 $MMTCO_2e$.[19] It is important to note that the stated U.S. reductions and the EU's Kyoto targets are economy-wide, while those in Brazil and China cover a segment of the economy (See Figure 3).

[14] UNEP Riso, CDM Pipeline, October 2006.
[15] In the China, these reductions are in agriculture, coal bed/mine methane, HFCs, landfill gas, N_2O, and reforestation projects. In Brazil, these reductions are in agriculture, fugitive, landfill gas, and N_2O projects.
[16] Not all these projects in the CDM pipeline will necessarily qualify as CDM projects and others may be developed.
[17] As noted in: U.S. Administration (2002), February. Value is noted online in State Department Fact Sheet, available at: www.state.gov/g/oes/rls/fs/2004/38641.htm
[18] WRI, Climate Analysis Indicators Tool. 2006.
[19] Values for the base year (4269 $MMTCO_2e$) and the expected use of Kyoto Mechanisms (110.5 $MMTCO_2e$) are from the European Environment Agency (2006), *Greenhouse gas emission trends and projections in Europe 2006*. Business as usual values in 2010 (4611 $MMTCO_2e$) based upon values presented in: European Commission: Fourth National Communication from the European Community Under the UN Framework Convention on Climate Change.

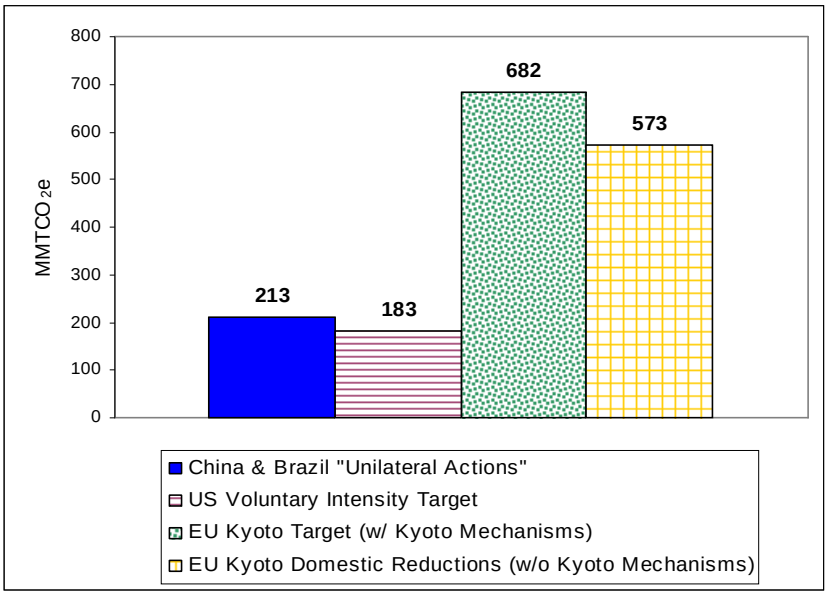

Figure 3. Brazil and China "Unilateral" Emissions Reductions Below Business as Usual Compared with Estimates for U.S. and EU Efforts (in 2010)

I.C.1 *Recent Chinese Policies and Programs*

In China, policies adopted between 2000 and 2005 will reduce GHG emissions in all sectors below their BAU levels—by almost 400 MMTCO$_2$ in 2020—with the combined emissions from these sectors expected to fall by 7%. This is equivalent to shutting down approximately one-third of China's existing coal-fired power plants. Emissions will fall most dramatically in pulp and paper, where emissions will fall by one-fifth in 2020. The largest reductions in absolute terms will occur in cement, where year 2020 emissions are projected to decrease by 162 MMT (15%), and in electricity, where they will decline by 142 MMT (5%). While these emissions reductions from "unilateral actions" are large, the growth in emissions in these sectors are so fast that emissions in 2020 still increase by 115% over 2000 levels. Table 1 shows the emissions reductions achieved in each sector from these policies and programs.

Table 1. Change in China's Emissions Due to Recent Policies

Sector	BAU Scenario		Recent Policies Scenario		
	2000 Emissions (MMTCO$_2$)	2020 Emissions (MMTCO$_2$)	2020 Emissions (MMTCO$_2$)	Emissions Change from BAU (MMTCO$_2$)	% Change from BAU
Electricity	1,199	3,102	2960	(142)	-5%
Cement	643	1,098	937	(162)	-15%
Iron/Steel	200	323	294	(29)	-9%
Pulp/Paper	63	141	111	(30)	-21%
Transport	195	676	643	(34)	-5%
TOTAL	2,299	5,340	4,945	(395)	-7%

These actions have been taken for reasons other than climate-related considerations. For instance, actions taken in electricity, iron & steel sector were aimed to increase reliability of the power network, enhance economic productivity and competitiveness, and improve air and water quality. Enhancing energy security and independence is another motivation behind these actions. In particular, China's growing demand for oil and limited domestic supply has led China to

import nearly half (an estimated 3.6 million barrels of oil per day) of its total demand in 2006 – a key factor motivating China's recent vehicle efficiency standards. Considering its reliance on imported oil, China is keen on improving energy-intensity of its economy through various actions such as these discussed here.

Some of these actions have been undertaken at a positive economic cost. While precise cost estimates for these unilateral actions are not available, the government's development of renewables (under the Renewable Energy Law and other recent programs) is a large source of the electricity sector reductions, and many of the renewable opportunities in China are estimated to cost greater than $10 per ton. A similar result is evident in the cement and iron and steel sectors, where a number of the mitigation options needed to meet the level of reductions achieved in the recent policies case cost in the $5 to $10 per ton range.

Many of the emissions reductions achieved through these policies are not being developed as CDM projects and are thus becoming China's "contribution to protection of the atmosphere". China has a total of 177 projects in the CDM pipeline with average total reductions of 82 $MMTCO_2$ per year.[20] Of this total, 123 are electricity generation projects—accounting for an average reduction of around 17 $MMTCO_2$ per year—far less reductions than the 142 $MMTCO_2$ estimated in the electricity sector through "unilateral actions". In addition, there are 17 industrial energy efficiency projects—accounting for 5 $MMTCO_2$ per year—significantly lower than the 220 $MMTCO_2$ reductions in 2010 from unilateral actions in the industry sectors. Lastly, the improvements achieved from the vehicle efficiency standard have not been developed into a CDM project—so the estimated reductions of 34 $MMTCO_2$ are not being captured by CDM projects.

Specifically, **Chinese policies and programs adopted between 2000 and 2005, including the following, have led to these reductions.**

<u>Electricity</u> (in 2020: 5% CO_2 reduction from BAU; 142 $MMTCO_2$; equivalent to offsetting emissions from more than 37 new coal-fired power plants; average projected growth in capacity between 2000 and 2020 is equivalent to adding over one 600 MW power plant per week)

- The *Renewable Energy Law* encourages the construction of renewable energy (RE) facilities, requires power grid operators to purchase resources from registered renewable energy producers, offers financial incentives for renewable energy projects, and stipulates penalties for non-compliance. The law also requires that the National Development and Reform Commission (NDRC) develop specific targets be set for RE development.[21] The most recent goals announced by China are 16% of primary energy from renewables in 2020, including large hydroelectric facilities—this includes RE capacity targets of 300 GW from hydropower, 30 GW from wind, 30 GW from biomass, 1.8 GW from solar photovoltaics, as well as targets for solar thermal, geothermal and solar hot water.[22] In addition, the government has developed a *renewables feed-in program* which provides direct incentives

[20] UNEP RISOE, CDM Pipeline, 20 October 2006.
[21] See http://www.renewableenergyaccess.com/assets/download/China_RE_Law_05.doc for an unofficial copy of the text of China's Renewable Energy Law.
[22] REN21, Renewables Global Status Report: 2006 Update, available at: www.ren21.net/globalstatusreport/download/RE_GSR_2006_Update.pdf

for renewable programs.[23] As a result, even though China is already the world leader in RE capacity (with 42 GW in 2005, excluding large hydro projects), China tied with Germany in 2005 for the largest national investment in renewable energy, excluding large hydropower—$7 billion. This was primarily directed to small hydro and solar hot water projects, and an additional $10 billion was invested in large hydro facilities. Wind generation also expanded significantly in China, with 500 MW of new wind capacity installed in 2005—the fifth largest amount among any country.[24]

- The *Tenth Five-Year Plan* includes several objectives for the electricity sector, including improving operations, shutting down inefficient power plants, developing nuclear power and renewables, etc. For example, as a result the government adopted a policy that requires that new coal facilities be greater than 300 MW and has shut down around 14 GW of small thermal units.[25]

Cement (in 2020: 15% CO_2 reduction from BAU; 162 $MMTCO_2$ in 2020; equivalent to shutting down half of the shaft kiln cement facilities in China in 2000[26]; projected growth in cement production between 2000 and 2020 is equivalent to adding about one of China's largest-capacity cement plants per week)

- *Policy Outlines of Energy Conservation Technologies* (rev. 1996) in the cement sector proposed to close small, illegal plants, promote retrofitting of inefficient operations (wet to dry process), and recover waste heat for re-use. More recent the National Development and Reform Commission's (NDRC's) 2004 China *Medium and Long Term Energy Conservation Plan* sets out a goals for the improvement of energy intensity to 148 kilogram of coal equivalent per ton (kgce/t) cement in 2010 and 129 kgce/t cement in 2020.[27]

Iron and Steel (in 2020: 9% CO_2 reduction from BAU; 29 $MMTCO_2$ in 2020; roughly equivalent to shutting down around 750 iron and steel facilities; projected growth in iron and steel production between 2000 and 2020 is equivalent to adding about one 100-ton electric arc steel furnace or one 1000-m^3 iron-making blast furnace per month)

- China *Medium and Long Term Energy Conservation Plan* (2005) in iron and steel sector, proposed to improve its energy intensity. Specific goals included: (1) industry-wide energy intensity to achieve the level of advanced world in the 1990's by 2010; (2) medium and large entities to achieve the level of advanced world levels in the 2000's by 2010; and (3) industry-wide energy intensity to achieve the level of advanced countries by 2020.[28]

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[23] "The China Sustainable Energy Program: China Program Update and Clippings." *The Energy Foundation.* Issue 19. February 2006. p2 &15. Available at: http://www.efchina.org/documents/CSEP_Clippings_Feb_2006.pdf

[24] REN21, Renewables Global Status Report: 2006 Update, available at: www.ren21.net/globalstatusreport/download/RE_GSR_2006_Update.pdf

[25] China September 2006 CCAP GHG Report Final. p37. Also available at: "Laws & Regulations – The 10th Five-Year Plan for Energy Conservation and Resources Comprehensive Utilization." Available at: http://www.ccchina.gov.cn/en/NewsInfo.asp?NewsId=5389. http://www.ccchina.gov.cn/en/Public_Right.asp?class=17

[26] China's shaft kiln cement facilities are estimated to have emitted 340.5 $MMTCO_2$ in 2000 (Tsinghua University of China, 2006).

[27] Price, L. and C. Galitsky (2006), Opportunities for Improving Energy and Environmental Performance of China's Cement Kilns, August, Lawrence Berkeley National Laboratory.

[28] "China Medium and Long-Term Energy Conservation Plan." National Development and Reform Commission (NDRC). People's Republic of China. January 2005. http://www.sdpc.gov.cn/ [in Chinese].

- The NDRC's 2005 *"China iron and steel industry development policy"* sets guidelines for the long-term development of this industry in China, including requirements for the production efficiency, energy consumption and environmental performance of steel companies in China. The policy also calls for the use of fiscal measures, such as tax rebates, to promote the production of high value-added steel.

Pulp and Paper (in 2020: 21% CO_2 reduction from BAU; 30 $MMTCO_2$ in 2020; equivalent to around half of the sector's emissions in 2000; projected growth in pulp and paper production between 2000 and 2020 is about 150%)

- Measures in the pulp and paper industry—composed mostly of state-owned enterprises—are modernizing facilities and operations that were significantly outdated compared to world standards. China's government is currently attempting to modernize its pulp and paper industry through restructuring – encouraging state-owned plants to automate their operations, promoting mergers (the largest manufacturing facilities are also the most efficient), facilitating foreign investment, and closing down smaller, older facilities.

Transportation (in 2020: 5% CO_2 reduction from BAU; 34 $MMTCO_2$; equivalent to 75% of car emissions in 2000)

- *"Maximum Limits of Fuel Consumption (L/100-km) for Passenger Cars"* establishes fuel efficiency standards for passenger vehicles – passenger cars, SUVs and multi-purpose vans. The requirements are divided into 16 weight classes, with each class having a designated maximum fuel consumption rate.[29] These standards are implemented in two phases with an estimated equivalent vehicle efficiency of 34 miles per gallon (MPG) in 2005 and 37 MPG in 2008 (An and Sauer, 2004). [30] Phase I of this program is consistent with the goal of the 10th Five-Year Plan to reduce oil consumption from current levels by 5-10%; it went into effect on July 1, 2005, for new models of vehicles and on July 1, 2006, for existing models. Phase II will take effect on January 1, 2008, for new models and on January 1, 2009, for existing models; this phase is expected to allow achievement of the 11th Five-Year Plan's goal of reducing oil consumption by 15% from current levels.

In 2006, China has adopted a number of additional efforts (not analyzed in this project as they were outside the scope) that could have a significant impact on overall emissions.

- The recently adopted *Eleventh Five Year Plan* sets a goal to reduce energy use per unit of GDP by 20% between 2005 and 2010. This is no small undertaking given that China has already improved energy intensity by 77% between 1990 and 2003, but has become a major focus of a number of initiatives.
- In the *"1000 highest energy-consuming enterprises"*[31] program the 1000 facilities accounting for the greatest energy use are to benchmark their energy performance, install efficient equipment, and attain a 20% efficiency improvement by 2010.

[29] Stricter standards apply for passenger cars with manual transmissions in each weight class; SUVs and multi-purpose vans must meet the same standards as passenger cars with automatic transmissions. The stringency of the maximum fuel efficiency standards also increases with weight, so lighter vehicles can meet their respective standards more easily than heavier vehicles.

[30] This standard was modeled in this analysis based upon the rates in the "Mid- and Long-Term Specific Plan on Energy Conservation" level of 6.7-8.2 L/100-km by 2010 (13.4 km/L, 31.5 mpg), so the level of reduction could be even greater depending on the fleet mix.

[31] These facilities account for an estimated 30% of China's energy consumption.

- *Vehicle excise taxes* are now based on the vehicle engine size—ranging from 1-20% of the vehicle purchase price—with the tax on four-liter engines (e.g., SUVs) quadrupling from 5% to 20% (to about $8,000 per vehicle).[32]
- The NDRC outlined goals for structural adjustment of the cement industry between 2005 and 2010, including: increasing the share of new dry process cement kiln production from 40 to 70%, closure of 250 million tons of inefficient production capacity, reducing the total number of facilities to 3500, and reducing energy intensity of production from 130 kgce/t clinker to 110 kgce/t of clinker.[33]

I.C.2 *Recent Brazilian Policies and Programs*

A similar trend is expected in Brazil, where recent policies will lower emissions in all sectors analyzed except cement (where the impact of recent policies will be negligible). **These policies will reduce the combined seven-sector CO_2 emissions in Brazil by a dramatic 14% in 2020—a total cut of 73 $MMTCO_2$—in 2020**. This is approximately equivalent to the total current emissions of all Brazilian light-duty vehicles, its seven coal-fired power plants, and cement facilities combined. The largest proportional reductions will occur in the residential and commercial sectors, where the combined emissions are expected to decline by over one-third. Emissions in the transportation sector will fall by almost one-fifth due to increased ethanol consumption from flex-fuel vehicles, and the development of renewables in electricity will lower emissions in that sector by 14%. Emissions are projected to be slightly higher than BAU levels in the cement sector, mostly due to the projected increased use of fuel oil in place of pet coke. While these emissions reductions from "unilateral actions" are large, emissions in these sectors grow at such a fast pace that emissions in 2020 still increase by over 80% over 2000 levels.[34] Table 2 shows the emissions reductions achieved in each sector from these policies and programs.

Table 2. Change in Brazil's Emissions Due to Recent Policies

Sector	BAU Scenario		Recent Policies Scenario		
	2000 Emissions ($MMTCO_2$)	2020 Emissions ($MMTCO_2$)	2020 Emissions ($MMTCO_2$)	Emissions Change from BAU ($MMTCO_2$)	% Change from BAU
Electricity	23	38	33	(5)	-14%
Cement	26	40	41	0.2	0.5%
Iron/Steel	46	82	76	(5)	-6.5%
Pulp/Paper	25	59	57	(2)	-3%
Transport	106	245	202	(44)	-18%
Residential	NA	36	23	(13)	-37%
Commercial	NA	12	8	(4)	-32%
TOTAL	227	512	439	(73)	-14%

Similar to China, **these Brazilian efforts have largely been undertaken for reasons other than climate change.** For example, the ethanol program was largely driven in response to

[32] China Program Update & Clippings, 2006, newsletter of The China Sustainable Energy Program, Issue 19, February, p. 3-4.
[33] CementChina.net, 2006, China Cement Industry Developing Goal till 2010, available at: www.cementchina.net/news/shownews.asp?id=1549.
[34] Excludes emissions in the residential and commercial sectors.

energy security concerns in response to the oil crisis in the mid-1970s and the energy efficiency programs were driven out of a variety of concerns including energy shortages, local air quality, sustainable development, and competitiveness.

Also significant is that **some of the recent measures have been high cost measures, highlighting that other positive benefits have driven these efforts**. For example, Brazil's flex fuel vehicle program, begun in 2003, is estimated to achieve about 20 MMT reductions in 2020 (about 1.7 tonne CO_2 per new vehicle) at a cost greater than $30 per ton.

Some of the emissions reductions achieved through these policies are not being developed as CDM projects and are thus becoming Brazil's "contribution to protection of the atmosphere." Brazil has a total of 190 projects in the CDM pipeline with average total reduction of over 21 $MMTCO_2$ per year.[35] The introduction of Brazilian flex fuel vehicles and the concurrent emissions reductions have not been registered as a CDM project, so the total estimated reductions in the transportation sector from "unilateral actions" of 20 $MMTCO_2$ estimated to be achieve in 2010 are not being scored as CDM projects. However, some of the ensuing reductions from these policies are likely being captured as CDM projects. For example, a large number of wind, hydro, and biomass projects have been proposed in Brazil as CDM projects. These projects are estimated to reduce emissions by around 5 $MMTCO_2$ per year[36] — roughly the same level of reduction estimated in the electricity sector from recent policies.

In particular, **Brazilian policies and programs implemented between 2000 and 2005, including the following, have led to these reductions.**

<u>Electricity</u> (in 2020: 14% CO_2 reduction from BAU; 5 $MMTCO_2$; equivalent to closing 42% of Brazil's current oil-fired electricity generation)[37]

- The *Program for Incentive of Alternative Electric Energy Sources (PROINFA)* launched in 2002 sets an overall goal to produce 10% of the total electricity from renewable sources by 2022 in two phases. The first phase is to achieve 3,300 MW of renewables—split equally among biomass, small hydro and wind—through long-term power purchasing agreements between Eletrobrás and independent power producers (IPPs) and fiscal incentives for each type of renewable energy (e.g., wind energy subsidy of $86.32 – 97.90/MWh).

<u>Transportation</u> (in 2020: 18% CO_2 reduction from BAU; 44 $MMTCO_2$; equivalent almost 1.5 times the total emissions from light-duty vehicles in 2000[38])

- The *National Program of fuel alcohol (PROALCOOL)* aimed to promote ethanol use in transportation in response to oil crisis of the 1970s. Although it was discontinued in the late 1980s, PROALCOOL transformed 85% of the vehicle fleet into ethanol vehicles. More recently, this program has laid an important groundwork for the introduction of flex fuel vehicles (which can use either gasoline or ethanol) into the market. As a result, these vehicles accounted for 50% of sales of new LDVs in 2005 and 77% in February 2006. This

[35] UNEP RISOE, CDM Pipeline, 20 October 2006.
[36] To be conservative, we have included all projects listed in the CDM pipeline classified as biomass, wind, and hydro.
[37] In 2000, oil-fired generation was estimated to emit 11.8 $MMTCO_2$ (Centro Clima, 2006).
[38] Light-duty vehicles in Brazil are estimated to emit a total of 31.9 $MMTC0_2$ in 2000.

is estimated to grow to the point where in 2020 all light-duty vehicles sold in Brazil are flex-fuel and 70% of the fuel used in these vehicles is ethanol.

- The *Program to Promote Efficient Use of Non-renewable Resources (CONPET)* has used a free testing and inspection program for tanker trucks that transport Petrobras fuel to reduce their diesel fuel use by 15% and their associated CO_2 emissions by 38,000 metric tons annually (through mid-2004).

Residential (in 2020: 37% reduction from BAU; 13 $MMTCO_2$; equivalent to 86% of the Brazilian iron and steel emissions in 2000)

- The *Brazilian Stove and Heater Compulsory Labeling Program*, which came into effect in March 2003, requires labeling of energy efficiency for all stove and heaters. As a result, the new models manufactured in Brazil consume on average 13% less liquefied petroleum gas (LPG) than the old models, which implies a saving of two gas canisters per household per year and an approximate annual reduction of 300,000 tons of imported LPG.[39]

I.C.3 *Recent Indian Policies and Programs*

India is projected to achieve emissions reductions by 2020 in the transportation and iron and steel sectors below "business as usual" (BAU) levels, but these reductions are projected to be offset principally by emissions increases in the electricity sector. In 2020, recent efforts are expected to reduce emissions in the Indian transportation and iron and steel sectors by 15% below BAU levels in transportation—97 $MMTCO_2$—and by 5% in iron and steel—17 $MMTCO_2$. Emissions increase due primarily to the implementation of the National Electricity Policy, which causes emissions to rise in that sector by 12% above the BAU levels. The net impact of these efforts is projected to increase emissions by 6 $MMTCO_2$ in 2020—a total increase for all sectors of less than 0.3%. While emissions reductions from "unilateral actions" decrease emissions in two of the sectors, emissions for the evaluated sectors grow at such a fast pace that emissions in 2020 from these sectors still increase by 230% above 2000 levels. Table 3 shows the emissions impacts in each sector from these policies and programs.

Table 3. Change in India's Emissions Due to Recent Policies

Sector	BAU Scenario		Recent Policies Scenario		
	2000 Emissions ($MMTCO_2$)	2020 Emissions ($MMTCO_2$)	2020 Emissions ($MMTCO_2$)	Emissions Change from BAU ($MMTCO_2$)	% Change from BAU
Electricity	427	952	1,062	110	12%
Cement	67	334	339	5	1%
Iron/Steel	66	317	300	(17)	-5%
Pulp/Paper	6	12	13	0	1%
Transport	97	644	547	(97)	-15%
Residential	47	76	80	4	6%
Commercial	7	18	18	-	0%
TOTAL	717	2,352	2,358	6	0%

Indian policies and programs implemented between 2000 and 2005 have led to these reductions, including the following.

[39] PETROBRAS/CONPET, 2004.

Iron and Steel (In 2020: 5% CO_2 reduction from BAU; 17 $MMTCO_2$; equivalent to one-third of the sector's total emissions in 2000)

- The *National Steel Policy 2005* seeks to increase the capacity and efficiency of steel production in India and is expected to spur the iron and steel industry to retrofit inefficient plants and build more efficient facilities. The minimum production in the most efficient BF-BOF facilities is thus estimated to increase from 20% of total production in 2036 (under BAU) to 60%.

Transportation (in 2020: 15% CO_2 reduction from BAU; 97 $MMTCO_2$; equivalent to the total Indian transportation emissions in 2000)

- Under the *Indian Integrated Transport Policy 2002*, the government seeks to meet the transport demand generated by higher rate of growth of GDP, realize the optimal inter-modal mix as well as freight-passenger mix in the railways through appropriate pricing and user charges, and promote sustainable transport system with increased emphasis on energy efficiency and environmental conservation. As a result of this and other policies (*Vision 2020 Transport* and a *draft national urban transport policy*), it is estimated that fuel economy will improve and the rail shares for both passengers and freight will increase.

Some recent policies are expected to increase emissions. For example, the Electricity Act 2003 is expected to expand electricity generation, largely driven by increased electricity access. The National Electricity Policy includes the following objectives: access to electricity available for all households in next five years; electricity demand to be fully met by 2012; supply of reliable and quality power in an efficient manner and at reasonable rates; and per capita availability of electricity to be increased to over 1000 kWh by 2012. To meet these objectives electricity production is estimated to expand by more than 110 TWh in 2020 due to increased demand for electric lighting and appliances—6% above the level without recent policies. The analysis assumes that demand for electricity will increase (e.g., for lighting, home appliances, and other services) as a result of access to the electricity grid. It also makes the conservative assumption that traditional fuels such as wood for cooking which are replaced by electricity generation are carbon-neutral as they are "sustainably" harvested. This does not account for some of the other climate change impacts from biomass combustion (e.g., black carbon, CH_4, etc.). On net, accounting for these factors could make the emissions implications of this policy neutral or lead to net emissions reductions, but the methodology employed here does not necessarily capture these factors. Based upon this, electricity sector emissions are estimated to increase by 110 $MMTCO_2$—a 12% increase above BAU—due to the introduction of recent policies.

Indian actions that occurred prior to 2000 (and therefore included in the baseline[40]) have been undertaken which have led to reduced or avoided emissions. India has long supported efforts for expanding renewable generation, particularly wind generation. For example, India has worked to develop a domestic manufacturing industry[41] and has provided incentives such as five-year tax holidays on income from sales of electricity, accelerated depreciation of 100 percent on investment in capital equipment in the first year, excise duty and sales tax exemptions

[40] This means that it isn't possible to pull out the impact of this policy since it is captured in the pre-2000 baseline.
[41] This has been done with the assistance of overseas companies such as Denmark, Germany, and the Netherlands.

for wind turbines, waiver of import duties on a variety of components, and moving toward a production tax incentive to encourage performance.[42] In addition, the India Renewable Energy Development Agency (IREDA) was formed to provide assistance in obtaining loans from the World Bank, the Asian Development Bank, and the Danish International Development Agency (DANIDA). As a result, India has the fourth largest amount of installed wind capacity—4,430 MW—and added almost 1,500 MW in 2005 alone.[43]

Some of the emissions reductions achieved through these policies are not being developed as CDM projects and are thus becoming India's "contribution to protection of the atmosphere". India has a total of 456 projects in the CDM baseline, with total average reductions of 38 $MMTCO_2$ per year.[44] Only one transportation CDM projects is in the CDM pipeline for India and it is expected to result in a small emissions reductions—estimated at 7 kt CO_2 per year—far lower than the 14 $MMTCO_2$ estimated to be achieved in 2010 in the transportation sector from recent policies. In contrast, India has a large number of industrial-based CDM projects, some of which are in the iron and steel sector which is estimated to generate emissions reductions of 17 $MMTCO_2$ through "unilateral actions".[45]

I.D Opportunities for achieving significant additional emission reductions at reasonable cost are also available

Additional emissions reduction opportunities are also available in each country, some are available at low cost while others require larger incremental investment. **A total emissions reduction of 1,534 $MMTCO_2$—a reduction of 19% below BAU levels—can be achieved in these three countries through implementation of "unilateral actions" and additional mitigation measures.** This is roughly equivalent to offsetting emissions from 410 new coal-fired power plants. In this analysis, estimates of the reductions from unilateral efforts (also referred to as Recent Policies) undertaken prior to 2006 were developed separately from the analysis of potential reductions that could be achieved through additional new mitigation ("Advanced Scenarios"). It should be noted that the Advanced Options scenarios assume implementation of both the unilateral actions and the select additional mitigation options. Therefore, a portion of the additional reductions claimed for the Advanced Options scenarios in some sectors will be the result of unilateral actions already undertaken. When comparing and interpreting the unilateral/Recent Policies reductions to the reductions obtained through additional mitigation measures (Advanced Options), it should therefore be kept in mind that the reductions are not additive. On an aggregate basis, the study projects cost-effective reductions (below \$10/ton CO_2) of four percent in India, four percent in Brazil and 10 percent in China below BAU levels in 2020 totaling more than 625 million tons of CO_2 per year – the equivalent of avoiding the construction of more than 150 coal-fired power plants.

[42] EIA, Wind Energy Developments: Incentives in Selected Countries, available at: www.eia.doe.gov/cneaf/solar.renewables/rea_issues/windart.html
[43] REN21, Renewables Global Status Report: 2006 Update, available at: www.ren21.net/globalstatusreport/download/RE_GSR_2006_Update.pdfENEWABLES
[44] UNEP Risoe, CDM pipeline, October 2006.
[45] It was impossible, without going through each project design document, to assess how many of the industrial CDM projects were in the iron and steel sector.

If China, Brazil and India chose to make the reductions outlined in this study by 2020, their efforts, coupled with other countries' efforts, could be sufficient to stay on track to stabilize global atmospheric CO_2 concentrations at 450 ppm.[46] To meet this concentration goal, other nations would need to make significant reductions along the lines of the: EU and other developed nations cutting their emissions to 30 percent below 1990 levels by 2020, U.S. cutting its emissions to 1990 levels by 2020, and other major developing countries making efforts similar to China, India and Brazil.[47] This proposed combination of emission reductions is simply illustrative. Any combination of reductions from developed and developing nations that achieves the same aggregate reduction can keep the achievement of a 450 ppm global atmospheric CO_2 concentration in play. Even given the huge projected growth in emissions in these three developing countries through 2020, the key point here is that the potential, largely cost-effective reductions identified in this study are significant – their achievement would mark important progress toward achieving the goal of limiting global increases in temperature to 2 degrees Centigrade.

Below we summarize the emissions reduction potential identified in this analysis for each sector in each country.

I.D.1 *China*

In China, an emission reduction of nearly 20% from these sectors[48] could be achieved with implementation of all feasible mitigation measures analyzed in 2020—equivalent to nearly a billion ton emissions reduction from 2020 BAU levels. This is equivalent to 83% of China's electricity sector emissions in 2000. Almost half (45%) of these reductions are available in the electricity sector, with over one-fifth available in both cement and transportation. Figure 4 shows the projected emissions trajectory in China from 2000 to 2020 under each mitigation scenario, for all five sectors combined.

[46] Stabilizing emissions at 450ppm CO_2 is roughly equivalent to stabilizing emissions at 500 ppm CO_2 equivalent. Source: den Elzen and Meinshausen (2005), Meeting the EU 2°C climate target: global and regional emission implications.

[47] Based upon analysis conducted by Ecofys Consulting for CCAP. Available at: www.ccap.org/international/Sector%20Straw%20Proposal%20-%20FINAL%20for%20FAD%20Working%20Paper%20%7E%208%2025%2006.pdf and www.ccap.org/FADforum/Hoehne%7ESector-Based%20Program%20GHG%20Implications.pdf

[48] The China analysis only included electricity, iron and steel, cement, pulp and paper, and on-road vehicles.

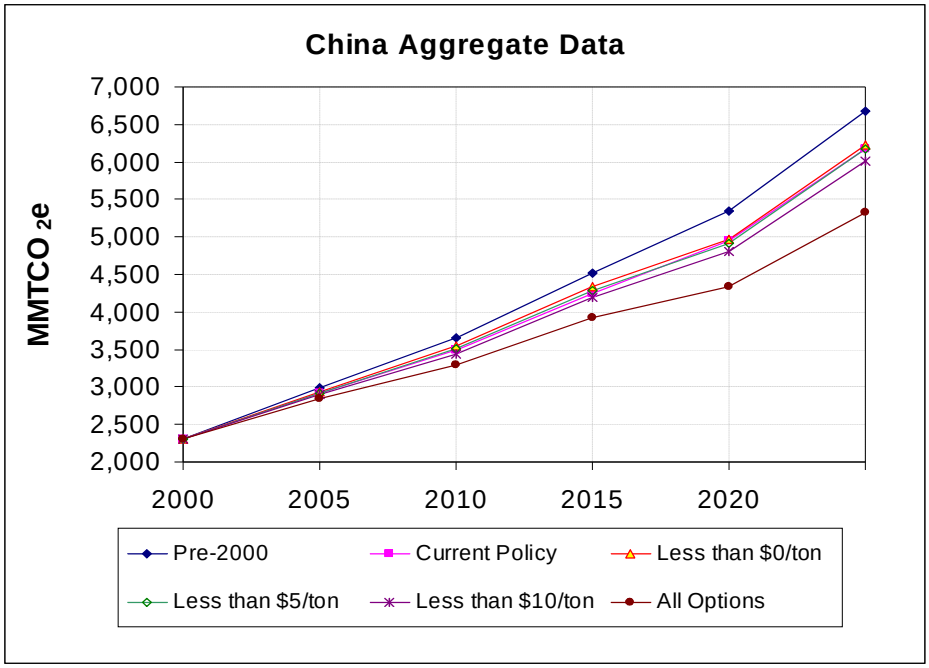

Figure 4. CO_2 Emissions in China Under Various Scenarios

Implementation of only the lower cost measures (with net savings or less than $5 per ton) in China would reduce GHG emissions from the five sectors by 7% below the BAU level in 2020—a 397 MMTCO$_2$ emissions reduction. This is roughly equivalent to offsetting the annual emissions of over 100 new coal-fired power plants. The majority of these reductions are available in the transportation sector (52% of the reductions), followed by cement (32%) and electricity (11%).

At higher cost of less than $10 per ton, emissions could be cut by 10% below BAU levels in 2020 for these sectors—a total reduction of over 510 MMTCO$_2$. This is equivalent to 44% of China's emissions from coal-fired electricity in 2000. These more expensive reductions are largely available in the cement sector (70 MMTCO$_2$ above the amount achievable at less than $5 per ton), followed by electricity (25 MMTCO$_2$) and iron and steel (19 MMTCO$_2$).

The table below (Table 4) shows the individual options for emissions mitigation in the sectors analyzed for China, and the associated costs and emissions reductions available in each sector in 2020.

Table 4. Chinese Emissions Reduction Options in 2020

Marginal Abatement Cost ($/tonne CO_2e)	Total Emission Reduction ($MMTCO_2$e)	Cumulative Reduction ($MMTCO_2$e)	Mitigation Options	Sector
-18.4	19.1	19.1	Transmission Technologies	Transportation
-12.0	43.8	62.9	Vehicle Technologies	Transportation
-11.9	136.0	198.9	Engine Technologies	Transportation
-11.1	3.8	202.7	Engine-Transmission-Vehicle Technologies	Transportation
-4.5	23.5	226.2	Preventative Maintenance	Cement
-3.8	21.5	247.7	Use of Waste Derived Fuels	Cement
-3.6	5.7	253.4	CFBC (Circulating Fluidized Bed Combustion)	Electricity
-3.6	3.6	257.0	Establish energy management center	Iron and Steel
-3.0	38.0	295.0	Demand side management	Electricity
-2.4	19.5	314.5	Process management and Control	Cement
-1.9	11.3	325.8	Kiln Shell Heat Loss Reduction	Cement
0.2	8.2	334.0	High-Efficiency Motors and Drives	Cement
0.9	10.2	344.2	Active Additives	Cement
1.5	14.3	358.5	Composite Cement	Cement
2.6	2.8	361.3	BRT	Transportation
3.0	9.1	370.4	Advanced coke oven	Iron and Steel
3.8	49.1	419.5	Conversion to Multi-stage pre-heater kiln	Cement
4.1	34.8	454.3	Combustion System Improvement	Cement
5.4	24.6	478.9	Advanced blast furnace technology	Iron and Steel
5.7	25.1	504.0	Reconstruction of conventional thermal power	Electricity
6.0	29.7	533.7	Supercritical/Ultra supercritical plant	Electricity
6.6	28.6	562.3	High-efficiency roller mills	Cement
8.2	43.6	605.9	Adjust ratio of iron/steel	Iron and Steel
9.7	10.2	616.1	High-efficiency Powder Classifiers	Cement
12.7	3.7	619.7	Efficient transport systems	Cement
19.2	136.9	756.6	Nuclear power	Electricity
21.5	10.3	766.9	Fuel Switch	Transportation
30.4	3.5	770.5	Dry coke quenching	Iron and Steel
31.0	171.2	941.7	Hydropower	Electricity
31.6	10.8	952.4	Advanced sinter machine	Iron and Steel
32.7	4.2	956.6	Natural gas	Electricity
34.9	4.4	961.1	Advanced direct steel rolling machine	Iron and Steel
38.0	7.6	968.7	Wind power	Electricity
38.8	14.1	982.8	IGCC (Integrated Gasification Combined-Cycle) & PFBC (Pressurized Fluidized Bed Combustion)	Electricity
52.7	25.6	1008.4	Smelt reduction technology	Iron and Steel
53.3	5.0	1013.4	CCS (Carbon Capture and Storage)	Electricity
61.0	7.6	1021.0	Advanced converter	Iron and Steel
131.4	5.7	1026.7	Advanced EAF	Iron and Steel
133.7	11.4	1038.1	Solar thermal	Electricity

Electricity

The analysis conducted for this sector indicates that **future GHG emission reduction potential in electricity is large in absolute terms, but may be achieved at relatively higher cost.** The electricity sector in China has the highest potential level of absolute reductions of all sectors analyzed, and accounts for 45% (444 $MMTCO_2$) of the total reductions analyzed. It is also the largest sector in terms of aggregate emissions in the Chinese economy. Implementing these measures would reduce electricity emissions by 14% in 2020, but 85% of these reductions would cost more than $10 per ton (see Figure 5).

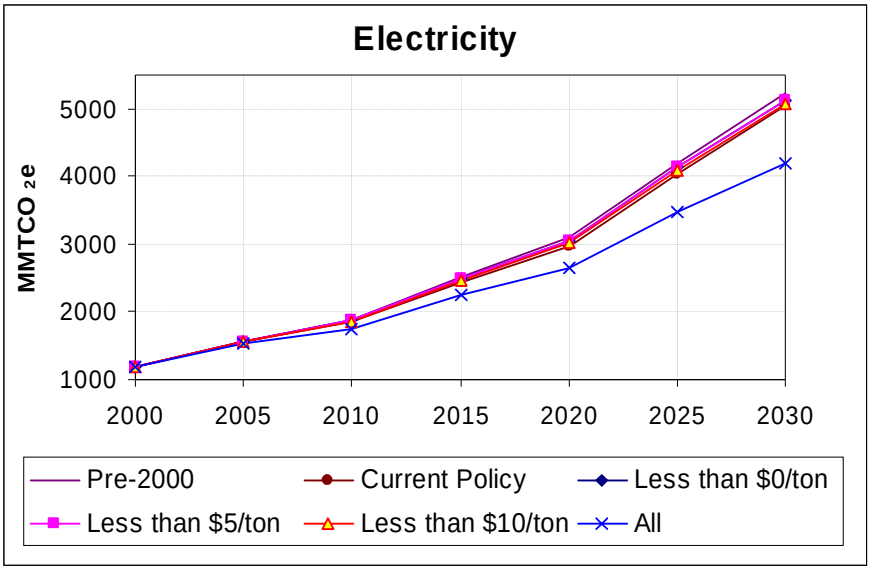

Figure 5 Electricity-Sector CO_2 Emissions in China Under the Various Scenarios

While policies already underway are expected to reduce emissions significantly and the availability of further low-cost reductions is uncertain, **some low cost emissions reductions remain in this sector**, including:

- demand side management in all sectors (38 $MMTCO_2$ reduction in 2020 at a savings of $3 per ton)—it is important to note that demand-side management assumed in this analysis is a first order estimate as detailed bottom-up data was not available for all sectors to make a more accurate assessment.[49]
- more efficient new coal facilities (35 $MMTCO_2$ in 2020 at a cost less than $6 per ton); and
- efficiency improvements at existing coal-fired units (25 $MMTCO_2$ at a cost of $5.7 per ton)

Co-benefits could also make some of the higher cost options more promising. For example, although replacing new coal plants with nuclear power, hydro, and natural gas all cost in the range of $20 to $30 per ton, these measures would produce significant benefits in the form of reduced coal consumption and a corresponding drop in SO_2, particulate and NO_x emissions, improved water quality, increased economic productivity, and enhanced power reliability and grid stability (in the case of nuclear power). More expensive options which have been pursued in China to date for a variety of reasons include:

- Nuclear power (137 $MMTCO_2$ at a cost of $19 per ton)
- Wind generation (8 $MMTCO_2$ at a cost of $38 per ton)
- Integrated gasification combined cycle with carbon capture and sequestration (5 $MMTCO_2$ at a cost of $53 per ton). It is important to note that this assumes the building of only one such plant as the Tsinghua team felt that the cost was too high and the technology development in China too low prior to 2020 for further plants to be likely to be deployed pre-2020. Technological development in China and further cost reductions through demonstration plants in China and elsewhere were considered pivotal in whether greater penetration of this technology can be expected post 2020 in China. Other analysis (Larsen

[49] Other analysis has found that 5.1 EJ of energy could be saved in the buildings sector alone through more building energy efficiency efforts (ERI and LBNL, 2003).

et al., 2003) found that 132-363 $MMTCO_2$ could be sequestered in China under a scenario with carbon constraints.

Table 5. Electricity Sector Mitigation Options for China

Sector	Electricity			
Advanced Options Scenario	BAU Baseline Emissions in 2020 ($MMTCO_2$)	Emissions under Scenarios in 2020 ($MMTCO_2$)	Emissions Reduction from Baseline in 2020 ($MMTCO_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	3,102	3058	44	1%
#2 (options < $5/ton CO2)	3,102	-	n/a	n/a
#3 (options < $10/ton CO2)	3,102	3033	69	2%
#4 (all options)	3,102	2658	444	14%

Domestic policy options that might be considered by China to achieve these reductions include: fuel pricing programs or energy taxes to promote conservation, as well as capacity building efforts to increase public awareness and encourage energy efficiency activities. Other approaches that could allow China to achieve significant additional emission reductions could include promotion of renewable sources through measures such as subsidies, production tax credits, expansion of the current Renewable Energy Law, carbon portfolio standards, caps, and other regulatory approaches.

Under all scenarios analyzed for the electricity sector, China's GDP is barely affected, and decreases by no more than 0.02%.[50] Implementation of all measures that cost less than $5 per ton, does not impact GDP at all. Undertaking actions that increase the production cost of electricity or implementing mitigation options less $10/ per $MMTCO_2$ therefore does not negatively impact China's GDP significantly. Analysis of the changes of Chinese industrial production prices further suggests that an increased electricity production cost would raise electricity prices by 2 to 3%, while causing only very minimal changes in the costs of most industrial products (less than ± 0.1%). Slightly greater changes in production prices of fossil fuels, especially coal and natural gas, were expected. Increased electricity production costs and implementing electricity mitigation options would lead other industrial production output to generally decrease slightly, although manufacturing increases only slightly. Coal and natural gas output and electricity generation decrease at a greater but still relatively small amount, ranging from 0.5 to 2%.

Lower cost mitigation actions (less than $10 per ton) could be undertaken in China's electricity sector with a minimal impact on the performance of other sectors. Electricity demand falls as electricity prices increase—by 0.2 to 0.4% on average. In the chemical, metal and metallurgy, water, and electricity sectors where prices increase slightly as electricity production costs increase, exports decrease as well. Some sectors see their exports increase, including textile, manufacturing and coal.

[50] Scenarios were analyzed for each sector considered in China, but only results of electricity sector are presented in the China report. More elaboration on all sectors and the results of analysis implementing costs across the entire economy will be discussed in Phase II of this project.

Cement

The cement sector in China is a promising source of low-cost emissions reductions. **Options analyzed in the cement sector are estimated to reduce emissions by one-fifth in 2020—233 MMTCO$_2$ below BAU** (see Figure 6)**.**

Most of these reductions are available at low cost—implementing only the less than $0 per ton measures would achieve an 8% reduction in 2020—93 MMTCO$_2$. Measures available at a net cost saving include:

- preventive maintenance (24 MMTCO$_2$ at a savings of $5 per ton)
- use of waste fuels (22 MMTCO$_2$ at a savings of $4 per ton)
- process control and management (20 MMTCO$_2$ at a savings of $2 per ton), and
- kiln shell heat loss reduction (11 MMTCO$_2$ at a savings of $2 per ton).

Table 6. Cement Sector Mitigation Options for China

Sector	Cement			
Advanced Options Scenario	BAU Baseline Emissions in 2020 (MMTCO$_2$)	Emissions under Scenarios in 2020 (MMTCO$_2$)	Emissions Reduction from Baseline in 2020 (MMTCO$_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	1098	1005	93	8%
#2 (options < $5/ton CO2)	1098	970	128	12%
#3 (options < $10/ton CO2)	1098	900	198	18%
#4 (all options)	1098	866	233	21%

Implementation of the less than $5 and $10 per ton options would achieve reductions of 12% and 18%, respectively. Many of the low-cost options are also expected to produce significant economic co-benefits through increased productivity; air and water quality would also improve from a major drop in the use of coal, which provides nearly all of China's direct fuel needs for cement production. For example, the cement sector accounts for 40% of industrial particulate emissions in the country. The ongoing effort by the government to retrofit old plants and improve energy efficiency indicates an awareness of the potential in these areas.

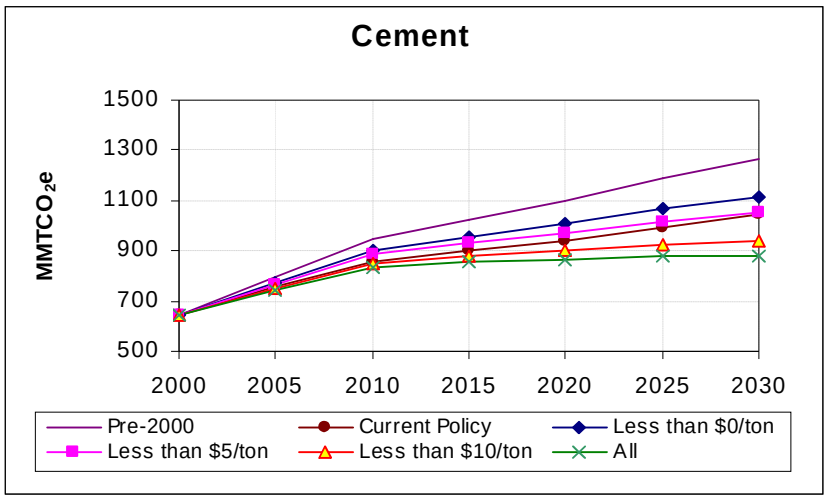

Figure 6. Cement-Sector CO$_2$ Emissions in China Under the Various Scenarios

Iron and Steel

Implementation of all measures costing less than $5 per ton are projected to achieve a 6% reduction in iron and steel emissions—a 19 MMTCO$_2$ reduction below BAU in 2020.

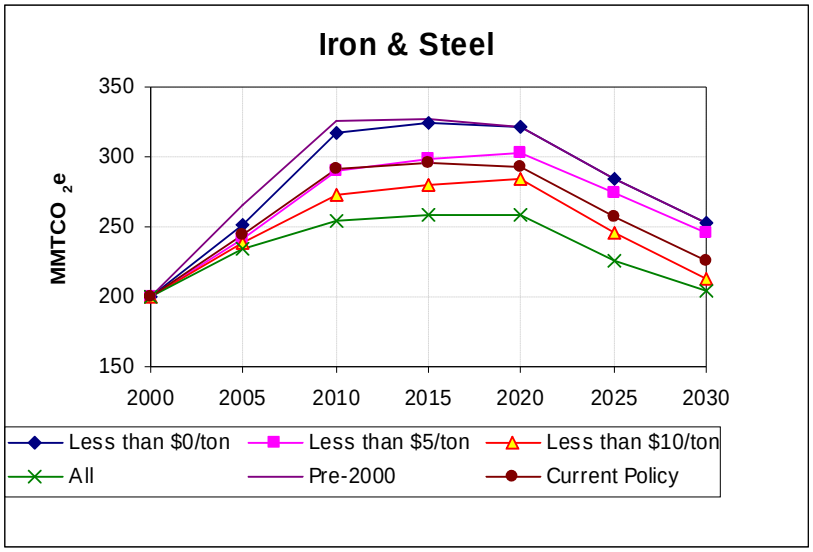

Figure 7. Iron&Steel-Sector CO_2 Emissions in China Under the Various Scenarios

Available options in this regard include:

- establishment of an energy management center (4 MMTCO$_2$ at a savings of $4 per ton) and
- advanced coke ovens (9 MMTCO$_2$ at a cost of $3 per ton)

Implementation of all measures less costing than $10 per ton would reduce emissions by 12% below BAU in 2020—a reduction of 38 MMTCO$_2$. Two additional measures are available at this cost level:

- advanced blast furnace technology (25 MMTCO$_2$ at a cost of $5 per ton)
- adjusting the ratio of iron/steel (44 MMTCO$_2$ at a cost of $8 per ton)

Table 7. Iron & Steel Sector Mitigation Options for China

Sector	Iron & Steel			
Advanced Options Scenario	BAU Baseline Emissions in 2020 (MMTCO$_2$)	Emissions under Scenarios in 2020 (MMTCO$_2$)	Emissions Reduction from Baseline in 2020 (MMTCO$_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	323	321	1.6	0.5%
#2 (options < $5/ton CO2)	323	303	19	6%
#3 (options < $10/ton CO2)	323	284	38	12%
#4 (all options)	323	257	65	20%

These efforts could be supported through government-run voluntary assistance programs where officials share knowledge and training with plant managers, as well as direct incentives (subsidies, tax credits, etc.) for capital investments in modern plants or advanced technologies and research and development. Since the Chinese iron and steel sector currently is a major

producer of global steel, measures that improve efficiency and competitiveness might be ideal for consideration.

Pulp and Paper

In the pulp and paper sector, emissions mitigation could reduce emissions by 25% in 2020, the second-largest proportional reduction after transportation. With respect to measures already underway, efforts to improve technology and energy efficiency undertaken in the industry since 2000 are expected to reduce emissions by 21% in 2020, the largest sectoral proportional reduction from recent measures of all five sectors analyzed. Specific mitigation options and costs were not evaluated for this sector. Instead, the mitigation scenario considered an industry-wide effort to increase the share of production with larger, more efficient plants. A detailed evaluation of the prospects for unilateral action in this sector would require a more in-depth analysis; however, one factor in favor of domestic GHG mitigation efforts in pulp and paper is the important co-benefits such actions would deliver. In addition to enhanced industrial productivity, increased efficiency would also improve local environmental quality, since the industry's fuel needs are met almost entirely with coal, and pulp and paper production typically produces significant amounts of organic and liquid waste. In fact, the desire to reduce such pollution has been a key driver in China's ongoing restructuring of the industry. Further unilateral action thus appears promising.

Table 8. Pulp & Paper Sector Mitigation Options for China

Sector	Pulp & Paper			
Advanced Options Scenario	BAU Baseline Emissions in 2020 ($MMTCO_2$)	Emissions under Scenarios in 2020 ($MMTCO_2$)	Emissions Reduction from Baseline in 2020 ($MMTCO_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	141	-	n/a	n/a
#2 (options < $5/ton CO2)	141	-	n/a	n/a
#3 (options < $10/ton CO2)	141	-	n/a	n/a
#4 (all options)	141	105	36	25%

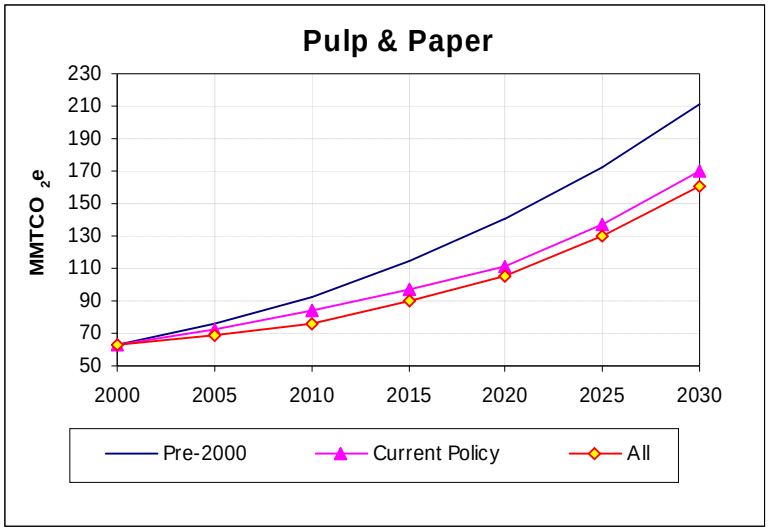

Figure 8. Pulp & Paper-Sector CO_2 Emissions in China Under the Various Scenarios

Transportation

Vehicle ownership in China is still low, so the passenger vehicle portion of the transportation sector[51], contributed less than 10% of the total emissions in 2000 from all sectors included in this analysis—an estimated 6% of China's total CO_2 emissions. However, emissions in this sector are growing rapidly, and a substantial opportunity for emissions reductions exists in China's transportation sector. **The emissions from passenger vehicles in China could be reduced by nearly one-third in 2020 through adoption of the mitigation measures evaluated here. A 30% reduction from BAU is achievable through fuel economy improvements in passenger cars alone, and the technologies required to achieve these gains are estimated to be cost-effective to consumers:**[52]

- transmission technologies (19 $MMTCO_2$ at cost saving of $18 per ton)
- vehicle technologies (44 $MMTCO_2$ at cost saving of $12 per ton)
- combined engine, vehicle, and transmission technologies (4 MMTCO2 at cost saving of $11 per ton)

Table 9 Transportation Sector Mitigation Options for China

Sector	Transportation			
Advanced Options Scenario	BAU Policy Baseline Emissions in 2020 ($MMTCO_2$)	Emissions under Scenarios in 2020 ($MMTCO_2$)	Emissions Reduction from Baseline in 2020 ($MMTCO_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	676	473	203	30%
#2 (options < $5/ton CO2)	676	470	206	30%
#3 (options < $10/ton CO2)	676	-	n/a	n/a
#4 (all options)	676	460	216	32%

In addition, bus rapid transit is being pursued in a number of regions in China for a variety of non-climate change reasons and has an estimated potential to reduce emissions by 3 $MMTCO_2$ at a cost of $3 per ton.

[51] The transportation analysis for China includes only specific types of passenger vehicles – buses, trucks, cars and motorcycles – but omits trains, ships, airplanes and all freight vehicles. Thus, the emissions discussed here do not represent the comprehensive emissions budget of the entire sector.

[52] The cost estimates only account for costs associated with deployment of specific vehicle technologies but do not include costs associated with retooling of manufacturing facilities, training, technology transfer, and similar activities that could constitute barriers to full deployment of advanced vehicle technologies.

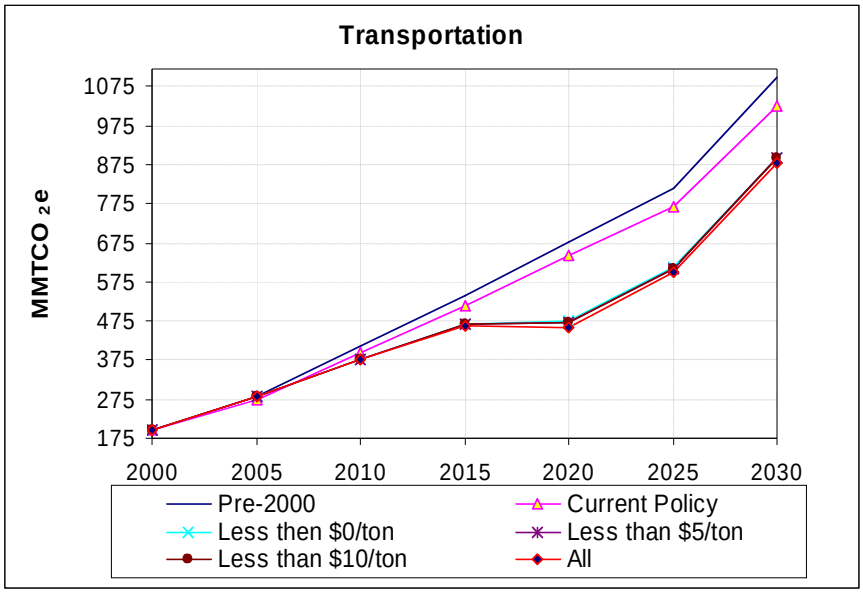

Figure 9. Transportation-Sector CO_2 Emissions in China Under the Various Scenarios

The China analysis proposes a number of policy options that could be implemented to attain the emissions reductions identified. These include some domestic measures – fuel taxes; financial incentives; criteria pollutant emissions standards; financial, technical, or training assistance provided by the government; urban planning – as well as some that are international – e.g., assistance with financing and technology transfer.

Table 10 All Sector Mitigation Options for China

Sector	TOTAL			
Advanced Options Scenario	BAU Policy Baseline Emissions in 2020 ($MMTCO_2$)	Emissions under Scenarios in 2020 ($MMTCO_2$)	Emissions Reduction from Baseline in 2020 ($MMTCO_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	5340	4998	342	6%
#2 (options < $5/ton CO2)	5340	4943	397	7%
#3 (options < $10/ton CO2)	5340	4829	511	10%
#4 (all options)	5340	4346	994	19%

I.D.2 *Brazil*

Implementation of all measures evaluated for Brazil in 2020 would reduce emissions from the seven sectors evaluated by nearly 30% below BAU—a reduction of 147 $MMTCO_2$—which is more than the total emissions in 2000 from electricity, cement, iron and steel, pulp and paper, and light-duty vehicles combined.[53]

[53] It is important to note that a large share of this reduction is through the introduction of flex-fuel vehicles. This is considered as a new option for this analysis since the emissions baseline for comparison was the pre-2000 scenario, under which flex-fuel vehicles weren't envisioned since they were only introduced after that date.

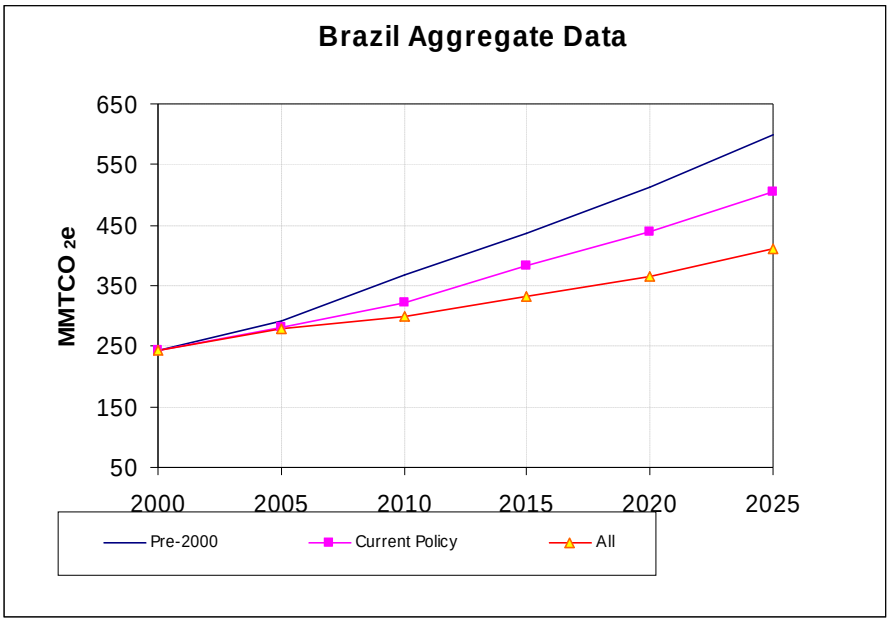

Figure 10. CO_2 Emissions in Brazil Under Various Scenarios

It was not possible to analyze the cost of all mitigation options considered viable in Brazil; however, **implementation of only the Brazilian measures which have no net cost would reduce emissions by 4% in 2020—a 22 MMTCO$_2$ reduction—which is roughly equivalent to the total electricity sector emissions in 2000.**[54] The following tables show the total and sector emissions reductions that can be achieved below each dollar per ton cost threshold in Brazil.

Table 11 shows the Brazilian emissions reductions available in each sector in 2020.

Marginal Abatement Cost ($/tonne CO_2e)	Total Emission Reduction (MMTCO$_2$e)	Cumulative Reduction (MMTCO$_2$e)	Mitigation Options	Sector
-182.5	6.21	6.21	Efficiency gains	Transportation
-115.7	15.2	21.4	Small Hydro	Electricity
-12.9 to -15.1	39.2*	n/a	Increasing Thermal Efficiency	Cement
-9.7	19.5*	n/a	Reducing Clinker ratio	Cement
30.1	21.2	42.6	Flex fuel vehicles	Transportation
30.9	19.6	62.2	Sugar-cane bagasse	Electricity
51.1	19.8	82.0	Wind power	Electricity
107.6	10.0	92.0	Biodiesel	Transportation

* Emission reductions given for multiyear period, so not included in totals

Electricity

The Brazilian energy sector is notable for its abundance of water resources and its lack of high-quality coal. As a result, hydro power accounts for about two-thirds of Brazil's electricity generation, and the sector has a very low average emissions rate. The generation share of fossil fuels is expected to increase, but will still account for only about 5 to 10% of total generation over the next two decades. The sector still offers **potential opportunities to cut electricity**

[54] In this analysis cost data was only available for electricity, cement and iron and transportation. Other cost-effective measures are likely to exist in other sectors, so the actual level of potential negative and low-cost reductions would most likely be higher.

sector emissions in 2020 by more than half (56%) below BAU—a reduction of 21 MMTCO$_2$ (see Figure 11)**.**

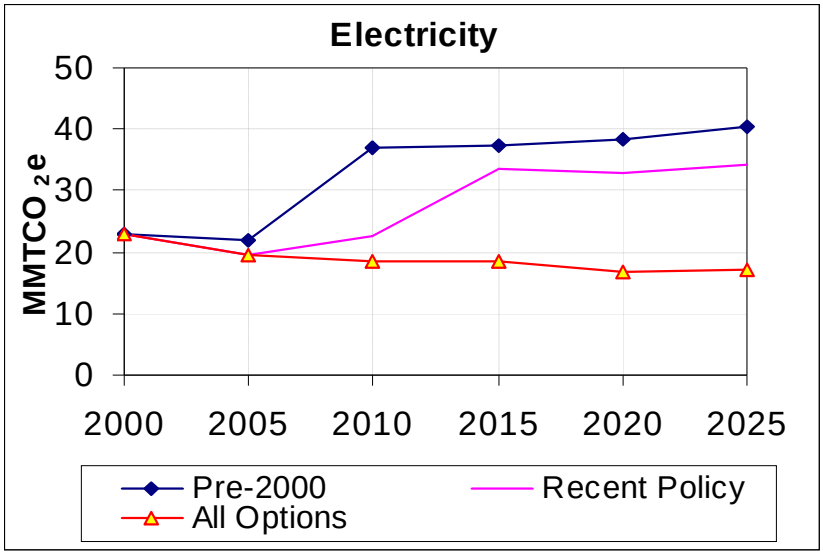

Figure 11. Electricity-Sector CO_2 Emissions in Brazil Under the Various Scenarios

Brazil's electricity sector has only one low cost emissions reduction option—small hydro (15 MMTCO$_2$ at a savings of $116 per ton), while the other renewable options are more costly:

- sugar-cane bagasse (20 MMTCO$_2$ at a cost of $31 per ton)
- wind power (20 MMTCO$_2$ at a cost of $51 per ton)

Table 12. Electricity Sector Mitigation Options for Brazil

Sector	Electricity			
Advanced Options Scenario	BAU Baseline Emissions in 2020 (MMTCO$_2$)	Emissions under Scenarios in 2020 (MMTCO$_2$)	Emissions Reduction from Baseline in 2020 (MMTCO$_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	38	23	15	40%
#2 (options < $5/ton CO2)	38	-	n/a	n/a
#3 (options < $10/ton CO2)	38	-	n/a	n/a
#4 (all options)	38	17	21	56%

To help achieve these reductions the PROINFA program could be expanded to include a higher level of renewables, and also to provide incentives for the development of some resources such as biomass, for which the tariffs in the initial phase of the program were too low to encourage a major expansion. In addition, with only one wind equipment manufacturer currently in business in Brazil, it would also be helpful to develop policies that encourage the opening of one or more additional domestic companies. This could be done with international financing, or by reforming PROINFA to expand the time of the program to accommodate lead-times of investors. An expansion of CDM projects in Brazil is another good prospect for emissions mitigation, particularly with respect to small hydro development, which is currently only partially tapped in the CDM.

Cement

The Brazilian cement industry is already quite efficient but still presents some opportunity for inexpensive emissions reductions. **The mitigation options examined in the cement sector in Brazil indicate that the cement industry can reduce its emissions by at least 17% below BAU in 2020—a 7 MMTCO$_2$ reduction** (see Figure 12).[55] Two options, both of which produce cost savings, yield these reductions:

- increasing thermal efficiency (39 MMTCO$_2$ at a savings of $13 to $15 per ton)
- reducing the ratio of clinker through increased cement blending (20 MMTCO$_2$ at a savings of $10 per ton)

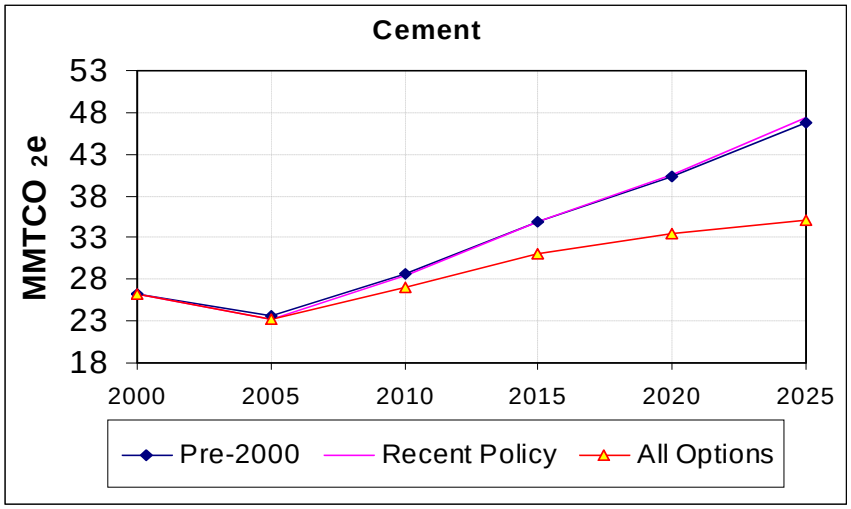

Figure 12. Cement-Sector CO$_2$ Emissions in Brazil Under the Various Scenarios

Table 13. Cement Sector Mitigation Options for Brazil

Sector	Cement			
Advanced Options Scenario	BAU Baseline Emissions in 2020 (MMTCO$_2$)	Emissions under Scenarios in 2020 (MMTCO$_2$)	Emissions Reduction from Baseline in 2020 (MMTCO$_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	40	33	7	17%
#2 (options < $5/ton CO2)	40	-	n/a	n/a
#3 (options < $10/ton CO2)	40	-	n/a	n/a
#4 (all options)	40	33	7	17%

Because cement blending is cost-effective and does not require any special technologies, Brazil could likely achieve significant reductions in its cement industry operations through domestic actions, but may require some capacity building or technical assistance. For example, the demand for blended cement in Brazil has been inhibited by public opinion – blended cement

[55] Lack of cost information prevented an analysis of many cement-sector mitigation options in Brazil. An evaluation of more advanced technologies for cement production (such as exclusive use of 6-stage pre-heaters with pre-calciners), use of alternative fuels, or other mitigation options may identify further opportunities for emissions reductions. For example, CHP was not seen as a viable alternative in cement facilities because it is more expensive in cement plants than in many other industrial applications due to the high content of clinker dust in the exhaust gas.

often has a darker color than typical cement, so in some cases the Brazilian public has not found it to be as attractive.

Iron & Steel

In Brazil, **the potential reductions identified in iron and steel production could reduce emissions by 16% below BAU levels in 2020—a reduction of 13 MMTCO$_2$** (see Figure 13).[56]

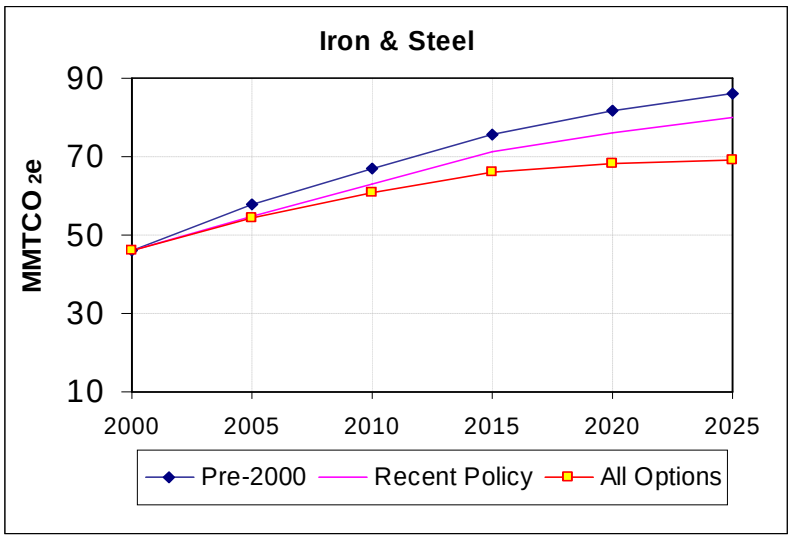

Figure 13. Iron and Steel-Sector CO_2 Emissions in Brazil Under the Various Scenarios

Table 14. Iron & Steel Sector Mitigation Options for Brazil

Sector	Iron & Steel			
Advanced Options Scenario	BAU Baseline Emissions in 2020 (MMTCO$_2$)	Emissions under Scenarios in 2020 (MMTCO$_2$)	Emissions Reduction from Baseline in 2020 (MMTCO$_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	82	-	n/a	n/a
#2 (options < $5/ton CO2)	82	-	n/a	n/a
#3 (options < $10/ton CO2)	82	-	n/a	n/a
#4 (all options)	82	69	13	16%

The total potential for emissions reduction in 2020 is achieved through a mix of mitigation measures – greater market penetration of some advanced technologies (such as electric arc furnaces), a 20% increase in the share of charcoal in the fuel mix (replacing coal coke), a 3% improvement in the efficiency of electric motors, and greater use of scrap in iron and steel production. The most significant of these options is likely to be fuel-switching of coal for charcoal.

[56] Due to a lack of cost information, the cost-effectiveness of mitigation options could not be evaluated for Brazil's iron and steel sector. Some preliminary data indicate that their may be some mitigation measures that were not examined in this study – such as programmed heating, blast stove automation and improved blast furnace control systems – that may be able to moderately reduce emissions cost-effectively, while others (e.g., BOF gas and sensible heat recovery) could significantly reduce emissions at relatively low cost.

Pulp & Paper

Due to Brazil's large share of zero-emission electricity generation, the pulp and paper industry actually emits more CO_2 than the electricity sector. In this analysis, **emissions reductions of 6% below BAU levels in 2020—a reduction of 4 $MMTCO_2$—were identified** (see Figure 14)**.**

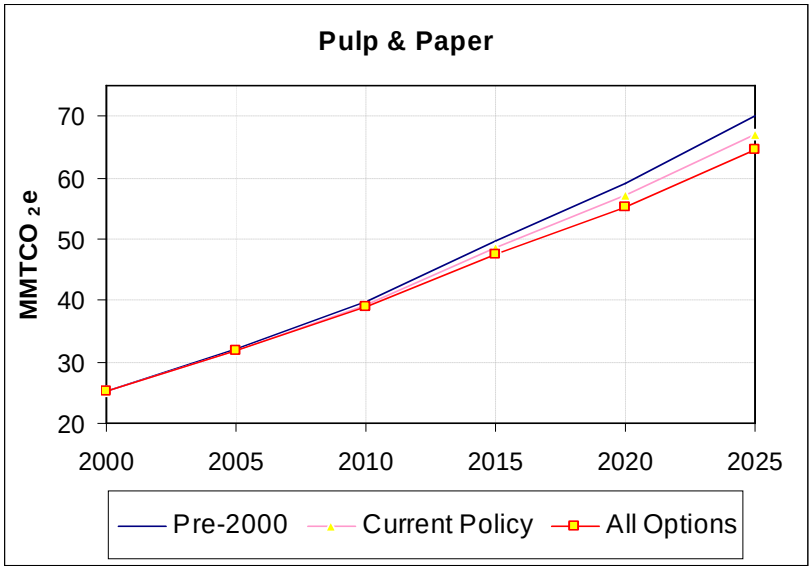

Figure 14. Pulp and Paper-Sector CO_2 Emissions in Brazil Under the Various Scenarios

Table 15. Pulp & Paper Sector Mitigation Options for Brazil

Sector	Pulp & Paper			
Advanced Options Scenario	BAU Baseline Emissions in 2020 ($MMTCO_2$)	Emissions under Scenarios in 2020 ($MMTCO_2$)	Emissions Reduction from Baseline in 2020 ($MMTCO_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	59	-	n/a	n/a
#2 (options < $5/ton CO2)	59	-	n/a	n/a
#3 (options < $10/ton CO2)	59	-	n/a	n/a
#4 (all options)	59	55	4	6%

The primary mitigation options analyzed for Brazil's pulp and paper industry are increased use of natural gas as a fuel source and improved thermal efficiency of plant operations.[57] The analysis indicates that fuel-switching from fuel oil to natural gas is the most promising option to pursue in this sector, although the extent to which this can be achieved is dependent on Brazil's future supply of natural gas.

Transportation

[57] As in the iron and steel industry, cost information was not available to assess the cost effectiveness of the CO_2 emissions mitigation options analyzed for the pulp and paper sector.

The Brazilian transportation sector is already among the lowest-emitting globally because of their extensive use of ethanol in light-duty vehicles. Nevertheless, because Brazil's electricity sector is also extremely clean, transportation-related emissions account for more than half of Brazil's total CO_2 emissions in the sectors included in this analysis. Adopting the suite of **mitigation options examined for the transportation sector would reduce emissions in this sector below BAU by 36% in 2020—a reduction of 87 MMTCO$_2$** (see Figure 15).

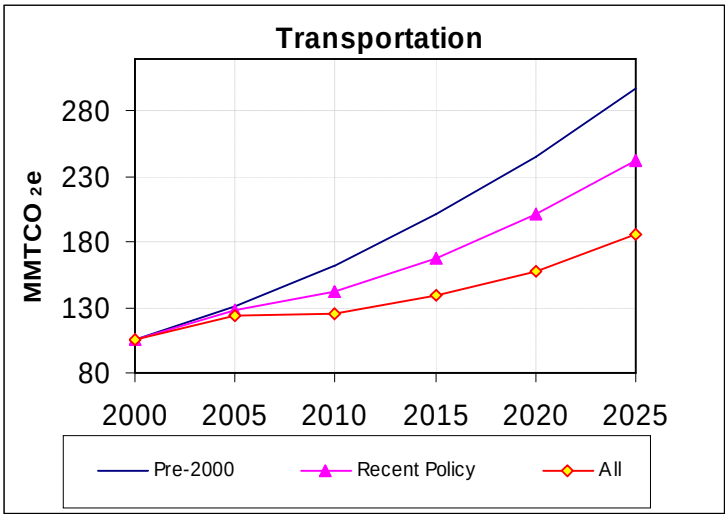

Figure 15. Transportation-Sector CO_2 Emissions in Brazil Under the Various Scenarios

Table 16. Transportation Sector Mitigation Options for Brazil

Sector	Transportation			
Advanced Options Scenario	BAU Baseline Emissions in 2020 ($MMTCO_2$)	Emissions under Scenarios in 2020 ($MMTCO_2$)	Emissions Reduction from Baseline in 2020 ($MMTCO_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	245	-	n/a	n/a
#2 (options < $5/ton CO2)	245	-	n/a	n/a
#3 (options < $10/ton CO2)	245	-	n/a	n/a
#4 (all options)	245	158	87	36%

An important GHG mitigation option in Brazil—in addition to the continued expansion of flex-fuel vehicle—is improving the average fuel efficiency of the LDV fleet through a vehicle labeling program.[58] Such a program, currently under development by CONPET, is estimated to improve the fuel economy of the LDV fleet by 15% between 2005 and 2008, in addition to the 10% improvement due to natural technological progress in the automotive industry. As current trends indicate that the ethanol supply will not grow as quickly as transportation demand, one mitigation option requiring further domestic support is expansion of the ethanol supply.

[58] Numerous mitigation options were analyzed for reducing GHG emissions in the Brazilian transportation sector, although cost information was again unavailable for many of these. For this reason, only three mitigation options were evaluated in terms of cost-effectiveness, and in each case, only the difference in fuel costs was included in the mitigation cost estimates.

For heavy-duty vehicles (HDVs) – trains, ships, airplanes and trucks transporting both freight and passengers – a wide variety of GHG mitigation activities are assumed to result from current industry trends and recent government programs, each of which is believed to be deployable to an even greater extent in the future. These include measures related to the fuel mix, the mode splits of freight and passenger transport, the occupancy of passenger vehicles and the load of freight vehicles, and the fuel efficiency of diesel trucks, diesel buses and natural gas buses. Some of these reductions are likely to be cost-effective, particularly those that are occurring as part of current market trends, rather than being spurred by any specific government policy. The only HDV mitigation option for which costs were estimated in the Brazil analysis is the use of 20% biodiesel blends (B20) in the place of diesel fuel. Such a goal could be attained through expansion of the current PROBIODIESEL program, which aims to achieve 5% biodiesel fuel (B5) use by 2010. However, this mitigation measure is estimated to cost more than $100 per tonne CO_2 in 2020.

Table 17. All Sector Mitigation Options for Brazil

Sector	TOTAL			
Advanced Options Scenario	BAU Baseline Emissions in 2020 ($MMTCO_2$)	Emissions under Scenarios in 2020 ($MMTCO_2$)	Emissions Reduction from Baseline in 2020 ($MMTCO_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	512	490	22	4%
#2 (options < $5/ton CO2)	512	490	22	4%
#3 (options < $10/ton CO2)	512	490	22	4%
#4 (all options)	512	365	147	29%

I.D.3 *India*

In 2020, the analyzed measures could reduce emissions in India by 17% below BAU—394 $MMTCO_2$—which is equivalent to 93% of the electricity sector's emissions in 2000 (see Figure 16)**.** It should be noted, however, that this includes increases in emissions in the Indian residential and commercial sectors; excluding these increases, the other sectors would together achieve reductions of 402 $MMTCO_2$.

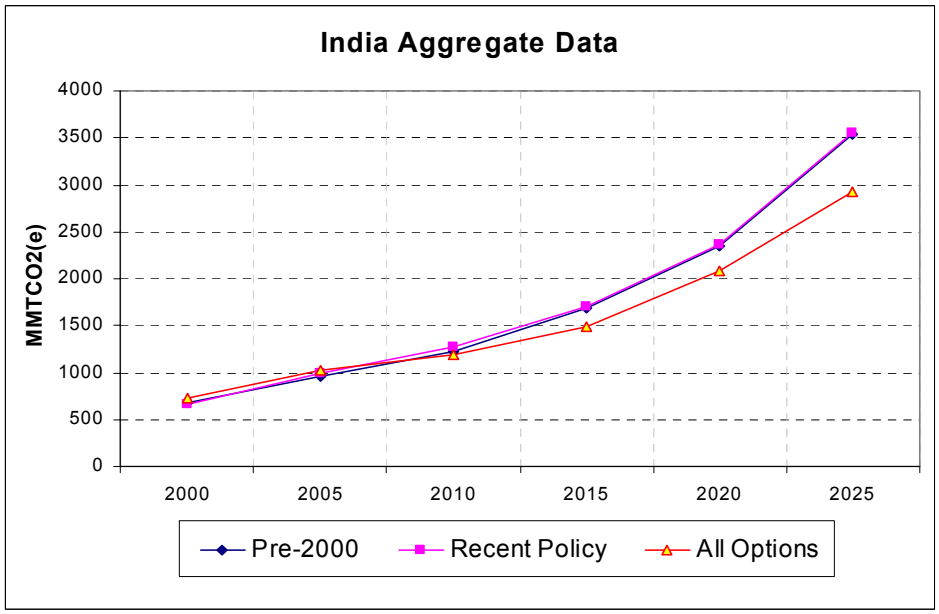

Figure 16. CO_2 Emissions in India Under Various Scenarios

The vast majority of these potential reductions occur in the electricity (178 $MMTCO_2$) and transportation (179 $MMTCO_2$) sectors. Of the identified reductions, only a small fraction—12%—have been identified as available at a net cost savings, and one-fourth of the reductions are known to cost less than $10/ton.

Implementation of only the measures that cost less than $5 per ton could reduce emissions by 3% below BAU—72 $MMTCO_2$—in 2020, which is equivalent to approximately the cement sector emissions in 2000. At higher cost (less than $10 per ton) a total reduction of 4% below BAU in 2020 could be achieved—95 $MMTCO_2$—in 2020, which is nearly equivalent to the total transportation emissions in 2000.

Table 18 shows the Indian emissions reductions available in each sector in 2020.

Marginal Abatement Cost ($/tonne CO_2e)	Total Emission Reduction ($MMTCO_2$e)	Cumulative Emission Reduction ($MMTCO_2$e)	Mitigation Options	Sector
-2081	37.0	37.0	Higher share of rail in freight movement + electrification	Transportation
-20.5	3.2	40.2	H -Frame Combined Cycle Gas Based Plant (60% Efficiency)	Electricity
-16.3	0.8	40.9	Wood based efficient -2	Pulp and Paper
-14.7	0.2	41.2	Retrofit- waste paper based	Pulp and Paper
-14.7	0.2	41.4	Retrofit agro based	Pulp and Paper
-7.5	6.8	48.2	6 Stage producing PPC cement	Cement
-7	36.0	84.2	Enhanced share of public-transport	Transportation
-6.7	3.8	88.0	6 Stage producing PSC cement	Cement
-6.2	23.4	111.4	Wind Power Plant	Electricity
-5	8.0	132.4	Switch towards CNG from conventional fuel based vehicles	Transportation
-4	13.0	124.4	Higher share of rail in passenger movement	Transportation
-3.8	0.3	132.7	Waste paper based efficient	Pulp and Paper
-3.6	145.9	278.6	Nuclear Power Plant	Electricity
0	119.0	397.6	Efficiency improvements	Transportation
6.1	29.1	426.7	Small Hydro Plant	Electricity
6.7	0.3	427.0	Agro based - efficient	Pulp and Paper
83.1	19.4	446.3	BF-BOF -Efficient	Iron and Steel
130	108.0	554.3	Replacing diesel by bio-diesel	Transportation

Electricity

The analysis for electricity generation in India finds that the GHG reduction potential in this sector is very large. In addition, compared to the likely baseline technology that would be installed under BAU conditions,[59] many of these reductions could be achieved in a highly cost-effective manner. **Implementing all measures considered would reduce annual emissions in 2020 by almost one-fifth below BAU levels—a 178 MMTCO$_2$ reduction** (see Figure 17)**.**

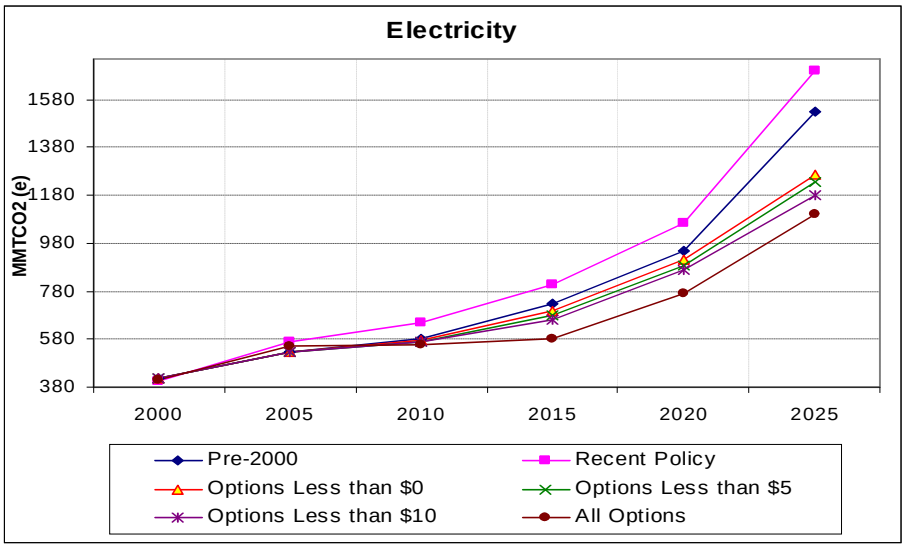

Figure 17. Electricity Sector CO_2 Emissions in India Under Various Scenarios

Introduction of only measures costing less than $0 per ton would reduce emissions in 2020 by 4% below BAU levels—a cut of 38 MMTCO$_2$. Promising options with cost savings include:

- More efficient natural gas combined cycle facilities (a reduction of 3 MMTCO$_2$ at a savings of $20 per ton)
- Wind power plants (a reduction of 23 MMTCO$_2$ at a savings of $6 per ton)
- Nuclear power plants (a reduction of 146 MMTCO$_2$ at a savings of $4 per ton)
- Demand-side management reductions from end-use energy efficiency measures (an approximate reduction of 80 MMTCO$_2$ and decrease in total generation needs of 7%)
- Advanced coal technologies such as coal fluidized bed combustion (CFBC), supercritical and others would also be available at cost savings, although this analysis concludes that their penetration would only be marginal compared to the other options considered.

Implementing measures that cost less than $10 per ton would achieve a 9% reduction in 2020 below BAU levels—a reduction of 81 MMTCO$_2$. Promising additional options in this regard include:

- Small hydro (a reduction of 29 MMTCO$_2$ at a cost of $6 per ton)
- IGCC based on imported coal

[59] Costs for coal, nuclear and renewable options are estimated by comparing to those of a new subcritical coal unit. Costs for the H-Frame combined cycle option are compared to those of a new combined cycle unit.

Table 19. Electricity Sector Mitigation Options for India

Sector	Electricity			
Advanced Options Scenario	BAU Baseline Emissions in 2020 ($MMTCO_2$)	Emissions under Scenario in 2020 ($MMTCO_2$)	Emissions Reduction from Baseline in 2020 ($MMTCO_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	952	914	38	4%
#2 (options < $5/ton CO2)	952	891	61	6%
#3 (options < $10/ton CO2)	952	871	81	9%
#4 (all options)	952	774	178	19%

Mitigation in this sector will also produce significant co-benefits, particularly in the case of renewable energy. The development of renewable energy technologies will create numerous new jobs in rural areas, which can in turn help to reduce India's rural poverty and also decrease migration of rural populations to urban areas. It will also reduce emissions of NO_x and other air pollutants considerably. In addition, the accelerated diffusion of these technologies will improve the general knowledge and experience with them in the country, and may thus reduce their future costs and enhance their performance.

Domestic policy options that might encourage the introduction of these measures, include: subsidies, tax credits, or development of renewable portfolio standards. The government's ongoing efforts to expand rural generation and electrification could also be coupled with an increased emphasis on wind and small hydro power for off-renewable power generation. Expanded demand-side management and energy efficiency programs in end-use sectors could be encouraged through government-industry partnerships to share knowledge and experience, as well as public capacity building efforts. IGCC based on imported coal is a promising option for 2020 and beyond. While its potential is uncertain, it could be explored as an option along with carbon capture and sequestration (CCS) through a domestic pilot program to study and test the technologies and their applicability in India.

Cement

The cement industry in India is modern, with nearly 99% of cement produced in plants that are only about 10 years old on average. In addition, the most inefficient plants are expected to be retired in the next few years, while the middle-aged plants are being upgraded to incorporate the latest technologies. Therefore, **the cement sector in India presents only a modest potential for emissions reductions—increased production of blended cements can reduce CO_2 emissions by approximately 3% below BAU (10 $MMTCO_2$ reduction) in 2020—but the reductions are available at a net cost savings** (see Figure 18)

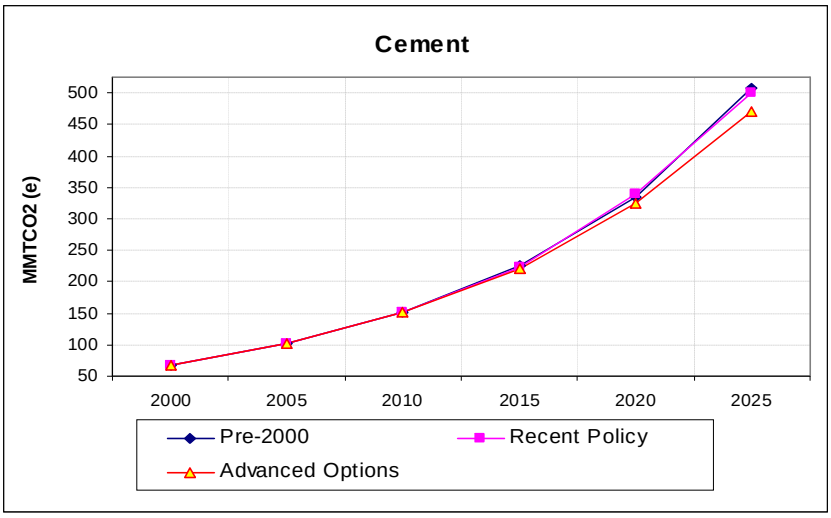

Figure 18. Cement Sector CO_2 Emissions in India Under Various Scenarios

Table 20. Cement Sector Mitigation Options for India

Sector	Cement			
Advanced Options Scenario	BAU Baseline Emissions in 2020 ($MMTCO_2$)	Emissions under Scenarios in 2020 ($MMTCO_2$)	Emissions Reduction from Baseline in 2020 ($MMTCO_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	334	324	10	3%
#2 (options < $5/ton CO2)	334	-	n/a	n/a
#3 (options < $10/ton CO2)	334	-	n/a	n/a
#4 (all options)	334	324	10	3%

Potential additional emissions reductions in the sector, not analyzed, could be achieved through fuel-switching measures. Improvements in the emissions intensity of cement manufacturing are limited by the insufficient supply of domestic coal. In the analysis, it is assumed that higher-emitting imported coal will be used to supplement domestic coal as its supply dwindles, but if an alternative fuel (and perhaps some financial assistance) could be found, greater emissions reductions may be possible from this sector. Implementing co-generation technologies is another option that could reduce emissions but would likely require financial and technical assistance.

Iron and Steel

The single mitigation option considered for the iron and steel industry in India – building new Blast Furnace – Basic Oxygen Furnace (BF-BOF) plants instead of Direct Reduced Iron – Electric Arc Furnace (DRI-EAF) plants – has the potential to reduce emissions in this sector by 10% (32 MMT) in 2020 (see Figure 19)**.**

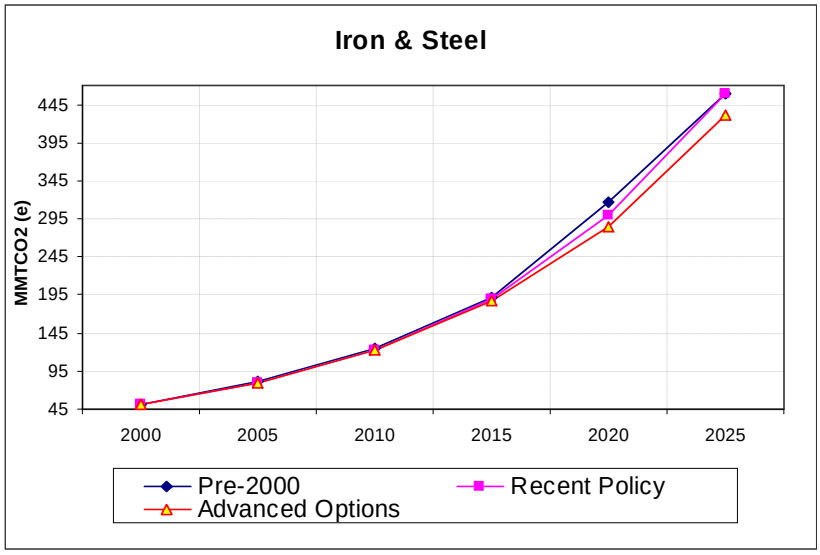

Figure 19. Iron and Steel Sector CO_2 Emissions in India Under Various Scenarios

The potential may exist for even further emissions reductions from this sector because limited supplies of fuel and scrap iron are predicted to increase the emissions intensity of steel production in the next few decades, after an initial decline. Future steel production is assumed to continue to be fueled by coal because demand in the power sector is expected to have priority for the available supply of natural gas. Because domestic coal supplies are limited, as steel production rises, imported coal, which is higher emitting than domestic coal, makes a greater fraction of the industry's fuel use. In addition, India does not have large supplies of scrap iron, so the percentage of iron and steel produced in Scrap-EAF facilities is expected to drop from current levels (~24%) to 10% in 2036. If policies or measures could be put in place to promote fuel-switching or increase scrap supplies, emissions could be reduced even further in this sector, but the costs of such reductions remains to be evaluated. Tax incentives or subsidies may help entities to pursue such mitigation actions.

Table 21. Iron & Steel Sector Mitigation Options for India

Sector	Iron & Steel			
Advanced Options Scenario	BAU Baseline Emissions in 2020 ($MMTCO_2$)	Emissions under Scenarios in 2020 ($MMTCO_2$)	Emissions Reduction from Baseline in 2020 ($MMTCO_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	317	-	n/a	n/a
#2 (options < $5/ton CO2)	317	-	n/a	n/a
#3 (options < $10/ton CO2)	317	-	n/a	n/a
#4 (all options)	317	285	32	10%

While the *National Steel Policy 2005* is expected to support some of these reductions, the remainder could be attained through expansion of this policy but may instead require some type of financial or other incentive to the industry, as the reductions from this measure are not cost-effective (estimated at $83 per ton CO_2). This may include broadening the scope of the Steel Development Fund: Consolidated Fund of India which currently funds options such as improving blast furnace productivity and automation of production processes.

Pulp and Paper

Although the pulp and paper industry only accounts for about 1% of the CO_2 emissions in the seven sectors examined in India, there is a large potential for emissions reductions. Unlike the cement industry, many facilities in this sector are old. In addition, the pulp and paper industry was long protected by the government, so there was no incentive for technological advancement, and the energy efficiency and technological sophistication of the average and best paper plants in India fall below those of the international community.

The mitigation options evaluated for the pulp and paper industry in India can reduce CO_2 emissions by 25% below BAU in 2020—a reduction of 3 $MMTCO_2$—and all of these reductions can be attained at less than $10 per ton (see Figure 20)**.**

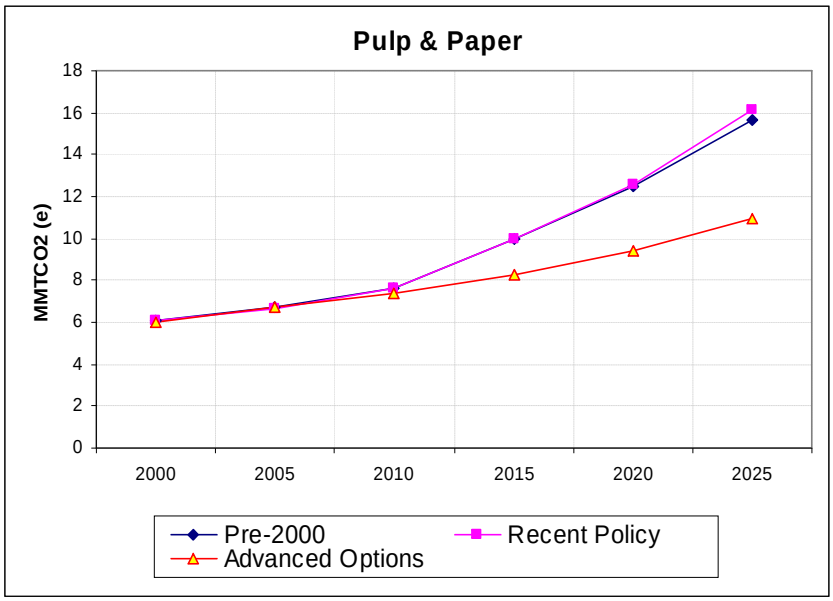

Figure 20. Pulp and Paper Sector CO_2 Emissions in India Under Various Scenarios

These mitigation options involve efficiency improvements – either retrofitting existing paper plants or constructing new plants that are more efficient than typical new facilities – and halting the expected decline in the percentage of waste-based paper production. The latter is expected to fall because significant amounts of waste paper is imported, and these imports are predicted to be phased out completely by 2036 due to concerns regarding their hazardous waste content.

Table 22. Pulp & Paper Sector Mitigation Options for India

Sector	Pulp & Paper			
Advanced Options Scenario	BAU Baseline Emissions in 2020 ($MMTCO_2$)	Emissions under Scenarios in 2020 ($MMTCO_2$)	Emissions Reduction from Baseline in 2020 ($MMTCO_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	12	-	n/a	n/a
#2 (options < $5/ton CO2)	12	-	n/a	n/a
#3 (options < $10/ton CO2)	12	9	3	25%
#4 (all options)	12	9	3	25%

Four of the five efficiency-based mitigation options in the pulp and paper sector are cost-effective; only the construction of more efficient agri-based paper plants has a positive cost, and thus may require subsidies or other fiscal measures to achieve, but it nonetheless remains less than $10 per ton of CO_2 reductions.[60] The waste paper supply could be augmented by a program to increase domestic recycling (India's waste paper collection rate is low from an international standpoint) or through regulation and monitoring of imported waste paper quality.

Transportation

CO_2 emissions from the transportation sector are the fastest growing of the seven sectors analyzed in India, rising from 14% of the nation's total from these sectors in 2000 to 27% of the total in 2020. **The transportation sector offers significant opportunity for emissions reductions, as mitigation options have been identified that will reduce emissions in 2020 by 28% below BAU—a reduction of 179 MMTCO$_2$, many of which are cost-effective.**

Existing government efforts to improve fuel-efficiency by 25% between 2001 and 2036 are expected to provide significant reductions, while **the remaining reductions can be obtained by a package of measures – further fuel economy improvements, electrification of rail systems, increasing the shares of freight and passengers transported by rail, increasing the share of passenger road travel by public transport, and fuel switching to CNG and biodiesel** (see Figure 21)**.**

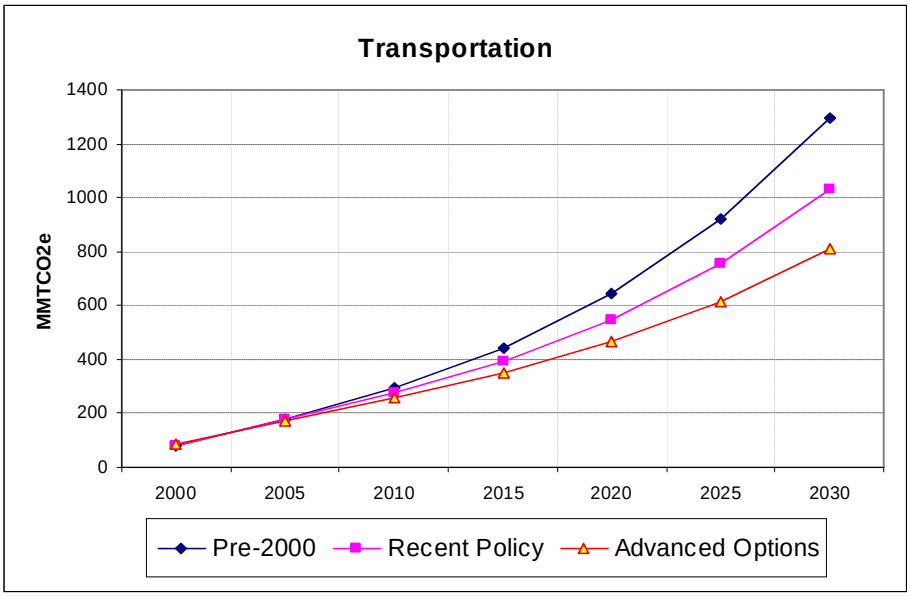

Figure 21. Transportation Sector CO_2 Emissions in India Under Various Scenarios

All measures, except for biodiesel, are estimated to be achieved at cost savings.

However, the transportation sector is unique in that it is influenced to a large degree by public perception and consumer attitudes. In many countries, for example, the personal prestige of car

[60] A cost analysis was not performed for the waste paper production option.

ownership has been identified as a key barrier to any attempts to increase the use of public transport. Some mitigation options may therefore need some type of regulatory push or incentive to reach their full potential, even if they are cost-effective. The Integrated Transport Policy 2001, Vision 2020 Transport, and a draft national urban transport policy have begun to address these issues, and each could be expanded or otherwise revised to include more concrete goals and mechanisms for their achievement. Government-funded research and development would likely be needed to implement a biofuels program, as well as either international or domestic financial or technical assistance.

Table 23. Transportation Sector Mitigation Options for India

Sector	Transportation			
Advanced Options Scenario	BAU Baseline Emissions in 2020 ($MMTCO_2$)	Emissions under Scenarios in 2020 ($MMTCO_2$)	Emissions Reduction from Baseline in 2020 ($MMTCO_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	644	-	n/a	n/a
#2 (options < $5/ton CO2)	644	-	n/a	n/a
#3 (options < $10/ton CO2)	644	-	n/a	n/a
#4 (all options)	644	465	179	28%

The mitigation options explored for India would provide benefits in addition to a reduction in GHG emissions. Increasing the public transit and rail mode shares can reduce congestion, noise, and road wear, while improving safety. Reduced use of motor fuels will also improve the country's energy security, by reducing its dependence on imported oil, and lower the emissions of pollutants, such as nitrous oxides. Decreased particulate emissions from diesel fuel, which accounts for about 80% of the motor fuel used in India today, would be a significant co-benefit of many of the CO_2 mitigation options.

Table 24. All Sector Mitigation Options for India

Sector	TOTAL			
Advanced Options Scenario	BAU Baseline Emissions in 2020 ($MMTCO_2$)	Emissions under Scenarios in 2020 ($MMTCO_2$)	Emissions Reduction from Baseline in 2020 ($MMTCO_2$)	Percentage Reduction from Baseline in 2020
#1 (options < $0/ton CO2)	2352	2304	49	2%
#2 (options < $5/ton CO2)	2352	2281	72	3%
#3 (options < $10/ton CO2)	2352	2258	95	4%
#4 (all options)	2352	1959	394	17%

I.E Role of International Policy in Domestic Implementation

As discussed above, these countries are undertaking domestic "unilateral actions" which if fully implemented will contribute sizeable emissions reductions. These reductions will make progress towards putting global emissions on a path towards lower stabilization levels, but further global reductions will be needed than achieved from these policies and programs alone. The analysis in

this project identified a range of mitigation options which can produce emissions reductions of the magnitude necessary to put global emissions on a lower stabilization level path. These options are available at a range of costs, some of which are available at net savings while others suggest cost levels that without significant co-benefits may not seem attractive to these countries. In some cases, even options which are estimated to produce cost savings could benefit from further policy support as there can be non-economic barriers to their introduction. Each of these elements suggests the need for a future international structure to climate change that:

- Recognizes and encourages "unilateral actions" and
- Provides incentives for more expensive actions.

A future international policy which recognizes and encourages "unilateral actions" is needed. "Unilateral policies and programs" already pursued in these countries if fully implemented could yield significant reductions in GHG emissions. In the current debate around the future of the international response to climate change, these "unilateral actions" by developing countries are often not fully recognized and could benefit from further support. In some cases, these reductions have greater certainty as they are supported by policies and programs with more likelihood of full enforcement. In other cases, further support for achieving these reductions may be needed through domestic or international policies and programs. This suggests that a future international effort to address climate change needs to establish mechanisms to recognize and encourage these and other "unilateral actions", which could be supported through international efforts including the following:

- *Establishment of "pledge and review" process for "unilateral actions".* A reporting system could be established to recognize the "unilateral actions" taken by these countries. This could serve as a means to "pledge" the unilateral actions that countries will undertake and serve as a mechanism to track progress against those actions.
- *Provide "positive incentives" for the successful implementation of these and further "unilateral actions".* Supporting these countries in their unilateral actions could potentially benefit from "positive incentives" such as capacity building to understand the options that are attractive for non-climate change reasons, assistance with full implementation and enforcement, technology support, help in overcoming non-economic barriers, among others.

The future international policy also needs to provide incentives for the more expensive emissions reductions options available in these countries. A range of mitigation options are available in these countries which can keep emissions on path for lower stabilization levels. While some of these could potentially be implemented "unilaterally" due to their cost savings, relatively low cost, or significant co-benefits, some of these options are available at relatively higher cost. This suggests the need for a future international structure which can provide assistance for these more expensive options, including through: financial support, technology development and transfer assistance, and capacity building. **These efforts could be supported through a variety of international options under discussion, including (among others):**

- ***Sustainable Development Policies and Measures (SD-PAMs)*** where developing countries undertake actions primarily focused on their sustainable development and where climate change is considered a "co-benefit"(Winkler et al., 2002; Winkler et al., 2005; Bradley et

al., 2005).[61] Countries begin by examining their development priorities and identify how these could be achieved in a more sustainable manner, either by tightening existing policy or by implementing new measures. In practice, a country might undertake a number of concrete steps under SD-PAMs (Winkler et al., 2005): identify policies and measures that would make the development path more sustainable; register nationally selected SD-PAMs in a registry maintained by the UNFCCC secretariat; mobilize investment and implement SD-PAMs; and review the implementation of specific SD-PAMs and quantify the changes in GHG emissions.

- ***Sector-Based "No-Lose" Target*** where key developing countries would pledge to achieve a voluntary, sector-wide "no lose" GHG intensity target (e.g., GHG / ton of steel) in major energy and heavy industry sectors (Schmidt et al., 2006a[62]). If a participating country does not meet the voluntary target, no sanctions are accrued. Emissions reductions achieved beyond the pledged target would be eligible for sale as emissions reductions credits (ERCs) to developed countries. Emissions reductions to meet the country's pledge would be permanently "retired from the atmosphere" and thus would not be eligible for sale. To encourage developing countries to pledge to meet more aggressive sectoral intensity targets, industrialized countries and international financial institutions (IFIs) would provide assistance through a *Technology Finance and Assistance Package*, aimed to support deployment of advanced technologies, development of small and medium-sized enterprises to assist in technology implementation, capacity-building activities, and pilot and demonstration projects.

- ***Sectoral Approaches to the CDM*** where sector-wide policies are adopted and net emissions reductions achieved in all facilities—not just the ones reducing emissions—in a single sector (e.g., electricity) or sub-sector (e.g., grid connected electricity) below the level that would have occurred without the project are eligible to generate emissions reduction credits for sale (Schmidt et al., 2006b[63]; Figueres, 2006[64]). This approach would require a baseline into the future—which could be a business as usual projection or an intensity level—that took account of the emissions for the entire sector without the project. Emissions reduction credits could be generated for the entire reduction below the baseline or could be discounted—with only a portion available for sale—and the remainder representing the developing country's "contribution to protection of the atmosphere".

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INTERNATIONAL DEVELOPING COUNTRY ANALYSIS AND DIALOGUE

Greenhouse Gas Mitigation in China: Scenarios and Opportunities through 2030

Tsinghua University of China

The Center for Clean Air Policy (CCAP)

CENTER FOR CLEAN AIR POLICY

November 2006

Center for Clean Air Policy

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I. Introduction

I.A Purpose and Description of Project

I.A.1 Background

At the annual United Nations Framework Convention on Climate Change (UNFCCC) meeting in Montreal in November 2005, Parties agreed to begin formal discussions under both the Kyoto Protocol and UNFCCC on the future international climate policy structure for the post-2012 period. A key element of this discussion will be what role developing countries will undertake in the international response to climate change. In many developing countries discussions about, as well as concrete policy steps to, reducing GHG emissions are already being undertaken, often out of concern over such issues as energy security, air quality, and economic development.

In February 2005, with financial support from the United Kingdom's Department for International Development (DFID), the Tinker Foundation, and the Hewlett Foundation, the Center for Clean Air Policy (CCAP) and leading partner organizations in four key developing countries (Brazil, China, India, and Mexico) launched the ***Assisting Developing Country Climate Negotiators through Analysis and Dialogue*** project. For this ongoing project, this team is working in concert to develop a comprehensive analysis of greenhouse gas (GHG) projections and potential mitigation options, costs, co-benefits, and implementation policies in these four countries. The project represents an important step in the discussions on the post-2012 international response to climate change, by providing concrete analysis and results to help both the internal deliberations in these four countries and the international community. This project has two phases, briefly described later in this section.

The in-country partners in this project consist of:

- a multi-disciplinary team from Brazil that cooperated on the recent Brazilian National Communication, including Haroldo Machado Filho, Special Adviser of the General Coordination on Global Climate Change at the Ministry of Science and Technology, Emilio Lèbre La Rovere, leading the team of the Center for Integrated Studies on Climate Change and the Environment (Centro Clima) at the Institute for Research and Postgraduate Studies of Engineering at the Federal University of Rio de Janeiro (COPPE/UFRJ), Thelma Krug of the InterAmerican Institute for Global Change Research, and Magda Aparecida de Lima, Luiz Gustavo Barioni, and Geraldo Martha of the Brazilian Agricultural Research Institute (Embrapa);
- a team from the Institute for Environmental Systems Analysis within the Department of Environmental Science and Engineering at Tsinghua University of China;
- The Energy and Resources Institute (TERI) of India; and
- the Centro Mario Molina of Mexico.

The results of Phase I have been presented in a series of reports. The reports for Brazil, China and India were released in November 2006. The report for Mexico will be released in 2007. CCAP has also prepared an integrated report, "**Assisting Developing Country Climate Negotiators through Analysis and Dialogue Project: Final Phase I Report**," which compares and contrasts the results achieved across the former three countries. This report presents the results of Phase I (GHG Mitigation Option and Cost Analysis) of the project analysis for China.

I.A.2 Phase I. GHG Mitigation Option and Cost Analysis

In Phase I of this project, the team conducted individual GHG emission mitigation analyses for major economic sectors. In China, the sectors analyzed were electricity; cement; iron and steel; pulp and paper; and transportation. Specifically, each country analysis included the following elements.

- ***Development of a current overview of each economic sector***, including annual number of units and production capacity, production, fuel consumption, GHG emissions, energy intensity, and GHG emissions intensity.
- ***Development of long-term (through the year 2025 or 2030) individual GHG emission projections*** under several baseline scenarios for each economic sector. This includes annual scenarios of production, fuel consumption, GHG emissions, energy intensity, and GHG emissions intensity.
- ***Development of detailed marginal abatement cost curves*** for key technologies and mitigation approaches in each sector. This includes the total GHG emissions reduction potential and cost (per metric ton GHG reduced) for 2010, 2015 and 2020.
- ***Evaluation of the impact of implementation*** of select packages of GHG mitigation options. The results to be provided include the annual changes (through 2030) in energy consumption and intensity, GHG consumption and intensity, total costs and production costs, as well as co-benefits.
- ***Assessment of economy-wide cost and economic impacts*** of mitigation packages on parameters such as GDP, employment, consumer prices, structure of economy, and distribution, using macroeconomic models and optimization frameworks that incorporate the detailed cost and GHG emission reduction potential data for key technologies.
- ***Preliminary analysis of potential domestic policies for implementation*** of each mitigation option, including the domestic legal and regulatory framework, political/economic/technical/legal barriers to implementation, potential key actors and institutions involved, and potential funding approaches.
- ***Evaluation of potential international policy options and the implications of the results*** for each economic sector for specific international approaches.

The GHG mitigation analysis was conducted using country-specific scenarios for annual population and gross domestic product (GDP). These and other major assumptions used are detailed in Section II.D.1. The teams developed two alternative GHG reference case scenarios for each sector, partly based on the A2 and B2 scenarios in the Intergovernmental Panel on Climate Change (IPCC) *Special Report on Emissions Scenarios* (SRES). The A2 and B2 scenarios were chosen because the teams felt that these represented divergent scenarios that each had a reasonable probability of representing the future reality. The A2 scenario is characterized by relatively lower trade flows, slow capital stock turnover, and slower rates of technological change; the B2 world is characterized by comparatively greater concern for environmental and social sustainability.[1] However, for the China analysis only one scenario was conducted based on expert in-country judgment on probable future trends.

It was also desired to develop scenarios that would display the impact of policies and measures undertaken in the past five years; these may include national energy and other policies, as well as projects undertaken as part of the Clean Development Mechanism (CDM) of the Kyoto Protocol. Accordingly, each of the two baseline scenarios was further divided into a scenario assuming implementation of only those policies and projects announced prior to 2000—**"Pre-2000 Policy" scenario**—and another scenario with implementation of all policies announced before 2006—**"Recent Policy" scenario**. Both scenarios begin in 2000. A scenario was then developed that assumes implementation of select packages of GHG mitigation options in years after 2005—called the "**Advanced Options" scenario**. Where appropriate, each country analysis conducted up to four variations of the Advanced Options scenario based on the potential cost effectiveness (measured in $/metric ton CO2e reduced) of the mitigation measures analyzed. The first three Advanced Options scenarios assumed implementation of all measures costing, respectively, <$0 per tonne, <$5/tonne, and <$10/tonne. The fourth scenario was the most aggressive, and considered all feasible (in the team's judgment) mitigation options.

[1] IPCC *Special Report on Emissions Scenarios*, Chapter 4, "An Overview of Scenarios." Available at http://www.grida.no/climate/ipcc/emission.

An important component of this project is an ongoing series of consultations, meetings and workshops to ensure the involvement of key governmental, industry and non-governmental officials and institutions China. Regular contact with policymakers provided a direct link to the government and policy process in each country, and has helped to ensure a realistic analysis and the evaluation of the most appropriate set of mitigation options and policies. At the start of the technical analysis, a workshop was held in Beijing by Tsinghua University and CCAP in July 2005 to obtain feedback and guidance from government policymakers and other stakeholders. This information was incorporated into the analysis. In March 2006, at another two-day workshop held in Beijing, the results were presented to a large group of government officials and representatives from industry, universities, think tanks, and non-governmental organizations. The stakeholders also provided significant input and guidance regarding the mitigation options and policies to be analyzed for Phase II of the project (see below).

An additional important foundation of the project is that it links directly with international climate change negotiators through CCAP's *Dialogue on Future International Actions to Address Global Climate Change*—the Future Actions Dialogue or FAD (Box 1) — the leading international dialogue on climate policy over the last five years. Preliminary results of this project have been presented at various FAD meetings and final results will be presented at future meetings of the group to help shape and inform these deliberations.

Box 1. Dialogue on Future International Actions to Address Global Climate Change

The Future Actions Dialogue brings together key senior negotiators from 15 developing and 15 Annex I countries several times each year to discuss options for future international response to climate change. This project includes six components:

(1) a series of joint dialogue meetings among high-level negotiators from developed and developing country Parties and select company representatives;
(2) a series of dialogue meetings, back to back with joint dialogue meetings, for only developing country negotiators to build capacity, develop policies that countries can implement to meet both climate and national sustainable development goals, and facilitate an exchange of ideas that will lead to more fruitful discussions with industrialized countries;
(3) regional workshops to broaden the network of countries and individuals that understand and contribute to the design of post-2012 options;
(4) in-depth analysis to identify, elaborate, and test options for designing climate change mitigation actions by industrialized and developing countries;
(5) working groups of interested Dialogue participants to explore issues in-depth in between meetings; and
(6) production of FAD working papers and a final compendium that presents the comprehensive analytical findings and policy recommendations developed throughout the project.

For more information on the process, including presentations and papers from the meetings see: www.ccap.org/international/future.htm

I.A.3 Phase II. Policy and Implementation Strategy

In the next phase of the project, to be conducted from mid-2006 through 2007, CCAP and its in-country partners will build upon the work and policy connections developed during Phase I. In consultation with in-county policymakers CCAP and its partners will select a number of the most promising options for GHG mitigation and conduct a more detailed and in-depth analysis of issues associated with implementation. This will include an evaluation of the implications of specific international climate change policy options for GHG mitigation in these four countries; development of a suite of potential policies and approaches for implementation of each option; and comprehensive and in-depth analysis of the key actors, barriers and co-benefits associated with each. Phase II will include a series of workshops in each country to obtain the views of and share results with domestic

policy makers and stakeholders. It will culminate in two international workshops, one in Latin America and one in Asia, to disseminate the results of the project to a wider regional audience and expand its policy relevance by allowing other countries to gain from the experience of this project. The results of Phase II for each country will also be available in a set of individual reports.

I.B Report Structure

This report begins in Chapter II with an overview of China, including population and economic statistics and a profile of its historical energy consumption and GHG emission trends. The chapter concludes with a summary of the macro assumptions, analytical methodologies and computer modeling tools used in the analysis. Chapters III through VII present the results of the GHG mitigation option and cost analysis for the individual sectors, beginning with electricity. This is followed in Chapter VIII with results of the macroeconomic modeling and analysis. The report concludes with a discussion of the likely mitigation options and implementation policies in China that may be explored in Phase II of the project.

II. Country Overview

In this section, we provide a brief description of key statistics of China.

II.A Population, Economy[2], and Emissions

II.A.1 Population and Gross Domestic Product

In 2000, China's population was about 1.26 billion, accounting for more than a fifth of the world population.[3] In that same year, China's gross domestic product (GDP) was approximately 1.1 trillion USD, accounting for 3% of the world economy. Chinese GDP per capita was about $865 in 2000, which is less than one fifth of the world GDP per capita of 5,217 USD (see Table 2.1).

Industry[4] sector contributed the largest share of value added to the Chinese national economy in 2000: its US $543 billion accounted for 50% of the economy-wide value added, led by the manufacturing sector with $375 and 35% of the economy-wide value added. Service[5] sector of $361 billion attributed 33% of the national value added, followed by agricultural[6] sector of $177 billion attributing 15% of the national value added. The global shares of Chinese economy in these sectors were 6% for industry, 2% for services, and 15% for agriculture.

Table 2.1 Population and gross domestic product of China in 2000.

	Population		GDP		GDP per capita	
	Billion	% World	Trillion US$	% World	US$	rel. % world
China	1.26	21%	1.1	3%	856	16%
WORLD	6.05	100%	31.6	100%	5,217	100%

Source: World Development Indicator 2005 (World Bank, 2005)

II.A.2 International Trade and Role/Position in the World Economy

China's international trade in goods accounted for approximately 40% of its GDP[7] in 2000. China was a net exporter of merchandise goods, exporting about $220 billion and importing $200 billion. Manufactures made up most of the traded merchandise, accounting for 32.5% of China's GDP (18% by exports and 14% by imports) and 8% of world's total traded manufacture goods. Fuel imports, food exports, and ores and metals imports made up the next large shares of merchandise trades, but each accounted for only marginal proportion of China's GDP at around 1% – 2%. Although accounting for not a large share of the domestic GDP, China's agricultural raw material and ores and metals trades accounted for relatively large shares, at 10% and 8.7%of the world's traded goods of respective categories.

Table 2.2. China's merchandise trading by category in 2000

	Exports			Imports		
	Billion US$	% of GDP	% of World Trading	Billion US$	% of GDP	% of World Trading
Merchandise TOTAL	**219.7**	**20.8%**	**3.9%**	**198.5**	**18.8%**	**3.4%**
Agricultural Raw Material	2.4	0.2%	2.3%	9.3	0.9%	7.8%
Food	11.9	1.1%	3.1%	7.9	0.8%	2.0%
Fuel	6.9	0.7%	1.2%	18.2	1.7%	3.0%
Manufactures	193.8	18.3%	4.5%	150.3	14.2%	3.4%
Ores and Metals	4.2	0.4%	2.6%	11.2	1.1%	6.1%
Other	0.5	0.0%	0.3%	1.5	0.1%	1.0%

Source: World Development Indicator 2005 (World Bank, 2005)

[2] In this section, all financial figures are in constant 2000 USD.
[3] Note that in this chapter and in those following , data for a given historical year (e.g., 2000) may have been taken from different sources. Identical parameters for the same year may therefore differ in different sections.
[4] Industry includes mining, manufacturing, construction, electricity, water and gas (World Bank, 2005).
[5] Services include wholesale and retail trade (including hotels and restaurants), transport, and government, financial, professional, and personal services such as education, health care, and real estate services (World Bank, 2005).
[6] Agriculture includes forestry, hunting, fishing, cultivation of crops, and livestock production (World Bank, 2005).
[7] Trade in goods as a share of GDP is the sum of merchandise exports and imports divided by the value of GDP, all in current U.S. dollars.

In 2006, China is expected to produce 3.8 million barrels of oil per day (bbl/d), and consume 7.4 million bbl/d.[8] China will thus continue to rely on imports to meet nearly half (3.6 million bbl/d) of its total demand. The US Energy Information Administration also forecasts that China's increase in oil demand in 2006 will represent 38 percent of the world total increase. Angola and Saudi Arabia are China's two largest oil suppliers, with Iran, Russia and other Middle East and African countries supplying most of the remainder.

In terms of financial flow, net foreign direct investment (FDI)[9] of $33 billion accounted for about 3% of China's GDP in 2000, almost exclusively driven by the FDI inflows. FDI inflows have grown in recent years along with China's rapidly growing GDP, reaching up to over 48 billion USD in 2004 and remaining at 3% of its GDP. With portfolio and other investment inflows and outflows, the total private capital flow accounted for 11.4% of its GDP, which is less than half of the world's gross private capital flow at 28.4% of its GDP.[10] Official development assistance and official aid[11] accounted for a very little part of the financial flow in China (only 0.1% of the GDP in 2000).

Table 2.3. Key statistics of financial flow in and out of China in 2000

	Foreign Direct Investment					Gross Private Capital Flows	Official Development Assistance and Official Aid	
	Net	Net inflows		Net outflows				
	BoP*, Billion US$	BoP*, Billion US$	% of GDP	BoP*, Billion US$	% of GDP	% of GDP	Billion US$	% of GDP
China	33.0	33.9	3.2%	0.8	0.1%	11.4%	1.5	0.1%
World	134.7	1,335.5	4.9%	1,200.8	4.3%	28.4%	51.4	0.2%

*BoP: Balance of Payment

Source: World Development Indicator 2005 (World Bank, 2005)

II.A.3 Geography

Despite the robust growth of its economy, China is suffering a bigger and bigger disparity between its rural and urban areas.

- Urban-rural income gap

A survey conducted by the Economic Research Institute of the Chinese Academy of Social Sciences shows that the income gap between rural and urban residents in China has kept growing in the past five years, and China has become one of the countries with the largest urban-rural gap in the world. A report based on the nationwide survey shows that the average income per capita of urban residents was 3.1 times that of farmers in 2002, much higher than 2.8 in 1995. Statistics show that in 2003, the income of farmers in China averaged 2,622 yuan (US$316.67) while that of urban residents averaged 8,500 yuan (US$1,026.57), more than three times that of their rural counterparts. However, even this does not tell the real disparity between urban and rural citizens. The income of urban citizens concerned does not count the welfare they have access to, including medical care, unemployment insurance and minimum living relief. Most farmers have no access to these. What's more, they have to pay the educational cost themselves while the central government covers most of such costs for urban residents. With all these factors concerned, the urban residents' income should be four, five or even six times of that of the rural residents.

[8] Energy Information Administration, US Department of Energy. Country Analysis Briefs: China. http://www.eia.doe.gov/emeu/cabs/China/Background.html

[9] Foreign direct investment (FDI) are the net inflows of investment to acquire a lasting management interest (10 percent or more of voting stock) in an enterprise operating in an economy other than that of the investor. It is the sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital as shown in the balance of payments (World Bank, 2005).

[10] Gross private capital flows are the sum of the absolute values of direct, portfolio, and other investment inflows and outflows recorded in the balance of payments financial account, excluding changes in the assets and liabilities of monetary authorities and general government. The indicator is calculated as a ratio to GDP in U.S. dollars.

[11] Net official development assistance (ODA) consists of disbursements of loans made on concessional terms and grants by official agencies of the members of the Development Assistance Committee (DAC), by multilateral institutions, and by non-DAC countries to promote economic development and welfare in countries and territories in part I of the DAC list of recipients (World Bank, 2005).

- Migration issues

Rural- urban labor migration in China nowadays is becoming one of the most obvious as well as influential social factors which is profoundly changing the current system and the society as a whole. There were approximately 120 million rural-urban migrants in 2002, a number exceeding the total population of most countries.

The resulting migration wave has alarmed both urban governments and the central government of China. Local host governments have become negative or even hostile toward migrants who pour into the cities. Urban leaders have questioned how the migrants could be accommodated by infrastructure facilities already under extreme pressure. Concerns about the high urban crime and fertility rates in the cities have been exacerbated, as migrants are thought to disproportionately contribute to both. Government leaders also have worried about how to pacify potential resentment between migrants and urbanites who view migrants as competitors in the job market.

II.A.4 Poverty and Development

The poverty of China's rural areas is a problem that arose over long years in the past. Alleviating and eliminating poverty remains a long-term historical task for China. The development-oriented poverty alleviation drive in rural China early in the 21st century is a rare historical opportunity, but it still faces serious challenges and problems.

China today is blessed with many favorable conditions, some of them much more favorable than in the past, in its poverty alleviation drive. Great attention has been paid to the work by governments at various levels; support has been given by all sectors of society; and the cadres and ordinary people of the poor regions are working hard with one heart and one mind. These are the most important conditions for guaranteeing the steady progress of the work.

The main difficulties and problems for China in the early period of the 21st century in the field of poverty alleviation are as follows: First, though the income of the poverty-stricken people has been obviously improved, the current standard for poverty relief in China is very low. Second, restricted by unfavorable natural conditions, weak social insurance system and their own poor comprehensive ability, the people who now have enough to eat and wear may easily sink back into poverty. Third, although the development-oriented poverty reduction drive has greatly changed the poverty and backwardness of the vast impoverished rural areas, there has been no qualitative change either in the basic production and living conditions of the poverty-stricken peasant households, or in the social, economic and cultural backwardness in those areas. Fourth, because of its large population, China will face employment pressure for a long period to come. This pressure is bound to adversely affect the employment of the impoverished population, so much so that many effective aid-the-poor measures will not play the roles they should play. Fifth, people who still do not have enough to eat and wear generally live in areas with adverse natural environments, a low level of social development and underdeveloped social services, where the contrast between input and result is very sharp.

China is a developing country, and it has a long way to go to shake off poverty. The basic solution of the problem of food and clothing of the poverty-stricken population in rural areas is the result of only one phase in the country’s effort to accomplish this historic task. Subsequently, it will still take a long period of hard work to enable the people in the poor areas to first live a comfortable life and then a well-off life. With the progress of the reform and opening-up and the modernization drive and the steady increase of China's comprehensive national strength, our development-oriented poverty reduction program for the rural areas is bound to be crowned with new success.

II.A.5 Sustainability and Development

With the rapid development benefiting from its reform and opening policy in the past decades, China is going to have more and more significant impacts upon world sustainability. It will also play an increasing role in the world economy and politics along with the process of globalization.

The Chinese government has just publicized the Program of Action for Sustainable Development in China in the Early 21st Century. This Program, based on past achievements and experience and taking into account new requirements for sustainable development in the new century, specifies the objectives, principles, priority areas and safeguard measures for the country's sustainable development in the early 21st century.

After a decade of efforts, China has achieved remarkable progress in sustainable development.

- Economic development

China has maintained sustained, rapid and healthy growth of its economy. As a result, the country's overall national strength has built up considerably, with its GDP exceeding 1 trillion US dollar. China today is the largest recipient of direct foreign investment in the developing world and the sixth largest trading power in the world. People's livelihood and quality of life have witnessed significant improvement. Furthermore, economic growth is increasingly based on more sustainable ways, relying on enhanced efficiency rather than greater input of resources. The economic structure is being gradually optimized.

- Social development

The trend of excessive population growth has been checked; science, technology and education have made positive headway; and remarkable progress has also been made in social security, poverty eradication, disaster relief and prevention, medical care, and narrowing the regional gap in development.

- Ecological conservation, environmental protection and rational exploitation of resources

The central government has greatly increased spending in ecological conservation and environmental protection; the pattern of energy consumption is being gradually optimized; measures for controlling water pollution have been stepped up for key water systems; breakthrough progress has been made in curbing air pollution; comprehensive use of resources has significantly improved; and the ecological environment has improved to some extent thanks to retiring fragile farmlands and switching them to conservation purposes, such as planting trees and grass, and expanding floodwater storage.

- Capacity-building for sustainable development

The strategy of sustainable development has been incorporated into various programs and plans by central government ministries and local governments. Public awareness of sustainable development has markedly increased, and relevant laws and regulations have been enacted and enforced.
Since the promulgation of the first Environmental Protection Law in 1979, China has adopted and enacted more than 20 statutes on pollution control, natural resource conservation, and human health and safety. In addition, dozens of regulations, procedures and initiatives, as well as hundreds of standards have been passed. Most recently, the Air Pollution Control and Prevention Law had been amended, the Environmental Impact Assessment Law had been into effect in 1st September, 2003, and was followed by another statute, and the Clean Production Law.

However, China still faces quite a few challenges in implementing sustainable development. The greatest challenges are: a conflict between rapid economic growth and voluminous consumption of resources and ecological deterioration; social development lagging behind economic development; widening disparities between different regions in social and economic development; constraints posed by a large population and scarce resources; and inconsistencies between some existing laws, regulations and policies and actual needs for sustainable development.

Major problems urgently needed to be resolved include: the comprehensive quality of life of the population needs improvement; aging of the population is accelerating; the social security system is inadequate; the pressure on employment is heavy; the economic structure is less than rational; the operation system of the market economy needs to be improved; clean energy has a low share in the

total energy consumption; infrastructure is under developed; the information infrastructure for the national economy is of a low level; a serious level of waste exists in the exploitation of natural resources; environmental pollution is serious; ecological deterioration is still not curbed; legislation on resources management and environmental protection needs improvement.

With increasing globalization of the world economy, the international community is enhancing its understanding of and stepping up its efforts for sustainable development and common development. China should, after its accession to the WTO, give full play to the advantage of its socialist market economic system. In particular, China should give full play to the role of government in organizing and coordinating the implementation of the sustainable development strategy and properly handle the relationship of economic globalization and sustainable development. China should also, based on the achievements of the Johannesburg world summit on sustainable development, actively participate in international cooperation, and safeguard the country's fundamental interests, including its economic and ecological security.

China is facing contradictions and problems in the course of the rapid economic development over the years, such as the widening gaps between urban and rural areas, among different regions, the pressure of higher unemployment rate and lack of a sound social security network. Such issues have further been compounded by population expansion, escalation of conflicts between economic development and ecological environment and natural resources, a backward mode of economic growth, poor performance and low competitiveness of the overall economy. Having fully thought over the dilemma situations, the new leadership group, headed by President Hu Jintao, has brought forward the new Scientific Development Concept to implement a series of sound actions.

The scientific concept of development, with the goal of building a well-off society by 2020 and the modernization of China by 2050, calls for "people-centered development, which is comprehensive, coordinated and sustainable, for the promotion of overall harmonic development of economy, society and human beings."

It also stresses "coordinated development between urban and rural areas, among different regions and between economic and social development, harmony between human beings and nature and coordination of domestic development and opening to the outside world" as means of pushing forward reform and progress.

II.A.6 Country's Role to Date in Climate Policy Negotiations

Since the end of the 1980s, when climate change was brought to the global political agenda, China has gone from generating a surplus of energy to becoming an importer of oil. The change is a symptom of a rapidly industrializing nation and comes hand-in-hand with many of the signs of a nation already suffering from the effects of climate change.

Recent figures show that China is the second most important emitter of greenhouse gasses in the world, after the United States. Research shows that its population and environment are likely to suffer the effects of extreme weather events made more frequent by climate change, that rising temperatures and changing rainfall will affect food production and that energy consumption — a major source of emissions — will continue to rise over the coming decades.

Yet China, as a developing nation, is not bound to limit its emissions under the Kyoto Protocol, and will not do so at the expense of its development. The government says developed nations must bear the responsibility for historical rises in concentrations of greenhouse gases in the atmosphere. Despite this, the Chinese government is aware of the complexities and effects of climate change. Although its primary motivation is not to align itself with international climate change policy, it is adopting measures to diversify its sources of energy and to increase energy efficiency, which could slow the steep rise of its emissions.

At the international level, China saw climate change negotiations as an integral part of its foreign policy, and a terrain on which it, and other developing countries, would need to protect development rights and opportunities.

China has responded positively to international initiatives to reduce greenhouse gas emissions, such as carbon capture and renewable energy development. In the forthcoming post-Kyoto negotiations, China is likely to be more flexible and open to international cooperation. Although China labels itself a developing country, the image it wishes to cultivate — of a large and responsible country — will probably make it more flexible in international negotiations.

II.A.7 National and Sectoral GHG Emissions and Global Contribution

Among non-Annex I countries, China is the largest emitter of GHGs.[12] The People's Republic of China Initial National Communication on Climate Change reports that China's GHG emissions in 1994 were 3,650 $MMTCO_2e$, 73% from CO_2. With a population of nearly 1.2 billion, per capita emissions were 3.0 $MTCO_2e$ in that year, less than half the global average. Thus, although large in absolute terms, China's per capita emissions continue to be low. In 2000, China accounted for about one-seventh of the global and less than one-third of the non-Annex I country GHG emissions. CO_2 emissions in 2000 were estimated at 3,090 million metric tons CO_2 ($MMTCO_2$), in large part contributed by the electricity sector.

On a sectoral basis, electricity generation in China accounts for about 40% of national CO_2 emissions, as well as 15% of global and 40% of the non-Annex I electricity sector emissions. China's industrial sectors, most notably cement and iron and steel, are also significant emitters and account for major shares of sectoral GHG emissions globally. In 2000, the Chinese cement sector (including electricity use) accounted for one-fifth of domestic CO_2 emissions and contributed 36% of global and 56% of non-Annex I cement sector emissions; the 10% of national CO_2 emissions from China's iron and steel sector accounted for 30% of global and almost two-thirds of non-Annex I emissions in that sector.

II.B Historical summary & explanation of China' national energy and emissions profile

II.B.1 Total annual fuel consumption by sector and fuel type

Table 2-1.China's fuel consumption by sector/PJ

Year	farming, forestry , animal husbandry, fishery and water conservancy	industry	construction	transport, storage, post and tele-communication service	wholesale and retail trade and catering services	residential consumption	others	total
1990	1421	19812	355	1331	366	4631	1017	28927
1993	1401	23798	387	1638	560	4601	1594	33997
1994	1498	25762	396	1650	542	4513	1624	35961
1995	1615	28194	393	1717	592	4631	1325	38452
1996	1676	29396	425	1756	665	5188	1606	40738
1997	1732	29337	346	2210	700	4807	1377	40504
1998	1697	27667	472	2418	747	4220	1527	38745
1999	1709	26612	404	2708	824	4279	1612	38130
2000	1697	26260	419	2907	847	4367	1676	38188

[12] Includes CO_2 and other greenhouse gases.

Table 2-2. China's fuel consumption by fuel type

Year	Total consumption(PJ)	Share(%)			
		Coal	Oil	Gas	Hydropower
1990	28927.00	76.2	16.6	2.05	5.14
1991	30416.72	76.1	17.1	2.00	4.80
1992	31995.54	75.7	17.5	1.90	4.90
1993	33997.28	74.7	18.2	1.90	5.20
1994	35960.92	75.0	17.4	1.90	5.70
1995	38452.10	74.6	17.5	1.80	6.10
1996	40738.12	74.7	18.0	1.80	5.50
1997	40503.66	71.5	20.4	1.80	6.30
1998	38745.18	69.6	21.5	2.20	6.70
1999	38129.71	68.0	23.2	2.20	6.60
2000	38188.32	66.1	24.6	2.50	6.80

II.B.2 Energy intensity (per unit of GDP) from 1990 to 2000

China has changed dramatically since the country adopted liberalization and economic reforms in the late 1970s. Growth of nation's economy and improvement of living standards for over two decades results in great energy consumption.

Table 2-3.Energy consumption and energy consumption intensity of China

Year	Energy consumption（PJ）	Energy consumption intensity(GJ/$)
1990	28927.88	0.13
1991	30416.72	0.12
1992	31995.54	0.10
1993	33995.23	0.08
1994	35971.76	0.06
1995	38445.06	0.05
1996	40722.88	0.05
1997	40385.84	0.04
1998	38749.28	0.04
1999	38135.28	0.04
2000	38187.44	0.04
2001	39540.3	0.03
2002	43440.9	0.03
2003	49178.82	0.03

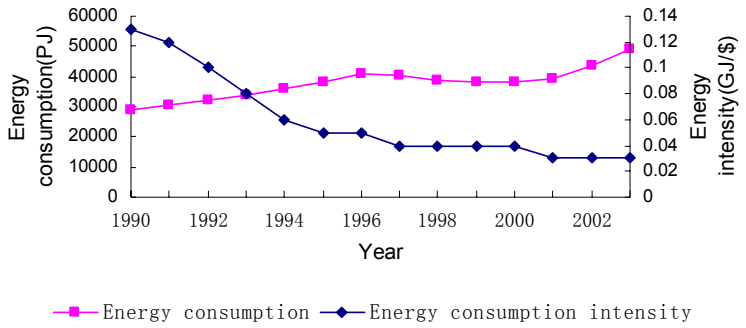

Figure 2-1.Energy demand and energy intensity of China
Source: China Statistical Yearbook 2003

China's energy demand kept growing till middle 90s mainly for two reasons:

The first, there has been a general shift in the structure of the economy away from primary to higher value-added products, and to a less degree from energy-intensive heavy industries to light industry and service sectors.

The second, older generating equipments are retired and more efficient power plants are introduced. Actually, for two decades energy use has grown only half as fast as the economy. From 1980~2000, the amount of energy consumption has only doubled while China's gross domestic product (GDP) has been quadrupled. But after 2000, especially from 2004, this trend of energy intensity has reversed. Table 2-4 shows energy consumption elasticity of China from 1990 to 2004[13]. From 2002, the energy consumption elasticity is more than 1. So China faces the challenge of maintaining economic growth with lower energy intensity.

Table 2-4. China's ΔE/ΔGDP

China's ΔE/ΔGDP	
1990	0.48
1991	0.56
1992	0.37
1993	0.45
1994	0.44
1995	0.63
1996	0.59
1997	-0.09
1998	-0.52
1999	-0.21
2000	0.02
2001	0.43
2002	1.08
2003	1.53
2004	1.51

Source: China Statistical Yearbook, 2005

For the recent increasing trend in energy consumption, increased coal consumption plays the most important role, as Figure 2-2 shows.

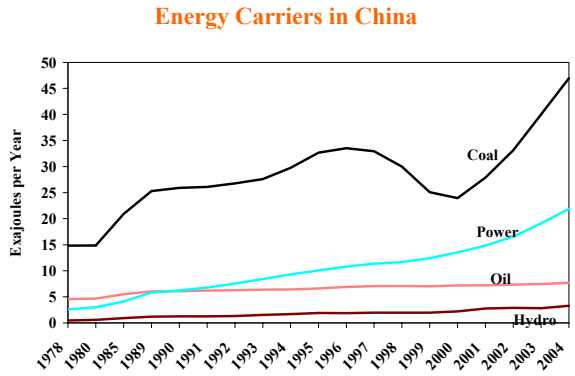

Figure 2-2.Energy carriers in China
Source: China Statistical Yearbook, 2005

[13] Data from 1997 to 2000 is odd, and may be a statistical problem.

II.B.3 Annual GHG emissions inventory for 2000

Table 2-5.China's Carbon Dioxide Emission by Source (Million Tonnes of Carbon)

	Fossil Fuels					Total
Year	Coal	Oil	Gas	Subtotal	Others	Emissions
2000	498.7	164.2	17.6	761.6	81.2	842.8
Share%	59.17	19.48	2.09	90.37	9.63	100%

II.B.3.i <u>Total national GHG emissions/sequestration by sector</u>

When accounting CO_2 emissions for cement and iron and steel, we should calculate both emissions from energy activities and industrial process. Asterisk implies emissions from electricity that is consumed at the same site or plant where it is generated, and not transmitted across the local grid. CO_2 emissions and the respective shares for each sector in 2000 are shown in the table and pie chart below.

Table 2-6.Structure of China's CO2 emission in 2000

Target Sectors	Electricity	Iron &Steel	Cement	Pulp &Paper	Transportation
CO_2 Emission ($MtCO_2$)(2000)	256.65*/1199	351.53	678.4	62.67	195.2

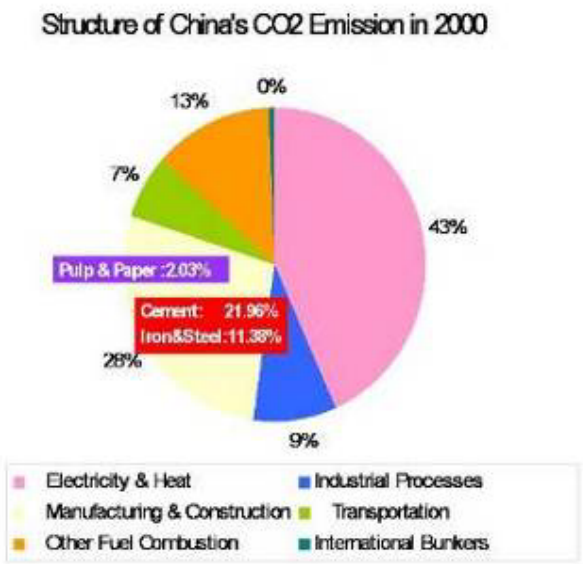

Figure 2-3. Structure of China's CO2 emission in 2000

II.B.4 Emissions Intensity (per unit of GDP and per capita) from 1990 to 2000

Table 2-7. Emission intensity from 1990 to 2000

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Per unit of GDP emission (tCO2/thousand dollars)	11.17	10.13	8.69	7.10	5.61	4.86	4.37	3.94	3.57	3.14	2.86
Per capita emission(tCO2)	2.09	2.16	2.24	2.35	2.46	2.64	2.71	2.64	2.49	2.24	2.20

Note : Current value
Source: Carbon Dioxide Information Analysis Center, 2002.

II.C Comparison with rest of world above areas

II.C.1 Ranking

Recent figures show that China is the second most important emitter of greenhouse gasses in the world, after the United States.

II.C.2 Qualitative similarities and differences

Table 2-8.Carbon Dioxide Emissions from Fossil Fuel Combustion, Cement Production (MtC)

Year	China	India	Japan	USA	FSU [1]	Total
1990	683	194	304	1,327	1,013	6,327
1991	722	207	310	1,325	977	6,426
1992	763	221	313	1,328	554	6,297
1993	810	230	307	1,406	504	6,311
1994	865	244	321	1,431	435	6,481
1995	937	257	323	1,433	418	6,632
1996	979	285	332	1,455	411	6,790
1997	968	292	330	1,502	394	6,897
1998	924	302	320	1,514	387	6,890
1999	849	307	326	1,516	392	6,742
2000	843	306	334	1,542	398	6,869

II.D Background for overall analysis

II.D.1 Discussion of all cross-cutting macro assumptions used and sources for assumptions

- *Population*:

As Family Plan was carried out from 1980s, the growth rate of Chinese population slowed down after the previous increase before 1987, with peak annual growth of 16.61%. In this project, we assume the annual growth rate of Chinese population will decrease year by year, and the population will reach 1.52 billion till 2030 (see table).

Table 2-9. China's population assumptions in the analysis

Year	2000	2005	2010	2015	2020	2030
Annual growth ratio	7.85‰		6.5‰		4.4‰	
Population（billion）	1.267	1.31	1.35	1.40	1.45	1.52

- *GDP*

It is said China's GDP in 2020 will quadrupled as it is in 2000 considering the Report of 16th Party Congress. We refer to a series of literature on Chinese energy and carbon scenarios and assume China's GDP will maintain the fast growth of the 1990s, so the annual growth rate is set at 7.5% during 2000 to 2010. Then the growth rate will slow down, with the annual growth rate is set at 6.5% during 2010 to 2020, and 5.5% during 2020 to 2030.

Table 2-10.China's GDP Assumptions and electric sectoral production in the Analysis

year	2000	2005	2010	2015	2020	2030
Annual growth ratio	7.5%		6.5%		5.5%	
GDP（billion dollar）	1080.7	1551.53	2227.44	3095.7	4181.19	7142.09

- *Policies scenarios*

We utilize LEAP model to analyze the abatement potentials, which is driven by a set of assumptions and scenarios which can be defined in this project as reference baseline scenario, recent policy scenario and new policy scenario.

- *Baseline scenario pre 2000*

The baseline scenario pre 2000 employed here is a conservative projection of China's energy intensive sectors' future that closely tracks previous Chinese forecasts. The scenario assumes that sector's relative policies will not change radically compared to the situations before 2000, although some technologies are projected to improve gradually. It is the least technology advanced scenario among the three.

- Baseline scenario between 2000 and 2005

In Baseline scenario between 2000 and 2005, we will evaluate projected emissions using combination of measures and policies in place before the end of 2005, and taking into account the Report of 16th Party Congress, the Tenth Five-Year Plan as well as relative industrial long term development policies and plans. The policy takes more consideration for environmental protection issues. The step of scale enlargement and technology advancement of present plants is faster than that in upper scenario.

- *Mitigation scenario*

The new policy scenario emphasizes sustainable development most, and even takes account of climate change issues. Here we assume a relative radical phase that China invests a lot to adopt more advanced technologies with lower energy intensity and less consideration of financing or technical barriers.

We change technology combination structures in the three scenario creations basing on expert consultation and literature survey to directly reflect the impacts of different policy tendencies. Implemented policies and measures will be discussed in each sector section in details.

- *Baseline setting for mitigation potential calculation*

Mitigation scenarios are compared to the Pre-2000 baseline. It should also be noted that China has already realized the significance of sustainable development issues; a series of statutes has been promulgated to guarantee environmental protection in China, dozens of regulations, procedures, and standards focusing on environmental issues have been passed and take substantial effect until 2005. Their impact can be seen in the scenario simulating the trend under policies undertaken through 2000 to 2005 (recent policy scenario).

It is important to be noted that at the early year of 2006, China promulgate the 11th Five Year Plan. The object of the 11th Five Year Plan is to double the GDP per capita in 2010 from the 2000 level while reducing energy consumption per unit of GDP by 20% in 2010 from the 2005 level .But it was not assumed in either of the baselines.[14] If it is included in scenario definition, the energy consumption of two baseline scenarios will be lower because this objective is very ambitious. The primary energy consumption sectors such as electricity and steel industry will be adjusted.[15]

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[14] The energy conservation objective from the 11th Five Year Plan in China is also being disputed..

[15] During the "11th Five-Year Plan Guidelines", adjustment of the industrial structure is the main task and is significant for energy conservation objective. It includes two-layer meanings: One is raising the level of industrial technology, The "Proposal" points out: To realize the adjustment of the industrial structure, "the key is to comprehensively enhance independent innovative capability, strive to master core technology and key technology, strengthen ability for the transformation of scientific and technological achievements and improve the overall technological level of industry". Second is developing key industries. The "Proposal" points out that the important tasks for adjustment of the industrial structure is to develop advanced manufacturing industry, increase the proportion of the service trade and strengthen infrastructure construction for basic industries.

It suggests policy support to boost localization of major technological equipment, especially breakthroughs in high-efficient and clean power generating units and transmission equipment, large petrochemical installations, advanced transportation equipment, high-grade numerical-control machine tools, equipment for automatic control and integrated circuits, and advanced power devices.

The principle of the 11th Five-Year Plan is consistent with our scenario analysis including industrial restructure and technology advancement. If it works out as planned the scenario definition in our analysis will be more feasible because the objective of the plan and mitigation scenario will be overlapped. But the specific impact of the plan on our analysis especially electricity, steel, transport need more meticulous analysis.

- *Other assumptions*

Exchange rate:1 US dollar=8.27 RMB
Discounting rate=10%

II.D.2 Analytical approach and methodology used

Developing a national abatement strategy requires a macro perspective of the principal options for GHGs abatement. It also requires specific information on the associated costs and potentials of individual GHGs abatement initiatives. The costs associated with the increasing supply of a given GHGs abatement initiative can be illustrated by its Marginal Abatement Cost (MAC) curve. MAC curve provides the different marginal abatement costs for all GHGs abatement initiatives in the sector.[16] By evaluating the sector MAC curves, a national strategy can be developed that selects various levels of different GHGs abatement options so as to yield a promising set of GHGs abatement initiatives.

II.D.3 Computer models and other tools used

LEAP model is a scenario based energy-environment accounting tool developed by the Stockholm Environment Institute-Boston.[17] LEAP has been used in previous research to conduct technology-level bottom-up analysis to estimate China's electricity sector future energy consumption and production with given alternative assumptions on economic development, technology, price and so on. In this project, we build up sophisticated simulations and data structures concerning the electricity sector's technology levels, energy demand, cost and corresponding CO_2 emission information. The scenario analysis time extension covers through 2000 to 2030 with 2000 as the baseline year.
The logical operating framework in LEAP model is described in Fig. 2-4, which can be summarized as five steps: sectoral production projection, corresponding energy demand, CO2 emissions, total costs, energy savings and CO2 abatement potentials calculation.

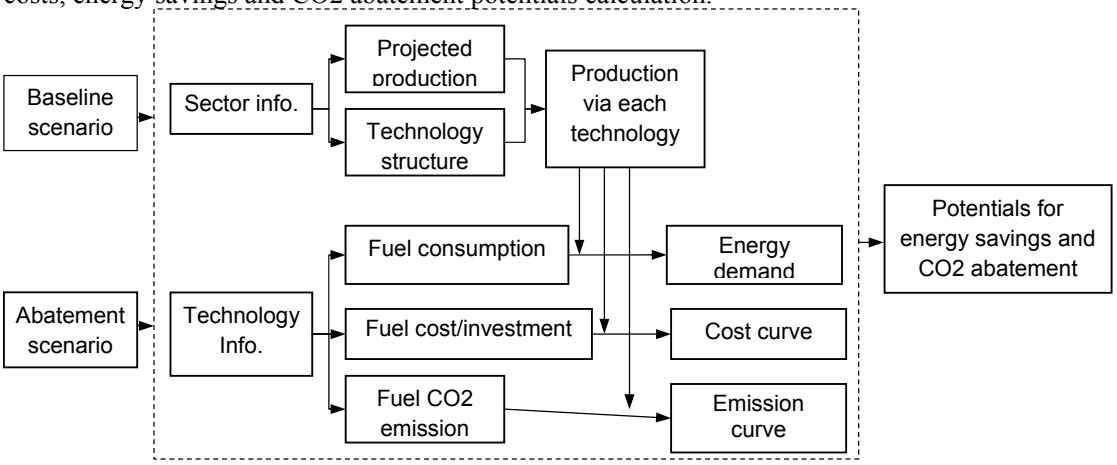

Figure 2-4. Logical operating framework for LEAP model

- Sectoral production

Sectoral production is projected consistent with historical generation data and China's economy development trend.[18] Technology structures are set basing on available data collection with adjustments according to policy tendencies we would like to emphasize in different scenarios. Basing on the above information, we get the separated production via each technology

$$P_{i,j} = P_j \times \tau_{i,j} \qquad (1)$$

[16] Methods for Developing Cost of Emission Reduction Initiative (CERI) Curves
[17] Stockholm Environment Institute, Tellus Institute. LEAP:Long Range Energy Alternatives Planning System,User Guide for LEAP 2005[EB/OL]. http://forums.seib.org/leap/documents/Leap2005UserGuideEnglish.pdf
[18] China Statistics Bureau. China Statistics Yearbook 2004□M□.Beijing :China Statistics Press, 2004. (in Chinese)

P_j is sectoral production in year j, $\tau_{i,j}$ is the production share of technology i among the total output in year j, $P_{i,j}$ is the separated production by technology i in this year.
With additional investigated parameters,[19] such as fuel consumptions, cost and CO2 emission factors, investment and operating cost for each kind of plants, we can calculate projected sectoral energy demand, costs, and CO_2 emissions in the target time extension.

- Energy demand

$$E_j = \sum_n \sum_i e_{n,i,j} \times P_{i,j} \qquad (2)$$

E_j is the total energy demand for sector in year j, $e_{n,i,j}$ is the energy consumption of fuel type n used in technology i for unit production.

- CO_2 emission

$$CE_j = \sum_n \sum_i f_{n,i,j} \times e_{n,i,j} \times P_{i,j} \qquad (3)$$

CE_j is total CO_2 emission of sector in year j, $f_{n,i,j}$ is CO2 emission factor of fuel type n through technology i for unit production.

- Costs

$$C_j = \sum_i \left[(\sum_n (e_{n,i,j} \times p_{n,j}) + fc_{i,j}) \times P_{i,j} \right] \qquad (4)$$

C_j is the total costs for sector in year j, $p_{n,j}$ is unit price for fuel n in year j, $fc_{i,j}$ is fixed price for unit production.

- Energy savings and CO_2 abatement potentials

By comparing the results driven by different scenarios, we acquire the energy saving potentials and CO2 abatement potentials in any target year or during the whole target period which will be input data in the next step marginal cost curve analysis.

II.E List of sectors to be covered in analysis

We choose five energy intensive sectors as analytical targets: electricity, iron & steel, cement, pulp & paper, transportation. Electricity sector, which plays the leading role of energy conversion and supply, is the largest CO_2 emitter in China. Iron & steel sector is one of the most important energy intensive industrial sectors, and contributes ten percent of the country's total CO_2 emission. Cement sector is important, with its CO_2 emissions coming from limestone decomposition in production process almost equal with fuel consumption. Pulp & paper causes severe water pollutions. Environmental co-benefits can be realized through sector's energy efficiency improvement and CO_2 emission reduction. Transportation has huge potential and soon will become large energy consumer and CO_2 emitter.

[19] HU Xiulian, JIANG Kejun, et al. Evaluation of Technology and Countermeasure for Greenhouse Gas Mitigation in China□M□.Beijing: China Environmental Science Press, 2001. (in Chinese); and ZHOU Dadi, et al. China Sustainable Energy Scenarios in 2020 □M□. Beijing: China Environmental Science Press,2003.（in Chinese）

III. Sector Analysis and Results: Electricity

III.A Sector Overview

III.A.1 Summary

III.A.1.i Total Output/Production

Table 3-1.China's Electric Power Output

	Installed Capacity（GW）	Power Generation（TWh）
1990	137.89	621.3
1991	151.47	677.5
1992	166.53	754.2
1993	182.91	838.4
1994	199.89	913.8
1995	217.22	994.2
1996	236.54	1065
1997	254.24	1119.8
1998	277.29	1143.1
1999	298.77	1217.6
2000	305.14	1368.5
2001	338.61	1470.6
2003	391.40	1905.2
2004	440.70	2187.0
2005*	508.41	2474.7

Data resource: Electricity statistics year book 2005; I* presentation from Zhaoyong of Current Status of Electric Power Sector in China on March 26, 2006. Beijing.

China's electric power industry has developed very rapidly over the past two decades as a result of economic development and rising incomes. Total national installed capacity increased from 69.13 gigawatts in 1981 to 508.41 gigawatts in 2005, an average annual growth rate of 8.7%. From Figure 3-1, readers can see that tremendous growth occurred after 2000. Both the installed capacity and power generation goes beyond the historical trend before 2000. If we make generation projections according to the development trend between 2000 and 2005, the analysis results will be much more aggressive. So we make modest assumptions tracking the previous trend before 2000 in this project. The capacity and generation assumptions may be more conservative compared to the actual value between 2000 and 2005.

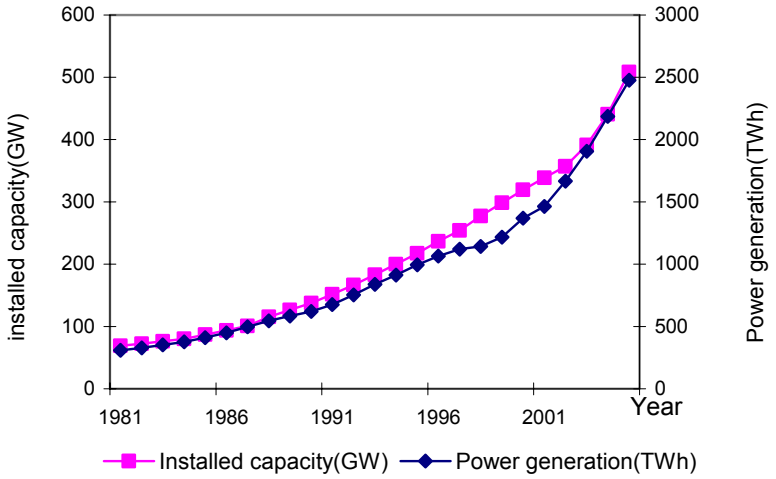

Figure 3-1.Development of China's electric power system

III.A.1.ii Revenues, share of GDP

China's system for power tariffs is both complex and economically inefficient. Both producer and consumer tariffs are based on Catalogue Prices which are approved by the central government. For each locality these define the tariff for eight or more classes of users, at three different voltages. Provincial and local governments levy further charges. The details of the tariff system and extensive discussion of its weaknesses have been documented elsewhere (World Bank, 1994; Shao et al., 1997; Andrews-Speed et al., 1999). The most important deficiencies are:

The power generators as a whole are not receiving consistent incentives to reduce costs because no procedures for a merit order exist.

III.A.1.iii Role of sector in overall economy as source of inputs to other sectors

Between 1996 and 2000, the 9th Five-Year period, electricity demand grew at an average of 6.3 percent annually. It is expected to exhibit an average annual growth rate of 5 percent during the 10th Five-Year period (2001–05). As is shown in Table 3-2, total electricity consumption in 2002 was 1,620 TWh, which was a 10.3 percent increase from consumption of 1,468 TWh in 2001. With the economy growing at a rapid pace thanks to economic reforms, the industrial sector consumed the most electricity of all sectors in 2002, accounting for 72 percent of total consumption. By contrast, the primary sector was a distant second at 4.8 percent.

Table 3-2.Total Electricity Consumption by Sector

	2002(TWh)	2001(TWh)	Growth Rate(%)	2002 Share(%)
Total Consumption	1620	1468	10.3	100.0
Industry	1422	1284	10.7	87.8
Industrial	1167	1049	11.2	72.1
Light	252	221	14.0	15.6
Heavy	915	827	10.5	56.5
Agriculture & Fishery	78	76	2.4	4.8
Construction	16	14	10.3	1.0
Transportation	33	29	12.6	2.0
Service	52	45	14.0	3.2
Other	76	69	8.9	4.7
Residential	198	183	7.7	12.2
Urban	114	106	6.9	7.0
Rural	84	77	8.7	5.2

Source: State Power Corporation (totals may not add due to rounding)

III.A.1.iv Role in exports, international trade

China's energy sector is self-sufficient. Exports and imports of energy products are small compared to overall consumption, although the amount of imported oil and gas products and exported coal are expected to rise. China’s self-sufficiency strategy has led it to depend heavily on coal for national energy needs.

III.A.2 Quantitative and qualitative characterization of sector

III.A.2.i **Power plants by fuel type in year 2000**

Table 3-3.Annual breakout by fuel type electricity sector in 2000

Fuel	Number of Plants (or generator units)*a	Capacity (MW)*a	Share of Total Sector Capacity (%)	Generation (TWh)*a	Share of Total Sector Generation (%)	CO2 Emissions (million metric tons)*b	Share of Total Sector CO2 (%)	Average Efficiency (%)	Average CO2 Intensity (kg CO2/kWh)*b
Coal	3546	212780	69.73%	1038.1	75.90%	1156.8	96.49%	35 ~ 45%	1.11
Gas	127	5118	1.68%	27.37	2.00%	13.0	1.08%	40 ~ 58%	0.47
Oil	497	5415	1.77%	41.1	3.00%	29.1	2.43%	45 ~ 50%	0.71
Thermal Plants Subtotal	4170	223313	73.18%	1106.57	80.90%	1198.9	–	–	–
Hydro	1209	79352.2	26.01%	243.134	17.80%	–	–	60 ~ 80%	–
Nuclear	11	2100	0.69%	16.7	1.20%	–	–	25 ~ 35%	–
Wind	530* (data in1998)	375.2	0.12%	0.5	0.04%	–	–	10 ~ 20%	–
Other Renewable	-	-	-	1.46	0.10%	–	–	5 ~ 15%	–
Total		305140.4	100%	1368.5	100%	1198.9	100%		

Data resource:*a Electricity statistic year book 2005; *b calculated results from LEAPChina model;*c data from internet: http://finance.sina.com.cn/stock/e/20050328/18481466678.shtml

III.A.2.ii Table with breakdown of facilities by range of average CO2 intensity

Table 3-4. Distribution of coal-fired plants by CO2 intensity in 2000 *

CO2 Intensity Range (metric ton/TWh)	Number of Plants/Units	Total Capacity (MW)	Share of Total Capacity (%)	Total Annual Generation (TWh)	Share of Total Generation (%)	CO2 Emissions (million metric tons)	Share of Sectoral total CO2 (%)
>1.25	2415	37405	17.58%	79.9	7.70%	109.1	9.10%
1.20-1.25	355	53934	25.35%	64.4	6.20%	81.4	6.79%
1.0-1.20	514	36598	17.20%	354.0	34.1%	438.8	36.60%
<1.0	262	84835	39.87%	539.8	52.0%	527.5	44.00%
Total	3546	212780	100%	1038.1	100%	1156.8	96.49%

* Estimated from data from Table 3-3 and results from LEAPChina model.

III.A.2.iii Table with breakdown of facilities by range of production capacity

Table 3-5.Electricity capacity range Distribution of coal-fired power plants by capacity in 2000*

Unit Capacity Range (MW)	Number of Plants/Units	Total Capacity (GW)	Share of Total Capacity (%)	Total Annual Generation (TWh)	Share of Total Generation (%)	CO_2 Emissions (million metric tons)	Share of Sectoral Total CO2 (%)	Average CO2 Intensity (kg CO2/kWh)
>600	20	22129	10.40%	130.8	12.60%	113.9	9.50%	0.87
300-600	242	62706	29.47%	409.0	39.40%	413.6	34.50%	1.01
200-300	193	36598	17.20%	189.5	18.25%	232.6	19.40%	1.23
100-200	321	33641	15.81%	164.5	15.85%	206.1	17.19%	1.25
50-100	355	20293	9.54%	64.4	6.20%	81.5	6.80%	1.27
<50	2415	37405	17.58%	79.9	7.70%	109.1	9.10%	1.36
Total	3546	212780	100%	1038.1	100%	1156.8	96.49%	1.11

* Estimated from data from Table 3-3 and results from LEAPChina model.

III.A.2.iv In-depth discussion and explanation of above breakdowns

China is making efforts to close thermal power plants with a unit capacity of 50 megawatts or less to improve efficiency, reduce pollution, and stabilize the power supply system. Many recently built coal plants have relatively high efficiencies because Chinese policy requires new coal-fired units to be 300 megawatts or larger to improve efficiency. Domestically manufactured 300-megawatt and 600-megawatt sub-critical and super critical units are becoming the backbone of the generation system. This stands in contrast to the many small, inefficient plants built quickly in the late 1980s and early 1990s to meet soaring demand. The share of electric power produced from large units will increase significantly since 2000 in the scenarios, although the addition of many very small (less than 50-megawatt) units has offset some of these efficiency gains. Pressurized Fluidized Bed Combustion (PFBC) and Integrated Gasification Combined-Cycle (IGCC) systems use coal but operate at higher efficiencies and generate fewer emissions than traditional coal-fired power plants. They would help solve the country's power problems while continuing to use domestic coal, but so far the costs and technical barriers of these systems prevent their widespread adoption.

China has the most abundant hydropower resources in the world, with an estimated potential of 380 gigawatts. China has aggressive program to build large hydropower stations in the next two decades, mainly to diversify power generation, help flooding control as well as irrigation. These plants are intended for the middle and upper reaches of the Yangzi, Yellow, and Lancang Rivers. China is constructing the world's largest hydro project, the massive Three Gorges Dam, in Hubei province with total installed capacity of 18.2 gigawatts. The plant is scheduled to be fully operational by 2009 after an investment of at least 25 billion US dollar. At that time, it will supply about 3 percent of the country's power needs. However, hydropower projects are expensive and capital intensive and can lead to mass resettlement of residents, loss of farmland and wildlife, and ecosystem damage. There is strong international opposition to the huge project of Three Gorges Dam. We suppose the share of hydro power generation grows modestly in our analysis.

Regarding technology advancement and international pressure on CO_2 mitigation, China will make efforts to exploit utilizing clean fuel source as important internal energy strategy.

China's estimated total natural gas reserves amount to 38 trillion cubic meters (over 1,450 Petajoules). Proven reserves, however, range from 1.2 to 5.3 trillion cubic meters (roughly 50 to 200 Petajoules) Additional reforms to exploration and development will be needed to further refine this estimate. After decades of bypassing natural gas development, China has focused greater attention on gas in the last few years as a relatively clean fuel source. China's first liquefied natural gas terminal project in Guangdong, DaPeng station will start to operate in April 2006, and will include one or two large combined-cycle power plants. More importantly, it signaled a shift in thinking about energy imports and environmental quality that would call for additional terminals in other coastal cities.

Until recently, China had ambitious plans to develop nuclear power, but high cost, waste disposal, and the risk of accidents present environmental challenges of a different magnitude than other technologies have combined with a slowdown in power demand to limit its future growth potential. China started commercial nuclear power production in 1992 with the 300-megawatt Qinshan station which was developed to reach 2.9-gigawatt total installed capacity at present. The Daya Bay nuclear station, with two imported 900-megawatt units, began operation in 1994. By the end of 2005, Tian Bay nuclear station with two 1.06-gigawatt units came on-line, and is expected to generate 14 Twh annually.

China also has abundant renewable energy resources, including reserves of 253 gigawatts of wind power and biomass energy resources estimated at an annual supply of 220 million tons of coal-equivalent. Despite the promising resources, these technologies have not been widely adopted mainly because of high costs, market distortions, and technical barriers.

III.A.2.v <u>Ownership patterns of sector</u>

The Chinese power sector went through three major phases prior to 2003, which can be divided into roughly the following periods:1949–1985,1986–1997,1998–Present

A. First phase (1949–1985):

State-run as part of centrally planned economy. During the first phase, the Chinese electricity industry was vertically integrated, government-owned and –operated. The Ministry of Power was the main regulatory arm of the central government. The industry followed a five-level management system with the central government overseeing the highest level. Regional, provincial, municipal, and county power bureaus managed the second through fifth levels, respectively.

Each higher-level bureau supervised the operations of its subordinates. The central government was the planner, investor, regulator, manager, and operator of the power industry. In addition, the government was the sole provider of capital for capacity expansion or construction of generation projects through budgetary allocations and government loans.

However, the capital provided by the government was generally insufficient to fully fund all necessary generation projects; the inadequate funding led to nationwide power shortages. Surging electricity demand brought about by economic reforms further exacerbated the power shortage

problem. Realizing the constraints that power shortages placed on the nation's economic and social development, the Chinese government was ready for industry reforms, mainly in raising capital for capacity expansion.

B. Second phase (1985–1997):

State-run and gradual opening of generation market In 1985, the State Council implemented the ''Provisional Regulations on Promoting Fund-Raising for Investment in the Power Sector and Implementing Different Power Prices.'' The main objective of this reform was to encourage investment in the country's power sector in order to ease the worsening power shortages.

Several steps were taken to achieve this goal:

1. For the first time non-central government economic entities—regional governments, local companies, and foreign investors—were allowed to invest in the power sector.

2. The government-modified tariffs to assure profits from generation investment. A 12–15 percent rate of return on investment was allowed. This gave incentives to investors in order to promote power generation construction to alleviate the power shortages that were severely damping China's economic growth.

3. Power project funds were set up and collected 0.02 yuan per kWh on electricity consumption nationwide. These funds were used for capacity expansion by provincial governments.

4. Lastly, a tax rebate was implemented to help improve corporate balance sheets.

This reform was successful and attracted large amounts of money from both local and foreign investors. According to the State Power Corporation (which was formed in 1997), approximately 70 percent of the US$ 101.3 billion total investment received during the 9th Five-Year plan (1995–2000) went to fund new generation projects. Also, investment from foreign entities accounted for approximately 17 percent of the total funding for new project construction.

C. Third phase (1998–2002):

Separation of government functions from corporate functions and testing of generation market competition through provincial pilot programs.

The State Power Corporation was formed in 1997 to run the power industry independently. It owned about 46 percent of total generation assets and 90 percent of transmission assets. In 1998, the Ministry of Power was dissolved. Three governing bodies, the State Economic and Trade Commission (SETC), the State Development and Planning Commission (SDPC)[20], and the Ministry of Finance (MF), assumed its governing functions. In a nutshell, the SETC was responsible for creating and enforcing industry rules and regulations and industry operating standards, and at the same time, balancing demand and supply within utility service territories. The SDPC was responsible for formulating the industry's strategic planning, power project construction and funding, and pricing policies, while the MF was essentially the industry's financial monitoring and enforcement agency.

In essence, the three agencies played the role of government watchdogs while the State Power Corporation was the autonomous operator of the power sector. The creation of these entities separated the responsibilities and functions of the government from those of a commercial enterprise within the power industry. In addition, the country's power sector took a major step toward slowly opening up to competition, at least in the generation market.

III.B Emissions Overview of Sector

III.B.1 Background and discussion of emissions

China is the largest emitter in the world of greenhouse gases after the United States. It accounts for just over one-seventh of the world's emissions (14.7 per cent in 2000; in comparison, the United

[20] The SETC no longer exists, and that most of its functions are now in NDRC, which is the current name of former SPDC.

States emitted 20.6 per cent of global emissions in the same year). According to researchers at the US-based Pew Centre on Global Climate Change, China is likely to be the number one emitter in twenty years.

For electricity sector, China has fueled sectoral robust growth with plentiful supplies of domestic coal. Thermal power plants (fired with coal, petroleum, or natural gas) accounted for almost three-quarters of China's installed capacity in 2000. Hydropower provided about 25 percent and nuclear power less than 1 percent of capacity. Oil and natural gas combined accounted for less than 6 percent of total power generation in 2000, see Fig.3-2 . Nearly all of the sector's CO2 emissions come from coal-fired generators, and they are also the largest sources of CO2 emissions in China. In 2000, China's electricity sector is estimated to account for 8.56% [21]of nation's total energy consumption, so future growth for China's electricity sector will take considerable consequent affects on both China and the global energy saving and environment problems.

Unlike some other countries, a significant share of China's coal-fired generator capacity is relatively small units. For example, nearly three out of every four such generators is less than 50 MW, and these generators account for about 20% of total electric capacity. The technology substitution assumptions of scenarios in this analysis are mainly generated from the plants distribution status in 2000 and China's policy trends.

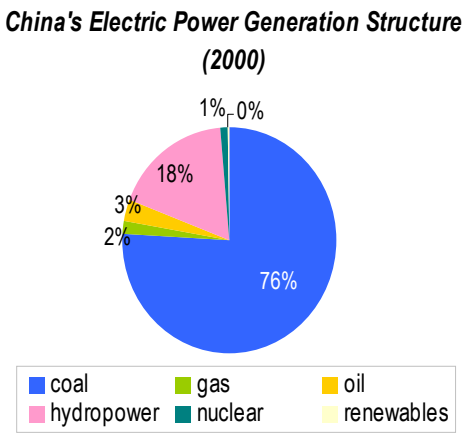

Figure 3-2. Composition of China's electric power generation in 2000

III.B.2 Annual GHG emissions inventory for a recent year

III.B.2.i <u>Total emissions by source</u>

Table 3-6.Electric sector CO2 emission by fuel type in 2000 (MMtCO2)

	Oil	Gas	Coal	Total
Emission	29.1	13.0	1157	1199

III.B.3 Historical annual fuel consumption and GHG emissions trends over time

Table 3-7. Fuel consumption of China's thermal-power plants (PJ)

Year	Coal	Oil	Gas
2000	12913	427.9	255.3

[21] Taking no account of supply for other sectors

III.B.4 Relative contribution of each sector in 2000

Table 3-8.Share of total national energy consumption and emissions

Target Sectors	Electricity	Iron &Steel	Cement	Pulp & Paper	Transportation
Share of China's total energy consumption (2000)	8.56%*	9.95%	7.86%	1.67%	
CO2 Emission (MtCO2)(2000)	256.65*	322.58	416.55	50.19	

Table 3-9. Share of total world sector emissions in 2000

Electricity			
Countries	$MtCO_2$	% of Developing Countries	% of World
China	1199	40%	15%

III.C Background Assumptions for Sector Analysis

III.C.1 Baseline with policies adopted before 2000

III.C.1.i <u>Policies under Consideration</u>

- *Increasing capacity to deliver power to the consumer*

A great portion of capacity is composed by smaller units which are characterized by low operational reliability and low efficiency. A large number of inefficient, unreliable units cause higher pollution and higher operational reserve requirements. Inadequate investment in power transmission and distribution capacity, at local, regional and national levels, meaning that power cannot be transmitted from locations with a surplus to those with a deficit. The unsuitable structure of the power generating capacity in many locations renders the generators unable to satisfy peak demand. The State Power Corporation has identified strategic areas for investment. This can be seen in the drive to construct mine-mouth power stations and to direct investment at the transmission and distribution networks. China attempts to carry out generation structure innovation, is determined to eliminate inefficient plants and introduce advanced technology to enhance the power generation efficiency.

The country has created an energy efficiency center - Beijing Energy Efficiency Center (BeCon) in 1994 with financial support from the U.S. The Chinese government needs to make a more extensive commitment to the establishment of an institutional framework to support energy efficiency and renewable energy development.

- *Improving the energy efficiency of end-users*

The energy efficiency of end-users is clearly a high priority in a country where economic growth is constrained, at least locally, by the availability of energy and this is illustrated by the passing of the Energy Conservation Law in 1997.

- *Ownership and Management reformation*

The State Power Corporation was formed in 1997 to run the power industry independently. It owned about 46 percent of total generation assets and 90 percent of transmission assets. In 1998, the Ministry of Power was dissolved.

Three governing bodies, the State Economic and Trade Commission (SETC), the State Development and Planning Commission (SDPC), and the Ministry of Finance (MF), were created to assume its governing functions. In a nutshell, the SETC was responsible for creating and enforcing industry rules and regulations and industry operating standards, and at the same time, balancing demand and supply within utility service territories. The SDPC was responsible for formulating the industry's strategic planning, power project construction and funding, and pricing policies, while the MF was essentially the industry's financial monitoring and enforcement agency.

In essence, the three agencies played the role of government watchdogs while the State Power Corporation was the autonomous operator of the power sector. The creation of these entities separated the responsibilities and functions of the government from those of a commercial enterprise within the power industry. In addition, the country's power sector took a major step toward slowly opening up to competition, at least in the generation market.

- *Market system renovation*

Before 1985, the central government was the sole investor in the power sector, and the lack of adequate government funding was the main cause of severe power shortages. The government-modified tariffs allow profits from generation investment. A 12–15 percent rate of return on investment was allowed. This gave incentives to investors in order to promote power generation construction to alleviate the power shortages that were severely limiting China's economic growth.

In 1984 the government allowed state owned enterprises to sell their over-quota surplus at prices within a 20% range over the state set prices. In Feb. 1985, the 20% limit was removed and prices for their surplus could be negotiated freely between buyers and sellers. At that point, the dual pricing system is generally considered as a positive, cautious step towards a full market price. Moreover, it is widely thought that introducing the dual pricing system can, among other purpose, encourage material and energy conservation and improved management, thus introducing economic efficiency in the use of the resources.

- *Nuclear power development*

China started commercial nuclear power production in 1992 with the 300-megawatt Qinshan station which was developed to reach 2.9-gigawatt total installed capacity at present. The Daya Bay nuclear station, with two imported 900-megawatt units, began operation in 1994.

- *SO_2 and NO_x control*

Key environmental issues concerned with electric power generation are SO_2 and NO_x control. According to the regulations and laws carried out by Chinese government and SEPA[22], we take consideration of SO_2 and NO_x control cost in the total cost assessments of each individual thermal power plant.

III.C.1.ii Assumptions about the Effectiveness of Policies

It's the least technology advanced scenario among the three. Measures mainly focus on demand side management and reconstruction of conventional thermal power. The share of clean fuel and renewable generation keeps growing modestly.

The recent baseline scenario employed here is a conservative projection of China's electricity power future that closely tracks previous Chinese forecasts. The scenario assumes that sector's relative policies will not change radically, although some technologies are projected to improve gradually.

III.C.2 Baseline with policies adopted between 2000 and 2005

III.C.2.i Policies under Consideration

- *Industry structure and ownership reformation*

The Chinese government is in the early stages of formulating a fundamental long-term restructuring of its electric power sector, embodied in the National Power Industry Framework Reform Plan promulgated by the State Council in early 2002. As with many other countries' reform programs, generating assets are being largely separated from transmission and distribution. The State Power

[22] Cleaner production standard ---Coal-fired power plant, 1990.

Emission standard of air pollutants for thermal power plants(GB13223-1996)

Corporation was broken up in December 2002 as the government tried to end the monopoly in the country's generation market. The State Power Corporation was divided into five generation companies (Huaneng Group, Huadian Power, Guodian Power, Datang Power Group and China Power Investment Company) and two power grid operators (State Power Grid Company and South China Power Grid Company). Each one of the generation companies took over less than 20 percent of the generation facilities of the former State Power Corporation.

The government will take more notice on restructure, competition and regulator, strategic option for deepening China's electricity reform. China's power industry will be more open to outside world with accession to WTO. Investors worldwide are welcome to participate in Chinese power construction.

- *Improving the energy efficiency*

In recent years China has successively introduced a batch of 300 MW, 500 MW 600 MW and 800 MW supercritical units. Through debugging and improvement these units have been operating smoothly with higher availability and efficiency gained. It has laid a certain foundation for China to develop home-made supercritical pressure units.

- *Tenth Five-Year Plan*

Targets of the 10th Five-Year Plan (2001-2005): total investment 900billion RMB, of which 40% for grid construction. Shut-down 14.2 GW of small thermal units. To reach 395 GW installed capacity, 1830 TWh generation, realize basic national inter-connection by 2005. Build west-to-east power transmission corridors, enhance regional & provincial grids. Continue urban & rural network construction and innovation. Strengthen construction of secondary system protection, communication and automatic control). To fully tap the potential of existing capacity. To promote the development of hydro-electric power. To optimize thermal power development. To develop nuclear power properly. To develop renewable energy in accordance with local conditions. To place equal emphasis on development and energy conservation. To attach great importance on environmental protection. To deepen the structural reform in power sector.

- *Nuclear power*

China's 10th Five-Year Plan incorporates the construction of nuclear power plants, though the timeline for contracts has been extended. Many of the major developments taking place in the Chinese electricity sector recently involve nuclear power. China's total installed capacity for nuclear power generation increased from 2 GW in the beginning of 2002 to 15 GW as of mid-2005. The first generation unit of the Lingao nuclear power plant in Guangdong province began commercial operation in May 2002, with a capacity of 1-GW. The second 1-GW generating unit began operating in January 2003. An additional 600-MW generating unit at the Qinshan nuclear power plant in Zhejiang province began operation in February 2002, and another 600-MW unit at the same site came online in December 2002. A new 6-GW nuclear complex is planned for construction at Yangjiang in Guangdong province, to begin commercial operation in 2010. A second generating facility also is planned for Daya Bay. Chinese government policy emphasizes nuclear power generation as a source of clean electricity generation and a means of reducing dependence on fossil fuels. China plans a total of 40 GW of nuclear generating capacity to be completed by 2020, it will reach 4 percent of total installed capacity at that point.

- *Renewable Energy Law*

The Standing Committee of the National People's Congress (NPC) endorsed the Renewable Energy Law on February 28, 2005. Effective from Jan.2006, the law requires power grid operators to purchase electricity generated by registered renewable energy producers. The law also offers financial incentives, such as a national fund to foster renewable energy development, and discounted lending and tax preferences for renewable energy projects.

China's new law sets the stage for the widespread development of renewables, particularly for commercial scale renewable generating facilities. Through this legislation, the State officially

encourages the construction of renewable energy power facilities. China's electricity grid is obligated to purchase all the electricity generated by approved renewable energy facilities located in its service area.

- *Hydro-electric power*

China is constructing the world's largest hydro project, the massive Three Gorges Dam, in Hubei province with total installed capacity of 18.2 gigawatts. The plant is scheduled to be fully operational by 2009 after an investment of at least 25 billion US dollar. At that time, it will supply about 3 percent of the country's power needs.

- *Wind Power*

For the sake of promoting wind power construction, the Chinese government has issued a Circular on Questions Concerning Advancement of Renewable Energy Resources in 1999, in which the preferential policy of renewable energy, in particular, wind power projects was set forward that bank-loaned projects would be given a fiscal subsidiary of 2 per cent and wind power projects putting Chinese-made equipment to use would be given a preferential treatment of 5 per cent on return rate of investment.

III.C.2.ii Assumptions about the Effectiveness of Policies

Power plants with less efficiency are forced to close. The step of scale enlargement and technology advancement of present thermal power plants is faster than that in baseline scenario. International advanced technologies such as IGCC and PFBC with carbon capture and storage are well introduced and implemented by the end of 2030. Nuclear and hydropower's great potentials are exploited substantially.

In this scenario, we will evaluate projected emissions using combination of measures in place before the end of 2005. Taking regards of Report of 16th Party Congress, Tenth Five-Year Plan as well as relative industrial long term development policies and plans. The policies adopted in this scenario take more consideration for environmental protection.

III.C.3 Description of analytical approach and methodology used.

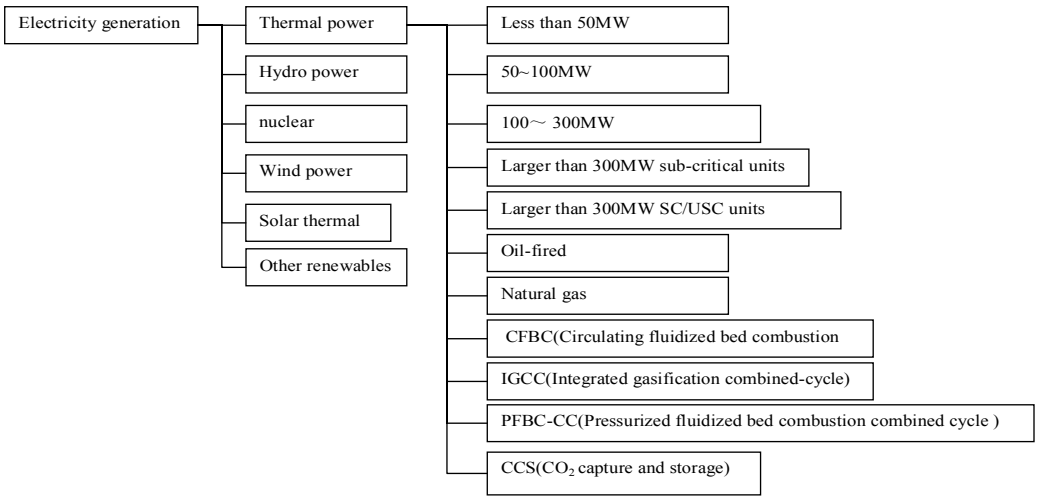

Figure 3-3 Data structure for China's electric technology analysis

In terms of input data of LEAP model, we use tree analysis to describe the industrial technology information of electricity sector. The generating equipments are classified by fuel types at the primary

level, the thermal power plants fueled by coal are further classified by their generating capacities with consideration of technology advancement. The simplified analysis structure is showed in Fig 3-3

III.D Baseline (business-as-usual) Forecasts for sectors

III.D.1 Production/output forecast

It is said China's GDP in 2020 will quadrupled as it is in 2000 in the Considering the Report of 16th Party Congress. We refer to series of literatures on Chinese energy and carbon scenarios[23] and assume China's GDP will keep the fast growth in 2000s, the annual growth rate is set to be 7.5% during 2000 to 2010. Then the growth speed will slow down, the annual growth rate is set to be 6.5% during 2010 to 2020, 5.5% during 2020. And electric sectoral production is projected consistent with economy development, see Table 3-10. The forecast trend of generation in the whole target analysis period is shown in Fig 3-4.

Table 3-10. China's GDP and Electric Production Assumptions in the Analysis

Year	2000	2005	2010	2015	2020	2025	2030
Annual Growth Ratio	7.50%		6.50%		5.50%		
GDP（billion dollar）	1081	1552	2227	3096	4181	5465	7142
Sectoral Production (Twh)	1368.5	1841	2313	3179	4046	5664	7282

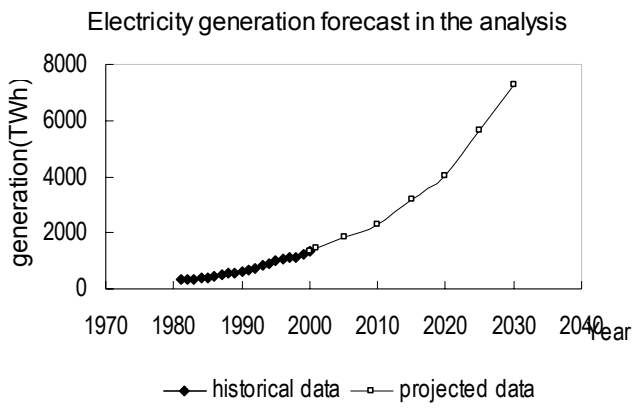

Fig 3-4 Electricity generation forecast in the analysis

III.D.2 Energy and fossil fuel consumption (by type) forecast

For the energy consumption forecasts in baseline scenarios, we list the results from LEAPChina model analysis, see Table 3-11 and Table 3-12.

Table 3-11. Energy consumption under 2000 baseline scenario

Year	Total Energy Consumption (PJ)				Energy Intensity (PJ/TWh)
	Coal	Oil	Gas	Total	
2000	12913	427.9	255.3	13596	9.93
2005	16617	508.4	420.6	17546	9.53
2010	19935	554.4	625.6	21115	9.13
2015	26779	579.9	919.3	28278	8.90
2020	33282	506.0	1245	35033	8.66
2025	45362	383.7	1876	47621	8.41
2030	56737	75.9	2581	59394	8.16

Data resource: analysis results from LEAPChina model.

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Table 3-12. Energy consumption under 2005 baseline scenario

Year	Total Energy Consumption (PJ)				Energy Intensity (PJ/TWh)
	Coal	Oil	Gas	Total	
2000	12913	428	255	13596	9.93
2005	16595	470	421	17486	9.50
2010	19882	458	626	20965	9.06
2015	26154	497	919	27570	8.67
2020	31785	464	1245	33494	8.28
2025	43510	354	1876	45740	8.08
2030	54670	76	2581	57327	7.87

Data resource: analysis results from LEAPChina model.

III.D.3 Annual GHG forecast

III.D.3.i <u>Total GHG emissions</u>

The corresponding CO2 emissions and emissions intensities related to fuel combustion are calculated; see Table 3-13 through Table 3-16, below.

Table 3-13. CO2 emission for China's electric sector under 2000 baseline scenario (MMtCO2)

	2000	2005	2010	2015	2020	2025	2030
Coal	1157	1512	1809	2424	3006	4087	5099
Oil	29.1	34.6	37.8	39.5	34.5	26.1	5.20
Gas	13.0	20.8	30.9	45.4	61.5	92.6	127.5
Total	1199	1567	1877	2509	3102	4206	5231
Emission intensity (kg CO2/kWh)	0.88	0.85	0.81	0.79	0.77	0.74	0.72

Data resource: analysis results from LEAPChina model.

Table 3-14. CO2 intensity by fuel type for China's electric sector under 2000 baseline scenario (kg CO2/kWh)

	2000	2005	2010	2015	2020	2025	2030
Coal	1.11	1.14	1.14	1.16	1.18	1.18	1.19
Oil	0.71	0.79	0.91	0.91	0.93	0.92	0.69
Gas	0.47	0.47	0.46	0.46	0.46	0.46	0.46
All Fuels	0.88	0.85	0.81	0.79	0.77	0.74	0.72

Table 3-15. CO2 emission for China's electric sector under 2005 baseline scenario(MMtCO2)

	2000	2005	2010	2015	2020	2025	2030
Coal	1157	1510	1803	2366	2866	3914	4906
Oil	29.1	32.0	31.2	33.8	31.6	24.1	5.20
Gas	13.0	20.8	30.9	45.4	61.5	92.6	127.5
Total	1199	1563	1865	2445	2960	4031	5038
Emission intensity (kg CO2/kWh)	0.88	0.85	0.81	0.77	0.73	0.71	0.69

Data resource: analysis results from LEAPChina model.

Table 3-16. CO2 intensity by fuel type for China's electric sector under 2005 baseline scenario (kg CO2/kWh)

	2000	2005	2010	2015	2020	2025	2030
Coal	1.11	1.14	1.14	1.13	1.12	1.13	1.14
Oil	0.71	0.72	0.74	0.79	0.88	0.85	0.69
Gas	0.47	0.47	0.46	0.46	0.46	0.46	0.46
All Fuels	0.88	0.85	0.81	0.77	0.73	0.71	0.69

III.E GHG Mitigation Options and Costs

III.E.1 Selection criteria for consideration of mitigation options

The major GHGs abatement options suggested here are important for the electric sector, and are consistent with sectoral development goals and relevant policies.

Therefore, they have significant potential for GHGs emissions reduction and their implementation is feasible. In the next parts, we firstly listed the corresponding description and development of each individual option, and then we give the technology structure assumptions in three scenarios for your information. For some options such as demand side management and reconstruction of conventional thermal power we didn't provide detailed measures information due to lack of data, so we make general assumptions of the total CO2 mitigation percentages they can achieve in target years.

III.E.2 Overview of each mitigation option evaluated

III.E.2.i Description, including technologies required

- *Demand side management*

Besides the energy supply sector, the energy end-use sectors have many technical measures to improve energy efficiency. This part contains industrial boiler, motor, transportation, residential, iron and steel sector, etc. Commonly used equipment such as boilers and motors are the most important ones and has the largest potential for energy savings. Technical options for improving boiler efficiencies may include fuel preparation, advanced combustion technologies and auxiliary equipment, as well as process control.

Output of China's electricity mostly depends on generation capacity. Although demand-side measures will reduce total outputs, the decline of demand will stimulate new demand. Fluctuation is common in both demand and supply for electricity market. Here we assume the outputs in three scenarios to be the same mainly for accelerating horizontal comparisons.

- *Circulating Fluidized bed combustion (CFBC)*

Generally CFBC is structured by the boiler and the high temperature cyclone. The intrafurnace gas velocity is as high as 4 to 8 m/s. Coarse fluidizing medium and char in the flue gas are collected by the high temperature cyclone, and are recycled to the boiler. The recycle maintains the bed height and increases the denitration efficiency. To increase the thermal efficiency, a preheater for fluidizing air and combustion air, and a boiler feed water heater are installed.

CFBC's advantages can be described as Wide range of fuel adaptability, low pollution, high combustion efficiency, space saving and high maintenance ability. There has been a long history for development of CFBC in China since 1960s. Although it's efficiency is much lower than clean coal combustion technologies such as IGCC and PFBC-CC, the negative marginal abatement cost will be key driving force for promotion of CFBC plants in all three scenarios.

- *Reconstruction of conventional thermal power*

It mainly focuses on four aspects: replacement and renovation of medium and low-pressure unit, new installation of large-scale unit, comprehensive renovation of existing large-scale unit, increases of cogeneration unit.

The regulation of closing less efficient medium and small plants has been carried out since early 1990s, but didn't work effectively because of loose implementation and supervision. There is still long way to go for China in this aspect. Also, Chinese government made the announcement that mainstream added equipments from 1990s should be big thermal plants more than 30 MW, so reconstruction of conventional thermal power plants will take great effect in CO2 mitigation.

- *Supercritical/Ultra supercritical plants*

Supercritical units operate at higher temperatures and pressures than sub-critical units, the higher pressures increase turbine efficiency and power output, so less coal is used to produce the same amount of electricity.

Ultra-supercritical plants use new advanced clean coal technology, allowing operation at elevated steam temperatures and pressures. Ultra-supercritical technologies are expected to become more prevalent in China because they can boost the efficiency of coal-based electricity generation by more than 50 percent, while maintaining superior environmental performance.

With break through the barriers of technologies, SC and USC will play important role in CO2 abatement area.

- *IGCC (integrated gasification combined-cycle),PFBC (pressurized fluidized bed combustion)*

IGCC systems are extremely clean, and are much more efficient than traditional coal-fired systems. IGCC uses a combined cycle format with a gas turbine driven by the combusted syngas from the gasifier, while the exhaust gases are heat exchanged with water/steam to generate superheated steam to drive a steam turbine. The result is an integrated gasification combined-cycle configuration that provides ultra-low pollution levels and high system efficiencies.

Pressurized fluidized-bed combustion (PFBC) technology uses a combustion process similar to that of AFBC, but the boiler operates at higher than atmospheric pressure (0.5 to 2 MPa), the gas is cleaned downstream from the PFBC boiler, and the gas is expanded in a gas turbine. It can provide advanced environmental characteristics including: SOx reduction through the in-bed desulfurization; NOx reduction through the low temperature combustion (about 860OC); Dust reduction by CTF; and CO2 reduction by increased efficiency.

As this two advanced technologies are not spread widely, there is still a period for them to be commercialized. So in the scenarios, we assume they are gradually utilized after 2010.

- *CCS*

The application of CO_2 capture and storage technologies to fossil fueled energy conversion processes raises a prospect for the implementation of technologies that contribute to near zero emissions of all forms of pollutant emissions and greenhouse gases into the atmosphere. CCS is not a silver bullet; other mitigation options are necessary to achieve the desired stabilization levels. In the analysis of CCS, it was assumed that the incremental cost of adding CCS is same regardless of plant type (IGCC, gas-fired CC, etc.) For CCS is not maturely developed even in the developed country. It is really hard to forecast CCS' abatement potential and marginal reduction in China in the near future. We optimistically suppose it will be taken on line and make effects after 2020 or later because of technical barrier and lack of capital. Here in Fig 3-5 we provide the stationary CO2 sources and geological storage opportunities in China's sedimentary basins.

- *Hydropower generation*

There is grate hydropower potentials in Southeast China. But no more than 25% is exploited because it's far from the center load areas. The payback period to build hydropower stations is long, so the thorny issue to develop hydropower generation in China is lack of money. Here in the mitigation scenario, we suppose the potential for hydropower is more utilized for the assistance of CDM projects, and the power generation percentage in total national generation increases from 17.77% to 24.8%.

- *Nuclear power*

Nuclear power has an important role, especially in the coastal areas remote from the coalfields and where the economy is developing rapidly.

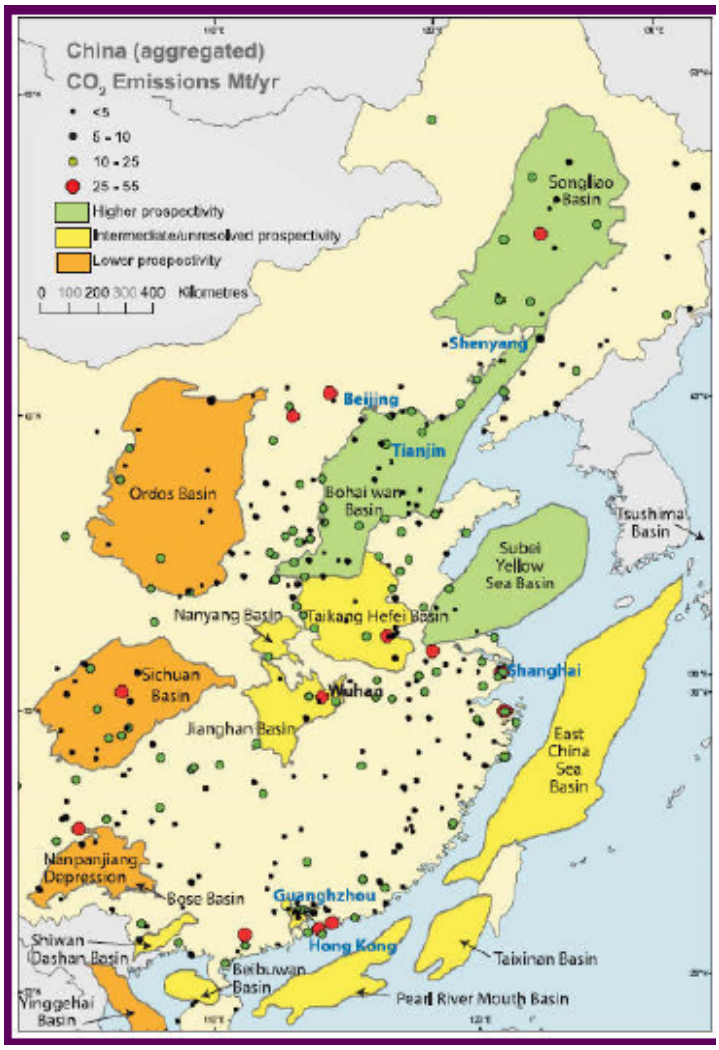

Figure 3-5. Stationary CO2 Sources & Geological Storage Opportunities in China's sedimentary Basins

- *Natural gas*

So far, natural gas takes only 2.5% more or less in our national energy consumption, and is mainly used in industrial process heating. Unless other countries, proportion of electricity generated from natural gas is quite low. So natural gas isn't an leading choose in our assumptions.

- *Other Renewable energy*

China is rich in wind energy resources[24]. By estimates of China Meteorology Research Institute the exploitable wind energy on the nationwide land totals around 253 GW, and the offshore wind energy is about 750 GW. Both of them add up to about 1000 GW. And the wind energy is widely distributed throughout the country. It is shown that China is provided with adequate conditions to develop wind power industry.

China has a very good solar resource, averaging above 4kWh/m^2/day, in some areas, particularly in the west of the country, solar radiation levels are high, population densities are low, and prospects for provision of mains electricity through grid extension in the foreseeable future are small.

[24] The transmission cost for hydropower, wind power and solar thermal power generation theoretically should be discussed, but we make rough general assumptions because lack of relative information.

III.F Analysis of GHG mitigation scenarios

Regarding the descriptions above related to each option, we provide the technology structure in three scenarios for your information, see Table 3-17.

Table 3-17.Generation proportion by different technologies under three scenarios(%)

		2000 baseline scenario				2005 baseline scenario				Mitigation scenario			
		2000	2010	2020	2030	2000	2010	2020	2030	2000	2010	2020	2030
Thermal power plants	<50MW	12.63	0	0	0	12.63	0	0	0	12.63	0	0	0
	50~100MW	6.85	6.4	5.5	4	6.85	6	5	3	6.85	5.4	4	2
	100~300MW	52.35	48.3	36.6	23.7	52.35	47.4	31.5	19.2	52.35	43.3	23.9	6.9
	Sub-critical units	3	5	7	10.5	3	5.5	8	12.5	3	5.8	8.3	12.6
	SC/USC units	0	8.5	12.3	15.7	0	9.1	13.4	16.2	0	9.5	14.5	17.2
	CFBC	1.03	3.5	7.8	12.3	1.03	3.7	8.5	13.3	1.03	3.9	9.4	15.6
	IGCC	0	0.3	0.9	1.9	0	0.3	1	2	0	0.3	1.5	2.4
	PFBC	0	0.3	0.8	1.4	0	0.3	1	1.6	0	0.3	1.4	2.3
	Oil-fired	3	2.3	1.2	0.1	3	1.9	1.1	0.1	3	1.8	0.9	0.1
	Natural gas	2	2.9	3.3	3.8	2	2.9	3.3	3.8	2	2.9	3.3	3.8
	CCS mitigation（$MtCO_2$）	0	0	0	0	0	0	0	0	0	0	5	60
Hydro power		17.8	19.3	20.1	20.2	17.8	19.3	21	21.3	17.8	21.5	22.8	24.8
Nuclear		1.2	2.6	3.4	5.1	1.2	2.9	5	5.6	1.2	4.5	8.5	10.6
Wind power		0.04	0.5	1	1.2	0.04	0.6	1.1	1.3	0.04	0.7	1.4	1.6
Other renewables		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total		100	100	100	100	100	100	100	100	100	100	100	100

III.F.1 Marginal abatement cost curve ($/metric ton GHG reduced vs. total GHG reductions)

The marginal cost for each option is calculated through its mitigation effect compared to average value of current thermal power plants. For instance, we gain the operational cost, fuel cost, and maintenance cost for each option[25]. We calculate CO2 emission basing on the fuel consumption information. Then we use the difference of total cost for certain option and average value of current thermal power plants times the difference of their CO2 emissions to obtain the marginal abatement cost for this certain mitigation option. Also, we do adjustments by checking the related literature of marginal abatement cost for mitigation measures and options[26,27]when the calculated results seem to be unreasonable.

[25] Wanghao. The potential in GHG Emission Mitigation and its Cost Benefit Analysis for Electric Power Sector of China under Clean Development Mechanism of Kyoto Protocol [D]. 1999. Tsinghua, Beijing.

[26] WANG Weizhong, GUO Risheng, ZHOU Hailin, et al. The Methodology Guidelines of Clean Development Mechanism[M]. Beijing: Social Science Literature Press, 2005.(in Chinese)

[27] WU Zongxin. WEI Zhihong, ZHANG Aling, et al. Asia Least-cost Greenhouse Gas Abatement Strategy [M]. Manila:Asian Development Bank,1998.

III.F.1.i 2010

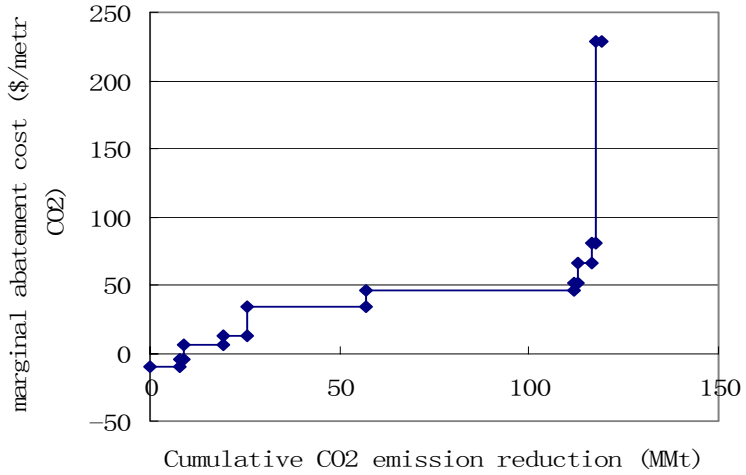

Figure 3-6.Marginal abatement cost curve of China's electricity sector in 2010

Table 3-18. Cost of mitigation options and relevant emission reduction in 2010

No.	Measures	Marginal Mitigation Cost (US$/tCO2)	Total Emission Reduction (MMt CO2)	Total Cost (million US$)	Cumulative Emission Reduction (million metric tons CO_2e)	Cumulative Net Cost (million US$)	Average Cumulative Cost Effectiveness (US$/metric ton CO_2e)
1	Demand side Management	-9.86	7.59	-74.8	7.59	-74.8	-9.86
2	CFBC	-4.55	1.21	-5.52	8.80	-80.3	-9.13
3	Reconstruction of Conventional Thermal Power	6.59	10.3	68.1	19.1	-12.3	-0.64
4	Supercritical Plant	12.5	6.58	82.0	25.7	69.7	2.71
5	Nuclear Power	34.2	31.1	1063	56.8	1133	20.0
6	Hydropower	46.0	54.9	2526	111.7	3659	32.8
7	Natural Gas	50.8	1.11	56.6	112.8	3715	32.9
8	IGCC &PFBC	66.4	3.54	235.1	116.4	3950	33.9
9	Wind Power	80.8	1.32	106.3	117.7	4057	34.5
10	Solar Thermal	229.3	1.52	348.1	119.2	4405	37.0

III.F.1.ii 2015

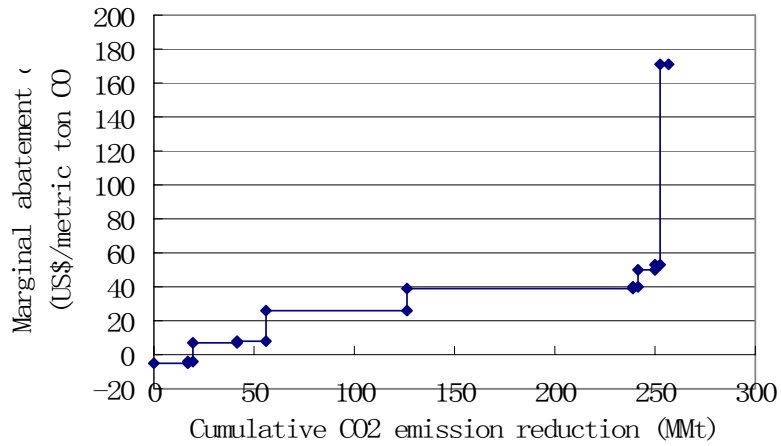

Figure 3-7.Marginal abatement cost curve of China's electricity sector in 2015

Table 3-19. Cost of mitigation options and relevant emission reduction in 2015

No.	Measures	Marginal Mitigation Cost (US$/tCO2)	Total Emission Reduction (MMt CO2)	Total Cost (million US$)	Cumulative Emission Reduction (million metric tons CO_2e)	Cumulative Net Cost (million US$)	Average Cumulative Cost Effectiveness (US$/metric ton CO_2e)
1	Demand Side Management	-5.28	17.0	-89.7	17.0	-89.7	-5.28
2	CFBC	-4.04	2.62	-10.6	19.6	-100.3	-5.11
3	Reconstruction of Conventional Thermal Power	6.67	22.2	148.3	41.9	48.0	1.15
4	Supercritical Plant	8.3	14.4	119.6	56.3	167.6	2.98
5	Nuclear Power	26.0	69.8	1816	126.0	1984	15.7
6	Hydropower	38.6	113.4	4373	239.4	6356	26.6
7	Natural Gas	40.3	2.40	96.7	241.8	6453	26.7
8	IGCC &PFBC	50.5	8.1	408	249.9	6861	27.5
9	Wind Power	53.0	3.1	161.8	252.9	7022	27.8
10	Solar thermal	171.3	3.5	598	256.4	7620	29.7

III.F.1.iii 2020

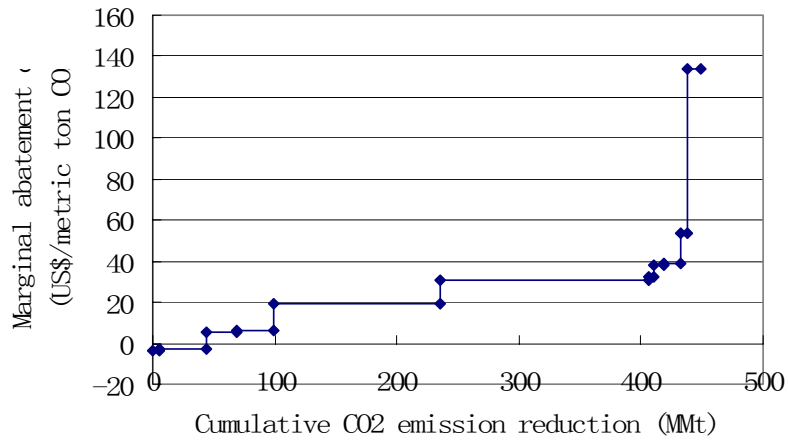

Figure 3-8.Marginal abatement cost curve of China's electricity sector in 2020

Table 3-20. Cost of mitigation options and relevant emission reduction in 2020

No.	Measures	Marginal mitigation cost (US$/tCO2)	Total emission reduction (MMt CO2)	Total Cost (million US$)	Cumulative Emission Reduction (million metric tons CO_2e)	Cumulative Net Cost (million US$)	Average Cumulative Cost Effectiveness (US$/metric ton CO_2e)
1	CFBC	-3.63	5.71	-20.7	5.71	-20.7	-3.63
2	Demand Side Management	-2.96	38.0	-112.6	43.7	-133.3	-3.05
3	Reconstruction of conventional thermal power	5.72	25.1	143.6	68.8	10.3	0.15
4	Supercritical plant	5.99	29.7	177.7	98.5	188.0	1.91
5	Nuclear power	19.2	136.9	2629	235.5	2817	12.0
6	Hydropower	31.0	171.2	5306	406.6	8123	20.0
7	Natural gas	32.7	4.18	136.8	410.8	8260	20.1
8	Wind power	38.0	7.61	289.1	418.4	8549	20.4
9	IGCC &PFBC	38.8	14.1	546.1	432.5	9095	21.0
10	CCS	53.3	5.00	266.5	437.5	9362	21.4
11	Solar thermal	133.7	11.4	1526	448.9	10888	24.3

III.F.2 Advanced Options (Mitigation) Scenario #1: All Zero- or Negative Cost Mitigation Options

This mitigation scenario includes CFBC (circulating fluidized bed combustion) and demand side management.

III.F.2.i Results from the mitigation scenario

Table 3-21. Annual fuel consumption, emissions and intensity forecast for electricity sector

Year	Total Production (TWh)	Total Fuel Consumption （PJ）				CO2 emissions (million tones)	Fuel Intensity (PJ/kWh)	Emissions Intensity (kg CO2 / kWh)
		Coal	Fuel Oil	Natural Gas	All Fuels			
2000	1368.5	12913	427.9	255.3	13596	1199	9.93	0.88
2005	1840.6	16579	507.4	419.8	17506	1564	9.51	0.85
2010	2312.7	19841	552.2	623.1	21016	1868	9.09	0.81
2015	3179.2	26568	576.0	913.1	28058	2489	8.83	0.78
2020	4045.7	32811	499.8	1230	34541	3058	8.54	0.76
2025	5664	44595	378.1	1848	46822	4135	8.27	0.73
2030	7282.3	55613	74.6	2537	58225	5128	8.00	0.70

Table 3-22. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions (MMTCO_2e)				CO_2 Intensity (kg CO2/kWh)			
	Coal	Oil	Natural Gas	Total All Fuels	Coal	Oil	Natural Gas	Total All Fuels
2000	1157	29.1	13.0	1199	1.11	0.71	0.47	0.88
2005	1509	34.5	20.8	1564	1.14	0.78	0.46	0.85
2010	1800	37.6	30.8	1869	1.14	0.90	0.46	0.81
2015	2405	39.2	45.1	2489	1.15	0.91	0.46	0.78
2020	2963	34.1	60.7	3058	1.16	0.94	0.45	0.76
2025	4018	25.7	91.2	4135	1.16	0.91	0.45	0.73
2030	4998	5.11	125.3	5128	1.16	0.70	0.45	0.70

III.F.3 Advanced Options Scenario #2: All mitigation options costing less than $5 per metric ton

This mitigation scenario includes CFBC (circulating fluidized bed combustion) and demand side management (SAME AS ABOVE)

III.F.4 Advanced Options Scenario #3: All mitigation options costing less than $10 per metric ton

This mitigation scenario includes CFBC (circulating fluidized bed combustion)， demand side managementSupercritical/Ultra supercritical plant and Reconstruction of conventional thermal power.

Table 3-23. Annual fuel consumption, emissions and intensity forecast for electricity sector

Year	Total Production (TWh)	Total Fuel Consumption （PJ）				CO2 emissions (million tones)	Fuel Intensity (PJ/kWh)	Emissions Intensity (kg CO2 / kWh)
		Coal	Fuel Oil	Natural Gas	All Fuels			
2000	1368.5	12913	427.9	255.3	13596	1199	9.93	0.88
2005	1840.6	16579	507.4	419.8	17506	1561	9.51	0.85
2010	2312.7	19841	552.2	623.1	21016	1862	9.09	0.81
2015	3179.2	26567	576.0	913.1	28056	2475	8.82	0.78
2020	4045.7	32808	499.8	1230	34538	3033	8.54	0.75
2025	5664	44592	378.1	1848	46818	4094	8.27	0.72
2030	7282.3	55608	74.6	2537	58220	5069	7.99	0.70

Table 3-24. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)				CO_2 Intensity (kg CO2/kWh)			
	Coal	Oil	Natural Gas	Total All Fuels	Coal	Oil	Natural Gas	Total All Fuels
2000	1157	29.1	13.0	1199	1.11	0.71	0.47	0.88
2005	1506	34.5	20.8	1561	1.13	0.78	0.46	0.85
2010	1794	37.6	30.8	1862	1.13	0.90	0.46	0.81
2015	2391	39.2	45.1	2475	1.14	0.91	0.46	0.78
2020	2938	34.1	60.7	3033	1.15	0.94	0.45	0.75
2025	3977	25.7	91.2	4094	1.15	0.91	0.45	0.72
2030	4938	5.11	125.3	5069	1.15	0.70	0.45	0.70

III.F.5 Advanced Options Scenario #4: All Feasible Mitigation Options[*]

Table 3-25. Annual fuel consumption, emissions and intensity forecast for electricity sector

Year	Total Production (TWh)	Total Fuel Consumption （PJ）				CO2 emissions (million tones)	Fuel Intensity (PJ/TWh)	Emissions Intensity (kg CO2 / kWh)
		Coal	Fuel Oil	Natural Gas	All Fuels			
2000	1368.5	12913	427.9	255.3	13596	1199	9.93	0.88
2005	1840.6	16138	460.4	420.6	17019	1520	9.25	0.83
2010	2312.7	18733	433.9	625.6	19792	1758	8.56	0.76
2015	3179.2	24105	447.3	919.3	25471	2253	8.01	0.71
2020	4045.7	28579	379.5	1245	30203	2658	7.47	0.66
2025	5664	37664	295.2	1876	39835	3488	7.03	0.62
2030	7282.3	45409	75.90	2581	48066	4184	6.60	0.57

Table 3-26. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)				CO_2 Intensity (kg CO2/kWh)			
	Coal	Oil	Natural Gas	Total All Fuels	Coal	Oil	Natural Gas	Total All Fuels
2000	1157	29.1	13.0	1199	1.11	0.71	0.47	0.88
2005	1468	31.40	20.8	1520	1.10	0.71	0.46	0.83
2010	1698	29.50	30.9	1758	1.07	0.71	0.46	0.76
2015	2177	30.50	45.4	2253	1.04	0.71	0.46	0.71
2020	2571	25.80	61.5	2658	1.01	0.71	0.46	0.66
2025	3375	20.10	92.6	3488	0.98	0.71	0.46	0.62
2030	4051	5.20	127.5	4184	0.94	0.71	0.46	0.57

[*] In electricity and in all other sectors, Advanced Options Scenario #4 includes all options from the marginal abatement cost curve.

III.F.6 Co-benefits

Mitigation Option	Water quality improvements	Increased economic productivity and competitiveness	Job creation	Technology development and transfer	Infrastructure development	Enhanced energy security and independence	Air quality improvement
Demand side management	☆☆	☆☆		☆	☆☆		☆
CFBC (Circulating Fluidized bed combustion)	☆	☆		☆			☆
Reconstruction of conventional thermal power	☆	☆☆		☆	☆☆	☆	☆
Supercritical plant	☆	☆		☆			☆
Nuclear power	☆☆☆	☆☆☆		☆☆	☆	☆	☆☆
Hydropower	☆☆	☆☆		☆☆	☆	☆	☆☆
Natural gas	☆☆☆			☆			☆☆
IGCC (integrated gasification combined-cycle)PFBC (pressurized fluidized bed combustion)	☆	☆		☆	☆	☆	☆
IGCC-CCS		☆☆		☆☆	☆	☆	☆☆☆
Wind power	☆☆	☆☆☆		☆☆	☆	☆	☆☆
Solar thermal	☆☆☆	☆		☆	☆		☆☆

Note:More☆ means specific mitigation option will produce more co-benefits

IV. Sector Analysis and Results: Iron & Steel

Iron and steel industry is a pillar industry for China's sustaining economic development. It is an essential basic industry, a major energy consuming sector and source of greenhouse gases and other pollutants. At present ,although there are several modern steel enterprises with advanced technology and equipment such as Baosteel , the general and average level of technology in China's iron and steel industry is about 10 or more years behind than those of industrialized countries, and the energy consumption of per ton of steel is much higher than that of industrialized countries. Its energy consumption and CO_2 emissions account for about 10% of the country's total. The industry has achieved great progress in energy conservation and emission reductions, but because of the general backward technology, there are still huge potentials for China's iron and steel industry to improve energy efficiency and mitigate greenhouse gases and other pollutants. These energy conservation measures will also help iron and steel enterprises reduce cost, enhance economic benefit and strengthen their market competitiveness. During this process, industry structure adjustment and technology advancement will play an important role in emission reduction.

IV.A Sector Overview

IV.A.1 Summary

IV.A.1.i <u>Total output/production</u>

China's iron and steel industry has gone through rapid development since 1990. At 1996, output of crude steel of China's iron and steel broke through 100 million tons. From then on China has become the largest steel-producing country of the world. The following table is the output of different productions of China's iron and steel industry including crude steel , steel product, pig iron, coke and ferroalloy. In the statistic for iron and steel industry, coke is special. Because besides being the input for iron making, coke is also used in many other industrial sectors. In this table output of coke is the total of China's all coke enterprises. But in the sector's energy consumption analysis, only that part of coke used for iron and steel is calculated. For example, at the year of 2000, total output of coke is 121.84 million tons. At that year, the average ratio of coke and pig iron into blast furnace is 0.437. So the demand of coke for iron-making is 13101×0.437=5725 million tons.

Table 4-1. Different output of China's iron and steel industry

Year	Crude Steel (million metric tons)	Steel Product (million metric tons)	Pig iron (million metric tons)	Coke (million metric tons)	Ferroalloy (million metric tons)
1990	66.35	51.53	62.37	73.27	2.38
1991	71.00	56.38	67.65	73.51	2.46
1992	80.94	66.94	75.89	79.85	2.66
1993	89.54	70.80	87.38	93.15	2.93
1994	92.61	84.28	97.41	114.29	3.40
1995	95.36	89.80	105.29	135.02	4.32
1996	101.24	93.38	107.21	136.46	4.33
1997	108.91	99.87	115.11	139.02	4.04
1998	114.59	107.38	118.52	128.19	3.55
1999	123.95	121.02	125.33	120.46	43.81
2000	128.50	131.46	131.01	121.84	4.03

Data source: China Steel Statistics 2001

The major challenge for China's iron and steel industry is the decentralization of the whole industry. The following table shows the proportion of different scales enterprises in total annual output. There are still many medium and small scale enterprises in steel market with backward technology and manufactural equipments. This structure is the main cause of China's iron and steel industry's lower energy efficiency. This energy efficiency status can be illuminated by several important ratios in the industry.

Table 4-2. Proportion of different scales enterprises in total annual steel output

Year	Proportion of different scales enterprises in total annual steel output, (%)			
	>5 million tons	3-5 million tons	1-3 million tons	<100 million tons
1990	11.80	19.56	31.69	36.95
1991	11.01	19.75	31.97	37.27
1992	25.46	5.88	29.70	38.96
1993	30.81	3.44	30.09	35.66
1994	31.05	3.28	31.75	33.92
1995	30.95	3.46	29.81	35.78
1996	28.59	4.00	34.44	32.97
1997	27.86	6.64	35.50	30.00
1998	28.00	8.95	39.23	23.82
1999	26.41	16.31	36.27	21.01
2000	27.08	19.49	38.40	15.03

Data source: China Steel Statistics 2001

Table 4-3 .Several important ratios in iron and steel industry

Year	Several important ratios %				
	Iron/steel	Yield of steel product	Proportion of Electric furnace steel	CC ratio	Steel plate add steel tube/total rolled steel
1990	0.94	0.78	21.4	22.3	37.0
1991	0.95	0.79	21.1	26.5	37.2
1992	0.94	0.83	21.8	30.0	37.4
1993	0.97	0.86	23.2	33.9	36.7
1994	1.05	0.91	21.2	39.5	36.6
1995	1.10	0.94	19.0	46.5	39.2
1996	1.06	0.92	18.7	53.3	39.5
1997	1.06	0.91	17.6	60.7	41.0
1998	1.03	0.94	15.8	68.8	38.6
1999	1.01	0.98	15.7	78.1	39.4
2000	1.02	1.02	15.9	82.5	41.86

Data source: China Steel Statistics 2001

These ratios show that product structure may have impact on energy consumption. For example, ratio of iron and steel is the ratio of the output of iron and steel. Pig iron is a kind of high energy intensive product and more output means more energy consumption. When the steel output is fixed, increasing the output of pig iron (that is to say, increasing the ratio of iron and steel) means the increase of average energy consumption per ton of steel. Increasing of proportion of electric furnace steel to total steel will decrease the energy consumption per ton of steel because electric furnace steel will shorten the whole process of steel making. But this ratio will be limited to the acquirability of waste steel. Other ratios also have energy conservation significance. From the above table, China's iron and steel industry has made some progress in energy conservation but some indicators are still at low level even retrogresses.

IV.A.1.ii Employment

Total work force of iron and steel industry is decreasing, from 3152.3 thousand at 1990 to 2515.9 thousand at 2000, along with the increasing of production output. So the productivity of the industry has been improved. The productivity indicator -ton crude steel per employee per year -varied from 21.05 at 1990 to 51.08 at 2000.

Table 4-4. Employment and productivity of iron and steel industry

Year	1990	1995	1996	1998	2000
Work force of iron & steel industry (thousand employee)	3152.3	3423.4	3329.8	2880.5	2515.9
Productivity (ton crude steel per employee per year)	21.05	27.86	30.40	39.78	51.08

Date source: China Iron and Steel Yearbook 2000

IV.A.1.iii Revenues, share of GDP

In the following table, at the year of 2000, iron and steel's proportion of the total gross industrial output added value is 3.28% and share of GDP is only 1.45%. But energy consumption of iron and steel industry is about 10%.Although the share of this industry in total GDP is smaller than ever, it is still an essential basic industry of China's economic. Because it provide steel product, an essential kind of raw material, for the construction of infrastructure and industrial production facilities.

Table 4-5. Output value of iron and steel industry

Year	GIOV of Iron & steel (billion USD)	GIOAV of Iron& steel (billion USD)	China's total GIOAV (billion USD)	Iron & steel's proportion in total GIOAV(%)	GDP(billion USD)	Iron & steel's proportion in GDP(%)
1990	15.83	3.84	82.84	4.64	224.05	1.71
1991	16.75	4.54	97.69	4.64	261.14	1.74
1992	19.20	6.13	124.23	4.93	321.78	1.90
1993	21.55	13.83	170.85	8.10	418.37	3.31
1994	22.34	13.37	233.86	5.72	564.84	2.37
1995	21.93	14.72	298.59	4.93	706.39	2.08
1996	24.27	10.94	351.31	3.11	820.02	1.33
1997	24.46	10.63	391.53	2.72	899.48	1.18
1998	22.39	9.85	403.31	2.44	946.38	1.04
1999	25.10	10.87	423.84	2.56	991.34	1.10
2000	41.88	15.69	477.99	3.28	1079.96	1.45

Note: GIOV: Gross Industrial Output Value
GIOAV: Gross Industrial Output Added Value
GIOV of Iron&teel industry is calculated at 1990 fixed price, others are calculated at current prices
Date source: China Steel Statistics 2000, 2001; China Statistical Yearbook 2001

IV.A.1.iv Role of sector in overall economy as source of inputs to other sectors

As we know, steel product is a kind of main raw and processed materials and is required in the whole economic system. Industry and construction sectors account for the most steel product demand. But along with the adjustment of economic structure, the steel product demand structure is also adjusted. Proportion of construction sector's demand is higher. China has 1.3 billion people and most of them expect improvements in their quality of life -- for instance, they want a bigger house. So during the foreseeable medium and long term, construction sector's demand of steel product will all through be increasing and so total demand of steel product will keep at high level. Then the supply of energy and other resources will under the pressure of this high demand.

Table 4-6. Main receptive sectors for iron and steel's output

Year	Construction (%)	Industry (%)	Transport, Post and Telecommunication Services (%)	Others(%)
1993	29.68	64.21	1.20	4.91
1994	35.84	61.33	1.86	0.97
1995	33.87	63.65	1.62	0.86
1996	38.22	59.62	1.52	0.64
1997	38.45	59.70	1.32	0.53

Data source: China Steel Statistics 1994-1999

IV.A.1.v Role in exports, international trade

Iron and steel industry is a competitive industry sector internationally. Although China is the largest steel production country, output of China's iron and steel industry can't meet the total domestic demand. At 2000, China's share of the world's steel export market is 3.65% and 6.93% of import market. There are two reasons for this gap between demand and supply. One reason is that rapid development of China's economy brings with it a huge demand for steel product; the other is that China's steel enterprises has lower technology capacity and can't produce many kinds of advanced steel product. Before 2000 China was a net import country for steel product (Note: from 2004, China

has become net export country). But the average unit price of imports is much more than the average unit price. Although China plays an important role in the international steel market, there is still huge potential for China's enterprises to participating in international competition and that potentially means the technology advancement and improvement of energy efficiency.

Table 4-7. Imports and exports of iron and steel industry

	Imports			Export		
Year	Volume (10 thousands tons)	Value (100 million USD)	Average Unit Price (USD per ton)	Volume (1000 tons)	Value (100 million USD)	Average Unit Price (USD per ton)
1990	368.26	20.7600	563.7	208.98	6.1970	296.5
1991	332.59	23.5300	707.5	329.33	9.8560	299.3
1992	617.81	33.4800	541.9	326.70	9.9160	303.5
1993	3026.00	110.7600	366.0	112.00	5.3000	473.2
1994	2282.84	87.4400	383.0	174.35	7.4600	427.9
1995	1397.23	66.7270	477.6	592.82	23.3252	393.5
1996	1598.38	71.0039	444.2	421.53	17.5367	416.0
1997	1322.45	65.1141	492.4	461.89	19.3414	418.7
1998	1241.55	62.8677	506.4	356.60	16.8698	473.1
1999	1486.27	70.0775	471.5	368.44	14.1319	383.6
2000	1596.14	85.3589	534.8	620.60	22.2933	359.2

Data source: China Economic and Trade Yearbook 2001

Table 4-8. Exports of semi-finished and finished steel products

	Exports			Imports		
Year	China (thousand metric tons)	The World total (thousand metric tons)	China's share of the world (%)	China (thousand metric tons)	The World total (thousand metric tons)	China's share of the world (%)
1994	2566	238568	1.08	25813	234220	11.02
1995	10745	246624	4.36	14806	236515	6.26
1996	7131	245416	2.91	16537	228348	7.24
1997	8907	267819	3.33	13619	249289	5.46
1998	5863	269541	2.18	13106	255408	5.13
1999	5875	280796	2.09	16998	265073	6.41
2000	11159	305802	3.65	20710	298696	6.93

Important Note: Some of the data in this table are based on exporters' figures and understate the actual volume of imports.
Data source: Statistical Yearbook 2004.International Iron and Steel Institute.

IV.A.2 Quantitative and qualitative characterization of Iron & Steel sector

The following table shows the advancement of the typical plants of China's iron and steel industry from 1990 to 2000. There kinds of plants include iron-making blast furnace, steel-making oxygen blown converter, steel-making electric furnace continuous casting equipment and open-hearth furnace etc. Obviously there has been much advancement in the industry's plants. For instance average production capacity per blast furnace vary from 103.2 m3 at 1990 to 611.7 m3 at 2000. Continuous casting ratio is 82.5% at 2000 comparing with 22.3% at 1990. Open-hearth furnace as an old kind of steel making technology is almost eliminated, and only 2 sets remain in 2000.

Table 4-9. Advancement of Plants in China's Iron and Steel Industry

Typical Plants in iron and steel industry			1990	1993	1995	2000
Iron-making blast furnace	Number	sets	1130	1502	3228	241
	Production Capacity	m3	116595	141765	275397	147427
	Average Production Capacity per plant	m3	103.2	94.4	85.3	611.7
	Coal injection per ton iron	kg/t	37.9	41.2	42.8	117
Steel- making oxygen blown converter	Number	sets	211	240	297	212
	Production Capacity	tons	4911	5811	7175	10070
	Average Production Capacity per plant	tons	23.3	24.2	24.2	35.8
Steel- making electric furnace	Number	sets	1403	1561	3380	204
	Production Capacity	tons	6220	8297	21280	4982
	Average Production Capacity per plant	tons	4.4	5.3	6.3	24.4
Continuous casting equipment	Continuous casting machine	sets	<100	176	267	281
	Continuous casting ratio	%	22.3	33.9	46.5	82.5
Open-hearth furnace		sets	68	70	90	2

Data source: China steel statistics 2001. Data of 2000 is only for key iron and steel enterprises

Table 4-10. Classification of several typical plants of iron and steel industry

	Class of equipment	CO_2 intensity (tCO_2/t)	Total number	Total production capacity per year*1 (mt)	Share of total (%)	Total annual production *2 (mt)	Annual CO_2 *2 (mt)
Blast furnace For iron-making	Total*3	1.25	321	165.47	100.00	202.62	252.85
	>3000m^3	1.09	5	14.23	8.60	17.43	18.91
	2000-2999m^3	1.17	19	32.53	19.66	39.83	46.56
	1000-1999m^3	1.21	31	27.88	16.85	34.14	41.41
	300-999m^3	1.31	184	79.79	48.22	97.71	128.00
	101-299m^3	1.33	70	10.06	6.08	12.32	16.33
	<100m^3	1.37	12	0.98	0.59	1.20	1.64
oxygen blown converter for steel-making	Total*4	0.07	245	163.68	100.00	187.20	12.72
	>300t	-0.01	3	6.78	4.14	7.75	-0.05*5
	100-299t	-0.03	39	47.27	28.88	54.06	1.60
	50-99t	0.08	60	46.27	28.27	52.92	4.07
	11-49t	0.10	141	62.86	38.40	71.89	7.02
	<10t	0.14	2	0.50	0.31	0.57	0.08
Electric furnace for steel-making	Total*4	0.64	182	34.52	100.00	31.37	19.97
	>100t	0.48	13	10.24	29.67	9.31	4.47
	50-99t	0.67	30	12.39	35.90	11.26	7.52
	11-49t	0.73	91	10.70	31.01	9.73	7.12
	<10t	0.80	48	1.18	3.43	1.08	0.86

Note:
*1 Incomplete statistic data for large and medium key enterprises;
*2 Uncertain data, estimated from product capacity by the same proportion
*3 By volume
*4 By weight
*5 Negative energy consumption means energy recovery realized by advanced steel-making converter

Iron production is the highest energy-intensity process during iron and steel production, and accounts for nearly 40% of China's total CO2 emissions from the industry. Blast furnaces between 300-999 m^3 accounted for 50.62% of China's total CO2 emissions from blast furnace in 2003. But average capacity per plant of China's new blast furnace will above 1000m^3. The CO2 intensity of China's largest blast furnaces (>3000 m^3) is 13.06% lower than average level for all furnaces, but the largest blast furnaces account for only 8.60% of total iron production.

In the past decade, the average production of China's iron plants has greatly increased, rising by 617.11% from 1995 to 2000. A similar trend has occurred in steel-making: 47.9% of oxygen blown converters, 287.3% of electric furnaces.

The following table shows that there is huge gap between advanced and laggard plants in China's iron and steel industry:

Table 4-11.Energy efficiency of several main processes in iron and steel industry (GJ/t)

	Sintering	Coking	Iron-making	Converter furnace steel-making	Electric furnace steel-making	Steel rolling
International level 1994	1.73	3.75	12.83	-0.26	5.82	0.00
China 2002 Average	1.99	4.32	13.31	0.79	6.75	2.97
China 2003 Average	1.93	4.13	14.18	0.75	6.17	2.85
China 2004 Average	1.95	4.17	13.66	0.78	6.15	2.72
2004 advanced domestic industry	1.53	2.58	11.59	-0.11	4.29	1.57
2004 laggard domestic industry	3.18	6.72	17.34	2.20	9.54	8.41

Data source: Wang Weixing. Iron and steel enterprises' process energy consumption and energy saving potential. Metallurgy management.2005.6.(in Chinese)

There are two types of iron and steel enterprise in China: key enterprises under the direct supervision of the former Ministry of Metallurgical Industry (MMI) , and local enterprises under the supervision of provincial governments, together with other small plants and non-state-owned enterprises. Before 1980, China's metal and mineral industry was tightly controlled by the MMI, and state-owned enterprises dominated the whole industry. With the reform policy, other types of ownership have been encouraged, and the non-state sector has expanded gradually. But even now, state-owned and state-holding enterprises still dominates the whole enterprises and new industry policy promulgated at 2005 encouraged the concentration of the industry.

Table 4-12.Structure of enterprise iron and steel industry

Type of Enterprises		State-owned and State-holding Enterprises		Urban Collective-owned Enterprises	
Year	Total	Enterprises number	Share of total output value	Enterprises number	Share of total output value
2003	267	66	78.29	46	3.82
2004	306	51	70.18	36	3.57
2005	385	43	46.49	28	4.73
Share Joint Ownership Enterprises		Share Holding Enterprises		Foreign-Funded (including Hong Kong, Macao and Taiwan) Enterprises	
Enterprises number	Share of total output value	Enterprises number	Share of total output value	Enterprises number	Share of output value
6	0.60	125	35.99	20	5.67
6	1.39	167	48.82	22	7.44
6	0.11	238	62.85	32	13.84

Note: Date of different type enterprises overlaps each other.
Data source: MacroChina industrial database

IV.B Emissions Overview of Sector

IV.B.1 Background and discussion of emissions

The following figure presents a simplified schematic of the production route. As we know iron and steel industry is a major energy consuming sector and source of greenhouse gases and other pollutants. Greenhouse gas emissions in the iron and steel sector are primarily the result of burning fossil fuels during the production of iron and steel.

The whole process can be divided into three parts: iron making, steel making and steel products making. Each part has several processes and has specific energy conservation technology. During the iron making process, sintered or pelletized iron ore is reduced using coke (produced in coke ovens) in combination with injected coal or oil to produce pig iron in a blast furnace. Limestone is added as a fluxing agent. Reduction of the iron ore is the largest energy-consuming process in the production of primary steel. Smelt reduction processes are the latest development in pig iron production and omit coke production by combining the gasification of coal with the melt reduction of iron ore. Processes under development include COREX, CCF, DIOS, AISI, and HISmelt. Currently, only few technology for instance the COREX process (Voest-Alpine, Austria) is commercial.

Currently there are two main routes for the production of steel: production of primary steel using iron ores and scrap and production of secondary steel using scrap only. Oxygen blown converter and electric furnace are two major kinds of plants for current steel making. A wide variety of steel products are produced by the industry, ranging from slabs and ingots to thin sheets, which are used in turn by many other manufacturing industries. (Worrell et al., 1997).

Future energy conservation in China's iron and steel industry has two directions: one is the application of specific energy conservation technology such as coke dry quenching, coal power injection etc. The other is the adjustment of whole production process structure, for instance introducing smelt reduction process for iron making and increasing the proportion of electric furnace steel.

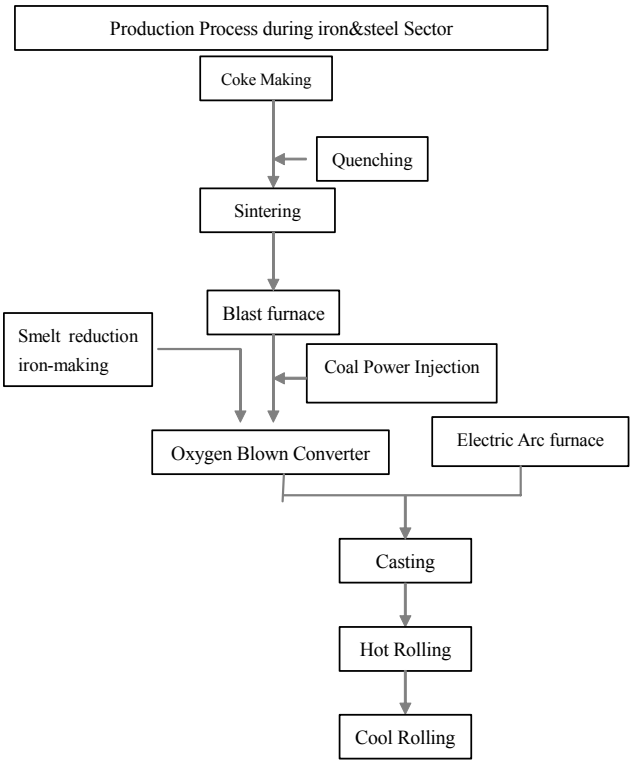

Figure 4- 1.Major processes in iron and steel industry

IV.B.2 Historical annual fuel consumption and GHG emissions trends over time

The following tables separately show total historical annual fuel consumption and CO2 emission if iron and steel industry and more detailed information by fuel type. At the year of 2000, total annual fuel consumption of China's iron and steel industry is 3888.24 PJ, rising by 34.39% from 1990. The similar trend occurs in annual CO2 emission, rising by 29.54% from 1990 to 2000.

In the total fuel consumption, coal is the most important fuel. In 2000, coal accounted for about 70% of total fuel consumption, including 46.06% coking coal and 24.95% power coal. Most of the remaining part is electricity. As all know, electricity production in China mainly depends on coal. So coal is the most important fuel type in China's iron and steel industry. This fuel structure also increases the emission per unit production.

Table 4-13. Total annual fuel consumption and CO2 emission of iron and steel industry[28]

Year	Total Annual Fuel Consumption, all Fuels (PJ)	Annual GHG Emissions ($MMTCO_2e$)
1990	2893.29	271.19
1991	3037.19	285.05
1992.	3156.18	296.77
1993	3395.04	319.85
.1994	3547.73	334.49
1995	3631.55	342.68
1996	3800.95	359.78
1997	3713.91	352.58
1998.	3760.22	357.11
1999	3771.94	359.27
2000	3888.24	351.50

Data source: Fuel consumption data is from China steel statistic 2001 and GHG emission data is estimated by author.

[28] Note: In this table, fuel consumption data is comprehensive fuel consumption, which includes energy used in iron and steel production but also other energy consumption in the industry, such as services, transportation in the factories, etc. In macro statistical data, "fuel consumption" sometimes means comprehensive fuel consumption, but in the statistical data from steel industry, "comprehensive" is distinguished from "comparable" energy consumption (fuel used for direct iron and steel production only). In this analysis we take into account all production process fuel use and corresponding assistant energy consumption, and in a sense that is comprehensive fuel consumption. According to relevant literatures (Zhou Dadi et al.,2003), the share of the energy not directly used in production in the total energy consumption is about 20%. So in the following context, if not specifically noted, energy consumption in the scenario analysis results of steel industry is comprehensive, which is also called integrated energy consumption. This energy consumption will be higher than that obtained in results calculated using only comparable production process energy (approximately 80% of the comprehensive consumption), but the extra portion of the energy consumption is also a necessary part of steel production in China's iron and steel industry.

Table 4-14. Historical annual fuel consumption and GHG emissions by fuel type

Year	Fuel Type	Annual Fuel Consumption (PJ)	Share of Total Annual Fuel Consumption (%)	Annual GHG Emissions ($MMTCO_2e$)	Share of Total Annual GHG Emissions (%)
1990	Coking coal	1459.08	50.43	135.60	50.00
	Power coal	531.21	18.36	48.48	17.88
	Electricity	686.29	23.72	72.89	26.88
	Fuel oil	187.77	6.49	12.79	4.72
	Natural gas	28.93	1.00	1.43	0.53
1991	Coking coal	1561.11	51.40	145.08	50.90
	Power coal	553.68	18.23	50.54	17.73
	Electricity	709.49	23.36	75.36	26.44
	Fuel oil	184.66	6.08	12.57	4.41
	Natural gas	30.37	1.00	1.50	0.53
1992	Coking coal	1593.24	50.48	148.07	49.90
	Power coal	564.96	17.90	51.56	17.37
	Electricity	778.31	24.66	82.67	27.86
	Fuel oil	193.47	6.13	13.17	4.44
	Natural gas	26.20	0.83	1.29	0.43
1993	Coking coal	1681.22	49.52	156.25	48.85
	Power coal	609.41	17.95	55.62	17.39
	Electricity	873.88	25.74	92.82	29.02
	Fuel oil	202.00	5.95	13.75	4.30
	Natural gas	28.52	0.84	1.41	0.44
1994	Coking coal	1776.70	50.08	165.12	49.36
	Power coal	648.53	18.28	59.19	17.70
	Electricity	898.64	25.33	95.45	28.54
	Fuel oil	196.19	5.53	13.36	3.99
	Natural gas	27.67	0.78	1.37	0.41
1995	Coking coal	1782.73	49.09	165.68	48.35
	Power coal	687.82	18.94	62.78	18.32
	Electricity	933.31	25.70	99.13	28.93
	Fuel oil	205.55	5.66	14.00	4.09
	Natural gas	22.15	0.61	1.09	0.32
1996	Coking coal	1941.91	51.09	180.47	50.16
	Power coal	708.12	18.63	64.63	17.96
	Electricity	961.64	25.30	102.14	28.39
	Fuel oil	170.28	4.48	11.59	3.22
	Natural gas	19.00	0.50	0.94	0.26
1997	Coking coal	1903.01	51.24	176.86	50.16
	Power coal	673.33	18.13	61.46	17.43
	Electricity	973.79	26.22	103.43	29.33
	Fuel oil	147.07	3.96	10.01	2.84
	Natural gas	16.71	0.45	0.83	0.24
1998	Coking coal	1869.96	49.73	173.79	48.66
	Power coal	767.46	20.41	70.05	19.62
	Electricity	973.90	25.90	103.44	28.97
	Fuel oil	132.74	3.53	9.04	2.53
	Natural gas	16.17	0.43	0.80	0.22
1999	Coking coal	1808.65	47.95	168.09	46.79
	Power coal	827.94	21.95	75.57	21.03
	Electricity	1013.14	26.86	107.61	29.95
	Fuel oil	105.24	2.79	7.17	2.00
	Natural gas	16.97	0.45	0.84	0.23
2000	Coking coal	1790.92	46.06	158.21	45.01
	Power coal	970.12	24.95	84.18	23.95
	Electricity	1009.39	25.96	101.90	28.99
	Fuel oil	94.87	2.44	6.15	1.75
	Natural gas	22.94	0.59	1.09	0.31

Data source: Fuel consumption data is from China steel statistic 2001 and GHG emission data is estimated by author based on emission factor of different fuel from IEA of China[29]

[29] HU Xiulian, JIANG Kejun, et al. Evaluation of Technology and Countermeasure for Greenhouse Gas Mitigation in China[M].Beijing: China Environmental Science Press, 2001. (in Chinese)

IV.B.3 Relative contribution of each sector in 2000

China's iron and steel industry share 9.95% of total energy consumption in 2000 and share of China's total CO2 emission is 9.88%, about 322.58 million tones.(Date source: China Statistical Yearbook 2002).Being the largest steel production country, China is also the largest emitting country in iron and steel industry, accounting for 65.22% to top 10 emitting developing countries and 30% to total world sector emission in 2000.(Date source: CCAP)

IV.C Background Assumptions for Sector Analysis

In the sector analysis for iron and steel industry, a scenario analysis method based on LEAP model has been used. In the model, abundant bottom-up technologies are included, and many kinds of policies which affect the adoption of specific technology are assumed based on current exiting industry policy.

IV.C.1 Baseline with policies adopted before 2000

IV.C.1.i Policies under Consideration

The government of China has consistently focused on energy conservation in the energy intensive industries, and iron and steel industry is one of the key industries.

By the year 2000,the Chinese government had formulated energy conservation plans from the sixth to the tenth five-year plan periods and the energy conservation plan for each year, identified concrete development goals ,key projects and principal policies for energy conservation.

Starting from 1980s, the Chinese government established and applied standards, labeling and certification of energy efficiency and effectively boosted the work on energy conservation and raising energy efficiency. Starting from 1980, government established enterprise energy balance and energy consumption standards systems in iron and steel sector. Since then, it has alloted concrete energy conservation tasks and assessed enterprises through energy conservation indexes such as integrated energy consumption per ton steel, total annual energy conservation, etc.

Since 1980s, the relevant departments successively promulgated and implemented a series of policies and regulations to direct and standardize sector development and energy conservation of iron and steel sector. In the industry technology policy some backward technologies and equipments are identified and needed to be eliminated such as mold casting, open healthy furnace, small blast furnace, small electric furnace etc. On the other way, these technology policies also boost the application of some new energy conservation technologies and equipments such as continuous casting, coke dry quenching, coal power injection, reuse of blast furnace gas, etc.

The Chinese government has drafted and implemented a series of incentive policies in terms of finance, credit and taxation toward energy conservation projects, including interest payment rebates, differential interest rates, revoking of import taxes, reductions of income tax of enterprises and accelerate depreciation, etc. These measures have been applied to energy conservation technical upgrade projects and purchase of energy conservation equipment. Furthermore, the relevant government promulgated and implemented some rules and standards about equipment design and production process energy conservation.

IV.C.1.ii Assumptions about the Effectiveness of Policies

In scenario analysis, the above policies are the basis of technology selection. And in our model, we convert this information into different proportions of selected specific technology.

From the above policies we can see major energy conservation technologies have been identified and already have high priority. But the initial goal of these policies is to encourage steel enterprises to

save energy consumption and decrease production cost. So in the assumptions of baseline scenario, these policies' effectiveness is limited.

IV.C.2 Baseline with policies adopted between 2000 and 2005

IV.C.2.i Policies under Consideration

Starting from 2000, based on existing polices, measures and standards, some new polices with more ambitious objective are promulgated and implemented.

In 2004, the National Development and Reform Commission promulgated "China medium and long term energy conservation plan". Iron and steel sector is listed in the key area of energy conservation. In this plan energy consumption indicators of per unit main product including steel are enacted from year 2000 to 2020. The basic principle is "at 2010,in the mass reach or near the advanced world level of the early year of the 1990s, thereinto large and medium sized corporation reach the advanced world level of the early years of this century; reach or near the advanced world level in the 2020."

In 2005, NDRC promulgated "China iron and steel industry development policy" This new policy indicates a further restructuring of the steel industry in the future. The policy is a guideline for the long-term development of China's iron and steel industry aiming to increase the concentration of steel production by the large State-owned steel makers such as Baosteel and to boost the industrial upgrading of the steel sector through new technologies and management and production efficiency.

The policy covers very detailed aspects of the steel sector, from corporate management to government macro-controls. The new policy sets new requirements for steel makers in China in a number of different areas including the scale of production and efficiency, technical expertise, energy consumption and environmental protection performance. So a large number of medium and small-sized steel companies are facing being closed down or be merged by larger steel enterprises. Minimally, these medium and small-sized steel companies need to upgrade their old steel production equipments.

According to the policy, a raft of market measures such as tax rebates will also be introduced to promote the high value-added steel production.

IV.C.2.ii Assumptions about their effectiveness

Comparing with the policies before 2000, policies adopted between 2000 and 2005 had some characteristics. These new policies emphasize on sustainable development and the restructure of the industry. Energy conservation is a kind of indicator for the increasing of the industry's competition capacity not only a way for production cost decreasing.

These new policies have some medium and long-term development objectives and these objectives including the future industry structure and share of specific technology are the basis of model's future scenarios definition.

But these policies still haven't dealt with climate change mitigation options, because there have been no clear climate change policies in China. The objective of these new polices is ambitious, but there is a large emission reduction potential in China's iron and steel industry, and mitigation is the focus of our analysis.

IV.C.2.iii Assumptions about the Clean Development Mechanism in the sector

There is huge CDM project potential in China's iron and steel industry. But because of the high transaction cost and comparative small capital size of CDM projects, there is some barriers existing in CDM projects development in iron and steel industry. And currently in China, projects in renewable

energy exploitation and landfills gas recovery and utilization have higher priority. So, in this project, CDM will not play an important role in iron and steel sector.

IV.C.3 Sources for assumptions

In the scenarios definition, our main task is to confirm the technologies' development trend, and the proportion of specific technology. The above polices and their measures and objectives are the main sources for our assumptions. Then we used other similar research for useful related information. These research reports include: Research Report of Structure Adjustment Strategy and Related Policy for China High Energy Intensity Industries (China Information Center for Resources Conservation and Comprehensive Utilization), China Sustainable Energy Scenarios in 2020 (ZHOU Dadi, et al.) and Evaluation of Technology and Countermeasure for Greenhouse Gas Mitigation in China(HU Xiulian, JIANG Kejun, et al.)

IV.C.4 Description of analytical approach and methodology

In the LEAP model, data structure of iron and steel industry is layered based on the industry's technology characteristic. The first layer is divided by different processes. Traditional process includes coke making, sintering, blast furnace iron making, oxygen blown converter steel making, casting, hot rolling and cool rolling. The final production is steel product. Coke dry quenching and coal power injection in the blast furnace are separated. Then in the whole process, electric furnace and smelt reduction iron making technology are included. The second layer of data structure is the classification of facilities in each process according to their scale and level of advancement. In scenario definition, the proportion of different facilities should be adjusted. On the third layer, for each kind of facility, model links unit production energy consumption factor, CO2 emission factor and cost factor and gather all energy consumption from bottom to up.

In the analysis of iron and steel industry, total emission includes industrial process emission from CaCO3 in the production of iron making.

IV.D Baseline (Business as usual) Forecasts for sector

IV.D.1 Production/output forecast

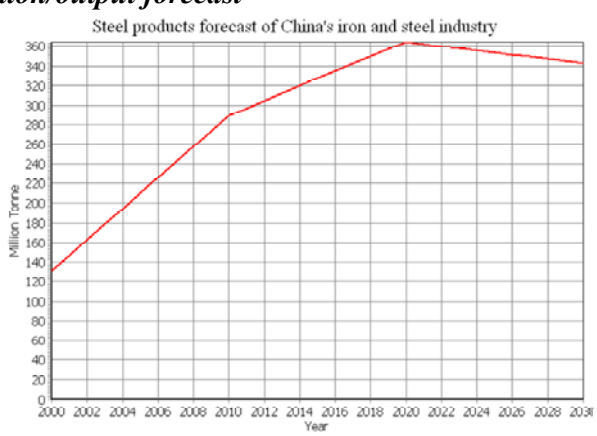

Figure 4-2.Output forecast of steel product in China's iron and steel industry

The industry's output forecast is the first stage of whole analysis process. But it is difficult to forecast the output of China's iron and steel industry into medium and long term. The following figure shows the forecast results. Before 2010, due to the Beijing Olympic Games and other large construction projects, domestic demand of steel product will increase rapidly, then after 2010 the increase will be slow and reach the peak at 2020. From then on production will keep at steady level and decrease

slowly. China's domestic demand is mostly met by domestic production, so the production trend is similar to the demand trend. [30]

According to this assumption, total steel products of China during 2000 and 2030 will be 9.147 billion tons. As a reference we can see the total accumulative steel assumption amount. During 1901 and 2004, accumulative steel assumption amount of USA is 8.2 billion tons, Former Soviet Union is 6.0 billion tons, Japan is 3.8 billion tons and China is 3.0 billion tons (Luo, 2005). So although there exits many uncertainties in steel production output forecast, we can judge that the rough trend is reasonable.

IV.D.2 Energy and fossil fuel consumption forecast

In our analysis, one important assumption is all scenarios have the same production forecast, and we don't divide the baseline scenarios into A2 and B2 scenarios. Two baseline scenarios have similar trend for energy consumption and CO2 emission. But due to some new industry policies, energy consumption and GHG emission of baseline between 2000 and 2005 will lower than baseline pre 2000. The following figures show the initial forecast results.

Before 2010, increase of production is the main driving force for energy consumption and all fuels consumption keep increasing rapidly. Then, technology advancement will play more important role in total energy consumption especially along with the slow decreasing of production.

From comparison of energy consumption of different processes, energy consumption in blast furnace iron making account for the largest proportion especially in the near future. In the longer term, along with the industry restructuring (more electric furnace steel and more smelt reduction iron) and the advancement of blast furnaces, this proportion will be lower.

Because of the adoption of more advanced facilities which have higher priority in those new policies between 2000 and 2005, the energy consumption of the baseline (2000-2005) will be lower than baseline pre 2000 at each year. And the industry's restructure will also more rapid.

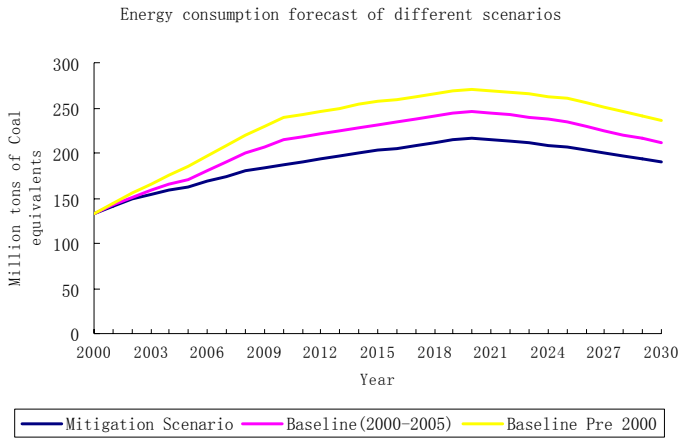

Figure 4-3.Energy consumption forecast of different scenarios

[30] It is difficult to forecast the output of China's iron and steel industry into the medium and long term. In the forecast of the steel production output, in order to simply the analysis process and acquire the core trend one important assumption is that output will be driven by domestic demand and import and export are not included. At present and in the future China's huge steel products demand will mainly rely on domestic production, and import will have only a small impact. In the following analysis, one important assumption is that all scenarios have the same production forecast. Such an assumption can ignore the uncertainties from production forecast and help the researcher focus on the analysis of the differences among scenarios, which is mainly due to industrial restructuring and technological advancing. So the slight absolute decline in production post-2020 is due to a drop in domestic demand leads to a steady and decline gradually trend post 2020, because 2020 is an important landmark year for China's development aiming to reach the level of moderately developed countries.

The figure with cumulative energy conservation between two baseline scenarios shows this huge potential. From 2000 to 2030, total energy conservation between these two baseline scenarios will be about 19 PJ; even not taking account of mitigation measures for climate change, the commitment of current sustainable development industry policies will thus bring a huge energy conservation and corresponding GHG emission reduction. For China's iron and steel industry, there is heavy historic burden and the commitment of current policy faces many barriers. This is a good starting point for the restructure of the whole industry, and is also a good basis for carrying out mitigation measures dealing with climate change.

The following figures about annual GHG emission forecast show the same trend.

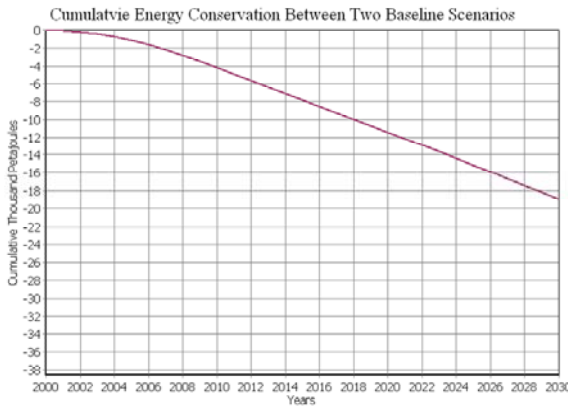

Figure 4-4. Accumulative energy conservation between two baseline scenarios

IV.D.3 Annual GHG forecast

IV.D.3.i <u>Total GHG emissions</u>

CO2 emissions in baseline pre 2000 increase from 351.50 million tonnes in 2000 to 632.78 million tonnes, at 2010. Then the growth rate will slow and reach the peak of annual emission at 2020, 717.46 million tonnes. Then annual emission keeps decreasing, and drops to 626.59 million tonnes at 2030.

Similar trend occurs for baseline with policies between 2000 and 2005. At 2010, emissions are 567.18 million tonnes, 65.6 million tonnes lower than baseline pre 2000. At 2020 and 2030, the emissions are respectively 653.92 and 559.13 million tonnes, and differences between two baselines are respectively 63.54 and 67.46 million tonnes.

The cumulative CO2 emission reduction between two baselines from 2000 to 2030 will be 1691.33 million tonnes.

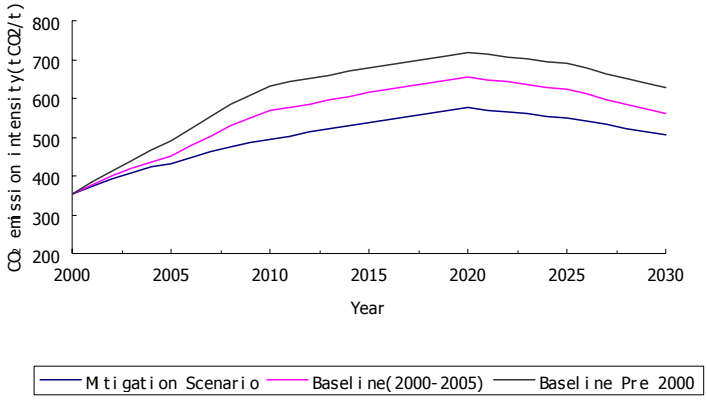

Figure 4-5.CO_2 emission forecast of different scenarios

Table 4-15 compares CO2 emission of different scenarios.CO2 emission of 2000 is assumed to be 1.00, then at 2010, emissions of three scenarios are respectively 1.80 times,1.61 times and 1.41 times to the emission of 2000. At 2020, the peak of annual emission, emissions are, respectively 2.04 times ,1.86 times and 1.64 times to the emission of 2000. In the meantime, steel product of 2020 is 2.78 times to 2000. This is mainly due to the reduction of emissions intensity through technological progress leads to.

Table 4-15 Compare of CO_2 emission of different scenarios (CO_2 emission of 2000 is 1.00)

Year	2000	2010	2020	2030
Baseline（Pre 2000)	1.00	1.80	2.04	1.78
Baseline(2000-2005)	1.00	1.61	1.86	1.59
Mitigation Scenario	1.00	1.41	1.64	1.44

IV.D.4 Energy intensity and CO_2 intensity forecast (per unit of output)

Total energy consumption and CO2 emission will be affected by industry output and technology advancement and at the early years the output increasing is the main driving force. So energy intensity and CO2 intensity are more appropriate in the description of technology advancement.
The following two figures show the change trend of energy intensity and CO2 emission intensity of three different scenarios.

For each baseline, energy intensity and CO2 intensity keep descending. Before 2010, the declining of intensity indicators is faster then the trend curve is more smooth. This trend accords with the judgment of many industry researchers, because currently relatively backward general technology level of China's iron and steel industry means greater scope for progress. Then the technology advancement will be difficult because the cost will rise sharply and the benefit will not always be obvious. In addition the products structure will also change and the industry will produce more advanced steel products. That means deeper processing for products and more energy consumption. For the industry this change is encouraging because the industry's competitiveness capacity will be upgraded, but on the other hand the energy consumption and emission intensity will be higher.

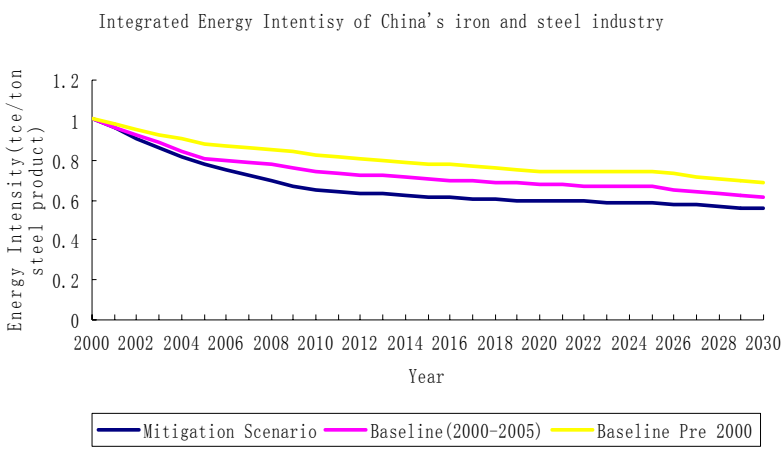

Figure 4-6.Integrated energy intensity of China's iron and steel industry

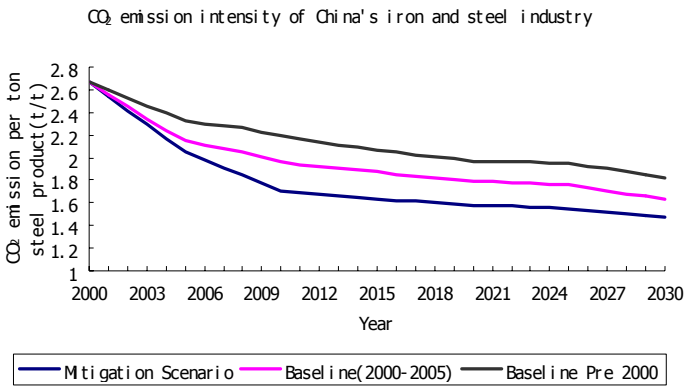

Figure 4-7.CO_2 emission intensity of China's iron and steel industry

The following table shows this trend. Energy intensity of baseline pre 2000 decreases from 29.6 GJ/metric tonne in 2000 to 20.2 GJ/metric tonne in 2030, about 68% of initial level. For baseline (2000-2005), energy intensity level at 2030 is only 60.89% of initial level. From 2000 to 2030, CO2 intensity of baseline pre 2000 declines by 31.7%. For baseline between 2000 and 2005, declining by 39.07%.

Greater degree of decline will occur in the mitigation scenario because of stronger industry restructuring and technological progress. CO2 emission intensity in 2030 will decline by 46% from 2000.

Table 4-16. Energy and CO_2 intensity of two baselines in iron and steel industry

	Baseline (Pre 2000)		Baseline (2000-2005)		Mitigation Scenario	
Year	Energy Intensity (GJ/metric ton)	CO_2 Intensity (tCO_2/t)	Energy Intensity (GJ/metric ton)	CO_2 Intensity (tCO_2/t)	Energy Intensity (GJ/metric ton)	CO_2 Intensity (tCO_2/t)
2000	29.59	2.675	29.59	2.675	29.59	2.675
2005	25.75	2.325	23.75	2.145	22.71	2.052
2010	24.26	2.19	21.74	1.963	18.94	1.712
2015	22.94	2.07	20.72	1.872	18.10	1.638
2020	21.83	1.971	19.86	1.796	17.45	1.581
2025	21.63	1.953	19.49	1.763	17.15	1.554
2030	20.23	1.827	18.02	1.63	16.30	1.447

IV.E Main results of baseline scenarios

For mitigation scenarios, we carry out a deeper analysis with specific mitigation options. The following two tables concluded main results of above two baselines including total production, total fuel consumption and fuel consumption by fuel type, total GHG emission, energy intensity and emission intensity.

Table 4-17. Main results about energy consumption and CO_2 emission for baseline pre 2000

Year	Total Production (million metric tons)	Total Fuel Consumption (PJ)[31]						Total GHG Emissions ($MMTCO_2e$)	Energy Intensity (GJ / metric ton)	Emissions Intensity (MT CO_2e / metric ton output)
		coking coal	power coal	electricity	fuel oil	natural gas	All Fuels			
2000	131.42	1790.92	970.12	1009.39	94.87	22.94	3888.24	351.50	29.59	2.675
2005	210.21	2361.60	1354.07	1551.16	108.84	36.26	5411.92	488.71	25.75	2.325
2010	289.01	2899.15	1712.51	2219.18	124.37	57.50	7012.71	632.78	24.26	2.189
2015	328.00	2946.64	1738.65	2628.57	138.04	71.47	7523.36	678.96	22.94	2.070
2020	364.00	2949.04	1761.98	3065.79	110.37	60.40	7947.57	717.46	21.83	1.971
2025	353.50	2687.81	1645.38	3079.74	181.66	51.23	7645.82	690.32	21.63	1.953
2030	343.00	2311.33	1480.29	2944.62	143.33	60.38	6939.96	626.59	20.23	1.827

Table 4-18. Main results about energy consumption and CO_2 emission for baseline (2000-2005)

Year	Total Production (million metric tons)	Total Fuel Consumption (PJ)[32]						Total GHG Emissions ($MMTCO_2e$)	Energy Intensity (GJ / metric ton)	Emissions Intensity (MT CO_2e / metric ton output)
		coking coal	power coal	electricity	fuel oil	natural gas	All Fuels			
2000	131.42	1790.92	970.12	1009.39	94.87	22.94	3888.24	351.50	29.59	2.675
2005	210.21	2175.92	1249.18	1431.01	103.16	33.45	4992.72	450.91	23.75	2.145
2010	289.01	2590.54	1534.09	1987.97	117.97	51.51	6282.08	567.18	21.74	1.962
2015	328.00	2651.21	1570.27	2374.02	134.74	64.55	6794.80	613.92	20.72	1.872
2020	364.00	2669.26	1602.91	2789.02	113.94	54.95	7230.07	653.92	19.86	1.796
2025	353.50	2406.94	1482.77	2775.39	178.96	46.17	6890.22	623.17	19.49	1.763
2030	343.00	2043.42	1318.68	2623.12	143.23	53.78	6182.25	559.13	18.02	1.630

[31] All of the energy or emissions numbers in the baselines, mitigation measures, or mitigation scenarios include electricity purchased from the local power grid. Share of electricity in total energy consumption in China's iron and steel industry is about 25% in 2000, and this proportion will rise according to the restructure of production process. Emissions factor assumed for electricity is from other similar research (Hu and Jiang, 2001) and the number is 0.1262 tCO_2/GJ

[32] All of the energy or emissions numbers in the baselines, mitigation measures, or mitigation scenarios include electricity purchased from the local power grid. Share of electricity in total energy consumption in China's iron and steel industry is about 25% in 2000, and this proportion will rise according to the restructure of production process. Emissions factor assumed for electricity is from other similar research (Hu and Jiang, 2001) and the number is 0.1262 tCO_2/GJ

Table 4-19. Main results about energy consumption and CO_2 emission for mitigation scenario

Year	Total Production (million metric tons)	Total Fuel Consumption (PJ)						Total GHG Emissions ($MMTCO_2e$)	Energy Intensity (GJ/metric ton)	Emissions Intensity (metric tons CO_2e/metric ton output)
		coking coal	power coal	electricity	fuel oil	natural gas	All Fuels			
2000	131.42	1790.92	970.12	1009.39	94.87	22.94	3888.24	351.5	29.59	2.675
2005	210.21	2059.70	1194.49	1381.83	106.13	31.99	4774.14	431.24	22.71	2.051
2010	289.01	2212.24	1336.85	1766.65	113.77	44.89	5474.39	494.77	18.94	1.712
2015	328.00	2247.21	1372.02	2136.15	125.16	56.40	5936.94	537.15	18.10	1.638
2020	364.00	2252.53	1408.53	2548.73	95.26	48.28	6353.34	575.62	17.45	1.581
2025	353.50	1946.75	1304.70	2711.73	66.83	32.74	6062.75	549.22	17.15	1.554
2030	343.00	1689.30	1192.74	2556.13	105.02	48.65	5591.84	506.49	16.30	1.477

IV.F GHG Mitigation Options and Costs

Mitigation options and costs are the basis of mitigation scenarios analysis. In this section, we will give an overview of each appropriate mitigation option, characteristic of each mitigation option, their costs, their emission reduction potential etc.

IV.F.1 Selection criteria for consideration of mitigation options

When considering the selection of mitigation options in iron and steel industry, several selection criteria need to be followed. They are cost, potential carbon emission, technology feasibility, technology availability, technology application complexity and the linking with current technology level.

Among these criteria, cost and marginal abatement cost of each measure and technology have high priority in the selection of mitigation options.

But cost is not the only factor. In China's iron and steel industry, technology innovation is not without foundation. In some way, different technology measures with different cost will be integrated into one consistent technology innovation plan. So in scenario analysis it will not happen that the applied proportion of A technology is 100% and B technology is 0% if marginal abatement cost of A technology is lower than B.

IV.F.2 Overview of each mitigation option evaluated

In the mitigation scenarios analysis for iron and steel industry, four kinds of measures are considered: energy management, structure adjustment, application of larger scale and more advanced plants and specific energy conservation technology.

Energy management: establishment of energy management center. EMC is a kind of managing mitigation option, but it also covers technologies, gathering information from first time users of technology, and optimizing utilization and allocation of different fuels – one example was the EMC set up in Shanghai. One estimate indicates that establishment of EMC across China will reduce by 5% the energy use for China's iron and steel industry (Huang, 2006; CICRCCU, 2002).

Structure adjustment: share of electric furnace steel, share of smelt reduction iron, proportion of casting, proportion of cool rolling etc.

Application of larger scale and more advanced plants: larger-scale blast furnace (including TRT technology and blast furnace gas recovery technology), larger-scale oxygen blown converter (also including oxygen blown converter gas recovery technology), higher power electric furnace, larger-scale sintering machine etc.

Specific energy conservation technology: dry coke quenching, coal power injection, construction and reconstruction of continuous casting machine.[33]

Energy consumption factor, emission factor and cost information of each measure are based on relevant literature and few of them is from experts interview in this field[34]. Cost information includes fixed cost and variable cost. Fixed cost mainly refers to the cost of facilities (including purchase, installation and maintenance etc. and amortizing to per ton products during their lifetime) .Variable

[33] In China's steel industry, cogeneration such as the recycle of waste gas and heat has been seen as an important mitigation option. In our model, in order to cover all energy consumption and CO_2 emission, recycle of waste gas and heat are included in larger scale and more advanced plants for instance blast furnace and converter. That means more advanced plants are equipped with relevant waste heat recovery equipment, and the energy consumption factor of these plants will be also linked with negative energy consumption factors because they recovery heat.

[34] Hu and Jiang, 2001.Zhang , 2006; Huang, 2006

cost mainly refers to energy cost and sometimes raw material cost. Energy cost information is based on the prices of 2000[35].

All parameters are based on the information of 2000. In order to describe future change, we add a whole technology development ratio that means energy consumption factor of each measure will be lower along with time.[36] Some measure such as energy management only have potential in the near future, and some technology such as smelt reduction iron making process will have potential in medium and long term. At present this kind of technology is too expensive to be applied.

This analysis approach can only consider exiting technologies and cannot cover possible technology innovation in the future.

IV.F.3 Marginal abatement cost of each mitigation option

The following table lists all potential mitigation options in our model and the corresponding marginal abatement cost information. Measure for management capacity increasing such as establishment of energy management center in steel enterprises has higher priority in the early years during scenarios analysis period. But along with the industry development, although the management measure cost will be lower the emission reduction potential will also be slow. So the cost effectiveness will decline. A similar thing occurs to BF coal power injection technology and continuous casting equipment etc.

Table 4-20.Marginal abatement cost of mitigations options

Mitigation Option	Cost Effectiveness of 2010 ($/metric ton CO_2e)	Cost Effectiveness of 2010 ($/metric ton CO_2e)	Cost Effectiveness of 2020 ($/metric ton CO_2e)
Establish energy management center and increase management capacity	-66.20	-14.89	-3.57
Increase coal power injection level	-60.08	-1.24	
More advanced continuous casting machine	-24.30	-22.64	
More advanced blast furnace with TRT	3.28	3.59	5.36
Apply dry coke quenching	4.95	11.35	30.36
More advanced coke oven	6.23	3.79	3.03
Adjust ratio of iron/steel	30.02	15.99	8.19
More advanced sinter machine	43.27	38.16	31.63
More advanced direct steel rolling machine	57.99	51.48	34.88
More advanced oxygen blown converter for steel-making	87.64	75.80	60.96
Apply smelt reduction iron-making process	146.68	82.85	52.67
More advanced electric furnace for steel-making	211.14	165.78	131.39

[35] We add fuel price index in the analysis. They are showed the next footnote. In China, the energy market is not an entirely competitive market. So the international energy market (especially oil market) will not determine the domestic energy market. Moreover, in steel industry, coal and electricity from coal plants are the main fuel types. So the price index will not match the general international oil price assumption.

[36] Some general assumptions in scenario definition.

		2010	2020	2030
Whole energy efficiency improvement ratio annual	Scenario 1	1‰	1.5‰	2‰
	Scenario 2	2‰	2.5‰	3‰
	Scenario 3	3‰	3.5‰	4‰
Fuel price index	Coal	1.1	1.2	1.3
	Electricity	1.2	1.3	1.4
	Natural gas	3	3.5	3.7
	Fuel oil	1.2	1.3	1.5
Exchange rate	1 US. dollar =8.2784 Yuan RMB			
Discount rate	10%			

IV.F.4 Share of different mitigation options in total emission reduction

We have mentioned that emission gap between two baseline scenarios is for the emission reduction potentials through China's current sustainable development policies and measures. The emission gap in the following context is the difference between mitigation scenario and baseline scenario (2000-2005) and it presents further mitigating effort based on current polices. That means more capital and more technology demand. This kind of potential will accord with the following listed mitigation options.

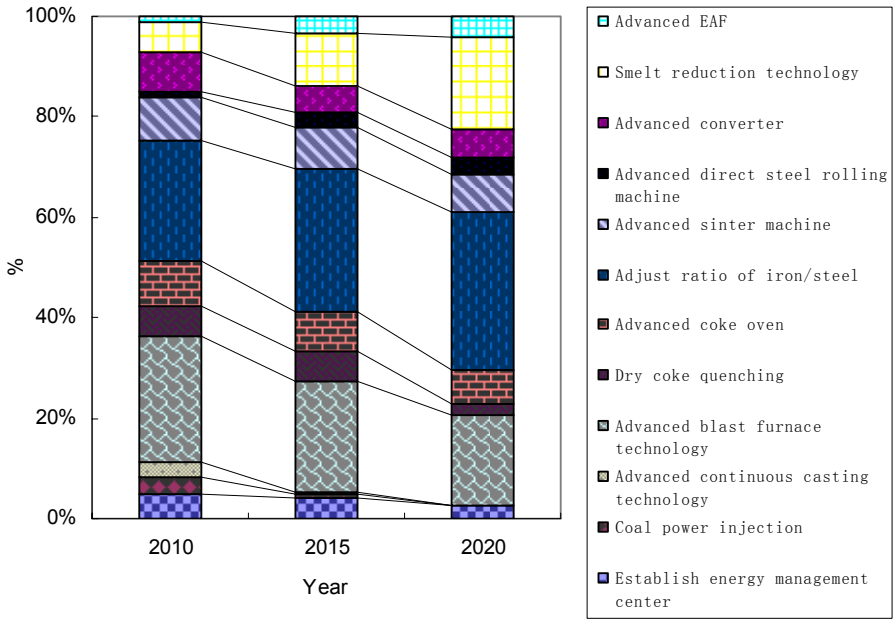

Figure 4-8.Share of different mitigation options in total emission reduction

From Figure 4-8, different mitigation options have different emission reduction potential and the share of each kind of option will change. Share of some negative-cost mitigation options which include energy management center, BF coal power injection and continuous casting will decrease from 2010 to 2020. More specifically, coal power injection and continuous casting technology will not be the candidate mitigation options. In China's steel industry, continuous casting rate is much high and future development scope is small. Similarly, China's steel industry has already made great progress in the application of coal power injection technology. More coal power injection level will be difficult because this technology needs higher standards in the design of blast furnace.

Share of some specific energy conservation technology will also decrease for example advanced blast furnace technology, dry coke quenching etc. On the other hand, with the restructure of production process, share of some measures such as adjustment of the ratio of iron and steel, smelt reduction iron making technology will rise

Nevertheless, abundant coal resources and historical technological characteristics decide the structure of production process that traditional process based on blast furnace and converter will dominate in China's steel industry. So advanced blast furnace technology will always on the technology selection list. In the meantime, adjust ratio of iron and steel and some new technologies such as smelt reduction will also be emphasized.

IV.F.5 Marginal abatement cost curves and tables

Combining marginal abatement cost information and emission reduction potential of each mitigation option and classified these measures according abatement cost, we can get marginal abatement cost curve of each year. The following is the marginal abatement cost curves at 2010, 2015 and 2020.

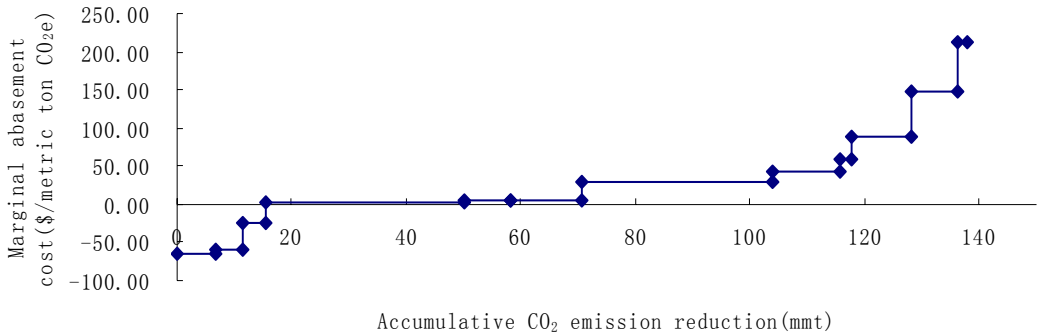

Figure 4-9. Marginal abatement cost curve of iron and steel industry at 2010

Table 4-21 Abatement potential and cost analysis of mitigation measures of 2010

Mitigation Options	Cost Effectiveness ($/ton CO_2)	Total Emission Reduction ($MTTCO_2$)	Total Cost (million $)	Cumulative Emission Reduction ($MTTCO_2$)	Cumulative Net Cost (million $)	Avg. Cumulative Cost Effectiveness ($/ton CO_2)
Establish energy management center	-66.20	6.75	-446.85	6.75	-446.85	-66.20
a-Direct fuel		4.57				
b-Electricity		2.18				
Coal power injection	-60.08	4.67	-280.57	11.42	-727.42	-63.70
a-Direct fuel		3.16				
b-Electricity		1.51				
Advanced continuous casting technology	-24.30	4.14	-100.60	15.56	-828.03	-53.22
a-Direct fuel		2.80				
b-Electricity		1.34				
Advanced blast furnace technology	3.28	34.51	113.19	50.06	-714.83	-14.28
a-Direct fuel		23.36				
b-Electricity		11.15				
Dry coke quenching	4.95	8.28	40.99	58.35	-673.85	-11.55
a-Direct fuel		5.61				
b-Electricity		2.67				
Advanced coke oven	6.23	12.42	77.38	70.77	-596.47	-8.43
a-Direct fuel		8.41				
b-Electricity		4.01				
Adjust ratio of iron/steel	30.02	33.13	994.56	103.90	398.09	3.83
a-Direct fuel		22.43				
b-Electricity		10.70				
Advanced sinter machine	43.27	11.73	507.56	115.63	905.65	7.83
a-Direct fuel		7.94				
b-Electricity		3.79				
Advanced direct steel rolling machine	57.99	1.92	111.34	117.55	1016.99	8.65
a-Direct fuel		1.30				
b-Electricity		0.62				
Advanced converter	87.64	10.72	939.50	128.27	1956.49	15.25
a-Direct fuel		7.26				
b-Electricity		3.46				
Smelt reduction technology	146.68	8.01	1174.91	136.28	3131.40	22.98
a-Direct fuel		5.42				
b-Electricity		2.59				
Advanced EAF	211.14	1.75	369.50	138.03	3500.89	25.36
a-Direct fuel		1.18				
b-Electricity		0.57				

Note: CO2 split as 67.7% fuel and 32.3% electricity from scenario analysis

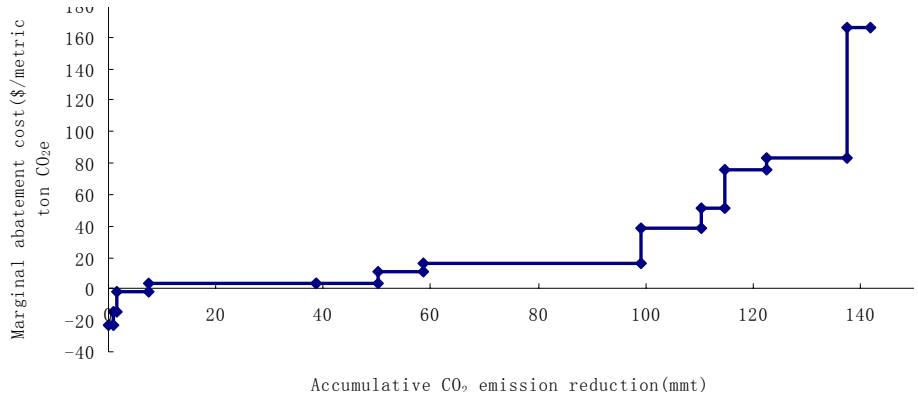

Figure 4-10. Marginal abatement cost curve of iron and steel industry at 2015

Table 4-22. Abatement potential and cost analysis of mitigation measures of 2015

Mitigation Options	Cost Effectiveness ($/ton CO_2)	Total Emission Reduction ($MMTCO_2$)	Total Cost (million $)	Cumulative Emission Reduction (MMT CO_2)	Cumulative Net Cost (million $)	Average Cumulative Cost Effectiveness ($/ton CO_2)
Advanced continuous casting technology	-22.64	0.85	-19.24	0.85	-19.24	-22.64
a-Direct fuel		0.54				
b-Electricity		0.31				
Coal power injection	-14.89	0.71	-10.57	1.56	-29.82	-19.11
a-Direct fuel		0.45				
b-Electricity		0.26				
Establish energy management center	-1.24	5.99	-7.43	7.55	-37.24	-4.93
a-Direct fuel		3.83				
b-Electricity		2.16				
Advanced blast furnace technology	3.59	31.24	112.15	38.79	74.91	1.93
a-Direct fuel		19.99				
b-Electricity		11.25				
Advanced coke oven	3.79	11.36	43.05	50.15	117.96	2.35
a-Direct fuel		7.27				
b-Electricity		4.09				
Dry coke quenching	11.35	8.52	96.70	58.67	214.66	3.66
a-Direct fuel		5.45				
b-Electricity		3.07				
Adjust ratio of iron/steel	15.99	40.46	646.96	99.13	861.62	8.69
a-Direct fuel		25.89				
b-Electricity		3.07				
Advanced sinter machine	38.16	11.40	435.02	110.53	1296.64	11.73
a-Direct fuel		7.30				
b-Electricity		4.10				
Advanced direct steel rolling machine	51.48	4.17	214.67	114.71	1511.32	13.18
a-Direct fuel		2.67				
b-Electricity		1.50				
Advanced converter	75.8	7.71	584.42	122.42	2095.73	17.12
a-Direct fuel		4.93				
b-Electricity		2.78				
Smelt reduction technology	82.85	15.02	1244.41	137.44	3340.14	24.30
a-Direct fuel		9.61				
b-Electricity		5.41				
Advanced EAF	165.78	4.54	752.64	141.98	4092.78	28.83
a-Direct fuel		2.91				
b-Electricity		1.63				

Note: CO2 split as 64% fuel and 36% electricity according to scenario analysis results

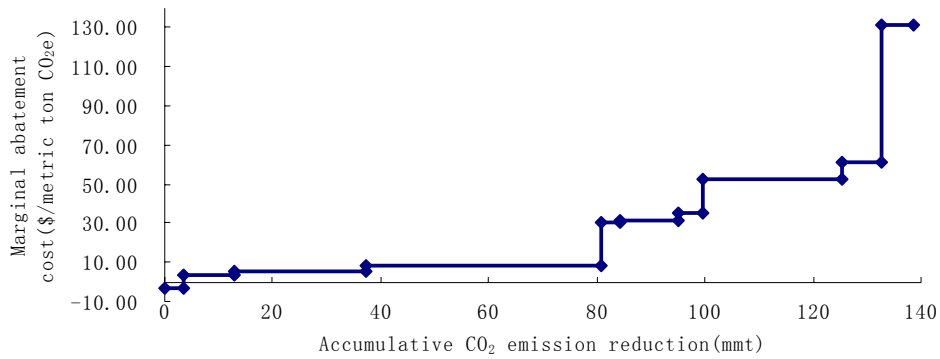

Figure 4-11. Marginal abatement cost curve of iron and steel industry at 2020

Table 4-23. Abatement potential and cost analysis of mitigation measures of 2020

Mitigation Options	Cost Effectiveness ($/ton CO_2)	Total Emission Reduction ($MMTCO_2$)	Total Cost (million $)	Cumulative Emission Reduction ($MMTCO_2$)	Cumulative Net Cost (million $)	Average Cumulative Cost Effectiveness ($/ton CO_2)
Establish energy management center	-3.57	3.64	-12.98	3.64	-12.98	-3.57
a-Direct fuel		2.18				
b-Electricity		1.46				
Advanced coke oven	3.03	9.07	27.44	12.72	14.46	1.14
a-Direct fuel		5.43				
b-Electricity		3.64				
Advanced blast furnace technology	5.36	24.63	131.92	37.35	146.37	3.92
a-Direct fuel		14.75				
b-Electricity		9.88				
Adjust ratio of iron/steel	8.19	43.55	356.57	80.90	502.95	6.22
a-Direct fuel		26.09				
b-Electricity		17.46				
Dry coke quenching	30.36	3.52	106.87	84.42	609.82	7.22
a-Direct fuel		2.11				
b-Electricity		1.41				
Advanced sinter machine	31.63	10.78	340.98	95.19	950.79	9.99
a-Direct fuel		6.46				
b-Electricity		4.32				
Advanced direct steel rolling machine	34.88	4.43	154.50	99.63	1105.30	11.09
a-Direct fuel		2.65				
b-Electricity		1.78				
Smelt reduction technology	52.67	25.63	1349.87	125.25	2455.17	19.60
a-Direct fuel		15.35				
b-Electricity		10.28				
Advanced converter	60.96	7.59	462.70	132.84	2917.87	21.97
a-Direct fuel		4.55				
b-Electricity		3.04				
Advanced EAF	131.39	5.68	746.27	138.52	3664.13	26.45
a-Direct fuel		3.40				
b-Electricity		2.28				

Note: CO2 split as 59.9% fuel and 40.1% electricity according to scenario analysis results

IV.G Analysis of GHG mitigation scenarios

In the analysis of GHG mitigation scenarios, we classify different mitigation scenarios according to the abatement cost.

- Mitigation scenario 1:All zero- or negative cost mitigation options
- Mitigation scenario 2:All mitigation options costing less than $5 per metric ton (including all zero- or negative cost options)
- Mitigation scenario 3:All mitigation options costing less than $10 per metric ton
- Mitigation scenario 4:A scenario that includes all zero- or negative cost mitigation options, plus any other mitigation options that appear likely or feasible based on evaluation of the country's situation and the options' potential co-benefits

IV.G.1 Advanced Options (Mitigation) Scenario #1: All Zero- or Negative Cost Mitigation Options[37]

This mitigation scenario includes establishment of energy management center, BF coal power injection and continuous casting.

IV.G.1.i **Results from the mitigation scenario**

Table 4-24. Annual fuel consumption, emissions and intensity forecast for Iron & Steel sector

Year	Total Production (Mt steel)	Total Fuel Consumption					Electricity (PJ)	Total Energy (PJ, fuel+ electricity)	CO2 emissions (million tones)	Fuel Intensity (GJ/tonne steel)	Energy Intensity (GJ/tonne steel)	Emissions Intensity (tonne CO2 / tonne steel)
		Cooking Coal	Non-Cooking Coal	Fuel Oil	Natural Gas	All Fuels						
2000	131.42	1790.92	970.12	94.87	22.94	2878.85	1009.39	3888.24	351.50	21.91	29.59	2.67
2005	210.21	2218.11	1286.36	114.29	34.45	3653.22	1488.11	5141.32	464.27	17.38	24.46	2.21
2010	289.01	2764.17	1670.38	142.15	56.09	4632.80	2207.41	6840.20	617.21	16.03	23.67	2.14
2015	328.00	2816.08	1719.34	156.84	70.68	4762.94	2676.91	7439.85	671.42	14.52	22.68	2.05
2020	364.00	2803.66	1753.16	118.57	60.09	4735.48	3172.34	7907.83	713.87	13.01	21.72	1.96
2025	353.50	2447.71	1640.44	84.03	41.17	4213.34	3409.54	7622.88	688.25	11.92	21.56	1.95
2030	343.00	2090.28	1475.85	129.95	60.20	3756.28	3162.86	6919.14	624.71	10.95	20.17	1.82

Table 4-25. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)			
	Coal	Oil	Natural Gas	Total All Fuels
2000	242.20	6.13	1.48	249.81
2005	305.62	7.35	2.21	315.18
2010	384.57	9.09	3.59	397.24
2015	391.44	9.98	4.50	405.92
2020	390.30	7.49	3.79	401.59
2025	347.35	5.27	2.58	355.19
2030	303.36	8.16	3.78	315.29

[37] According to marginal abatement cost information of each mitigation option of the year 2015

IV.G.2 Advanced Options Scenario #2: All mitigation options costing less than $5 per metric ton

This mitigation scenario includes 3 additional mitigation options to Advanced Option Scenario #1 "All Zero- of Negative Cost Mitigation Options": advanced blast furnace technology, dry coke quenching and advanced coke oven.

IV.G.2.i **Results from the mitigation scenario**

Table 4-26. Annual fuel consumption, emissions and intensity forecast for iron & steel sector

Year	Total Production (Mt steel)	Total Fuel Consumption					Electricity (PJ)	Total Energy (PJ, fuel+ electricity)	CO2 emissions (million tones)	Fuel Intensity (GJ/tonne steel)	Energy Intensity (GJ/tonne steel)	Emissions Intensity (tonne CO2 / tonne steel)
		Cooking Coal	Non-Cooking Coal	Fuel Oil	Natural Gas	All Fuels						
2000	131.42	1790.92	970.12	94.87	22.94	2878.85	1009.39	3888.24	351.50	21.91	29.59	2.67
2005	210.21	2124.72	1232.20	109.48	33.00	3499.40	1425.45	4924.85	444.73	16.65	23.43	2.12
2010	289.01	2522.16	1524.13	129.71	51.18	4227.18	2014.14	6241.31	563.17	14.63	21.60	1.95
2015	328.00	2591.40	1582.16	144.33	65.04	4382.93	2463.33	6846.26	617.85	13.36	20.87	1.88
2020	364.00	2648.69	1656.25	112.01	56.77	4473.72	2996.98	7470.72	674.41	12.29	20.52	1.85
2025	353.50	2356.87	1579.56	80.91	39.64	4056.98	3283.01	7339.99	662.71	11.48	20.76	1.87
2030	343.00	2033.67	1435.89	126.43	58.57	3654.55	3077.21	6731.76	607.79	10.65	19.63	1.77

Table 4-27. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)			
	Coal	Oil	Natural Gas	Total All Fuels
2000	242.20	6.13	1.48	249.81
2005	292.75	7.04	2.12	301.91
2010	350.90	8.29	3.27	362.46
2015	360.21	9.18	4.14	373.53
2020	368.73	7.07	3.59	379.39
2025	334.46	5.07	2.48	342.01
2030	295.14	7.93	3.68	306.75

IV.G.3 Advanced Options Scenario #3: All mitigation options costing less than $10 per metric ton

This mitigation scenario includes 1 additional mitigation option to Advanced Option Scenario #2 "All Mitigation Options costing less than $5 per metric ton": adjusting the ratio of iron/steel.

IV.G.3.i **Results from the mitigation scenario**

Table 4-28. Annual fuel consumption, emissions and intensity forecast for iron & steel sector

Year	Total Production (Mt steel)	Total Fuel Consumption					Electricity (PJ)	Total Energy (PJ, fuel+ electricity)	CO2 emissions (million tones)	Fuel Intensity (GJ/tonne steel)	Energy Intensity (GJ/tonne steel)	Emissions Intensity (tonne CO2 / tonne steel)
		Cooking Coal	Non-Cooking Coal	Fuel Oil	Natural Gas	All Fuels						
2000	131.42	1790.92	970.12	94.87	22.94	2878.85	1009.39	3888.24	351.50	21.91	29.59	2.67
2005	210.21	2101.37	1218.66	108.28	32.64	3460.94	1409.79	4870.728	439.839	16.46	23.17	2.09
2010	289.01	2369.13	1431.66	121.84	48.07	3970.70	1891.94	5862.6256	529.00408	13.74	20.29	1.83
2015	328.00	2431.93	1484.80	135.45	61.04	4113.21	2311.74	6424.9494	579.83184	12.54	19.59	1.77
2020	364.00	2485.26	1554.06	105.10	53.27	4197.69	2812.06	7009.7567	632.79972	11.53	19.26	1.74
2025	353.50	2111.36	1415.02	72.48	35.51	3634.38	2941.03	6575.4052	593.6752	10.28	18.60	1.68
2030	343.00	1761.12	1243.45	109.48	50.72	3164.77	2664.80	5829.5664	526.3356	9.23	17.00	1.53

Table 4-29. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)			
	Coal	Oil	Natural Gas	Total All Fuels
2000	242.20	6.13	1.48	249.81
2005	289.53	6.96	2.10	298.59
2010	329.61	7.79	3.07	340.47
2015	338.05	8.62	3.88	350.55
2020	345.98	6.64	3.36	355.98
2025	299.62	4.54	2.23	306.38
2030	255.59	6.87	3.18	265.64

IV.G.4 Advanced Options Scenario #4: All feasible mitigation options

This mitigation scenario includes all possible mitigation options.

IV.G.4.i **Results from the mitigation scenario**

Table 4-30. Annual fuel consumption, emissions and intensity forecast for iron & steel sector

Year	Total Production (Mt steel)	Total Fuel Consumption					Electricity (PJ)	Total Energy (PJ, fuel+ electricity)	CO2 emissions (million tones)	Fuel Intensity (GJ/tonne steel)	Energy Intensity (GJ/tonne steel)	Emissions Intensity (tonne CO2 / tonne steel)
		Cooking Coal	Non-Cooking Coal	Fuel Oil	Natural Gas	All Fuels						
2000	131.42	1790.92	970.12	94.87	22.94	2878.85	1009.39	3888.24	351.50	21.91	29.59	2.67
2005	210.21	2059.70	1194.49	106.13	31.99	3392.31	1381.83	4774.14	431.24	16.14	22.71	2.05
2010	289.01	2212.24	1336.85	113.77	44.89	3707.75	1766.65	5474.39	494.77	12.83	18.94	1.71
2015	328.00	2247.21	1372.02	125.16	56.40	3800.79	2136.15	5936.94	537.15	11.59	18.10	1.64
2020	364.00	2252.53	1408.53	95.26	48.28	3804.60	2548.73	6353.34	575.62	10.45	17.45	1.58
2025	353.50	1946.75	1304.70	66.83	32.74	3351.02	2711.73	6062.75	549.22	9.48	17.15	1.55
2030	343.00	1689.30	1192.74	105.02	48.65	3035.71	2556.13	5591.84	506.49	8.85	16.30	1.48

Table 4-31. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)			
	Coal	Oil	Natural Gas	Total All Fuels
2000	242.20	6.13	1.48	249.81
2005	283.79	6.82	2.06	292.67
2010	307.78	7.27	2.87	317.92
2015	312.37	7.96	3.59	323.92
2020	313.58	6.02	3.05	322.64
2025	276.26	4.19	2.05	282.50
2030	245.17	6.59	3.05	254.81

IV.G.5 Co-benefit analysis

All mitigation options will have different co-benefits such as water quality improvement, increased economic productivity and competitiveness, etc.

Because of data limitation, co-benefits analysis will be helped by the following judgment matrix. More in-depth analysis will be carried out at future work.

IV.G.6 Policy Analysis

Twelve kinds of mitigation options are identified and analyzed in this project. For each option, there will be some policies which can promote advanced technology application. Possible polices are listed in the following table.

In this first stage research, main task is to identify possible mitigation options and analysis the emission reduction potential and corresponding cost and give these measures different priorities. Then we can judge which measure has higher priority at different period.

The next question is how to promote the application of specific measures and policies evaluation is very important. It is also the future task for our analysis.

Table 4-32. Possible polices of iron and steel sector

Policy description
Direct government regulation to mandate (or allow) adoption of specific measure, new technology, or product standard
Government-run voluntary assistance program to provide information and training to companies or individuals
Investment tax credit (may be for installation, research and development)
Direct subsidy (investment, research and development, etc.)
Emission standards (usually per unit of output or facility) (possible, in the future)
Energy consumption standards (usually per unit of output)
Local air pollution regulations; energy intensity standard per unit of GDP; emissions intensity standard per unit of GDP; national emission growth limits; emissions cap and trade; carbon tax; energy taxes

Table 4-33. Co-benefits

Mitigation Option	Water quality improvements	Increased economic productivity and competitiveness	Job creation	Technology development and transfer	Infrastructure development	Enhanced energy security and independence	Air quality improvement
Increase coal power injection level	☆☆	☆		☆	☆	☆	☆☆
More advanced continuous casting machine		☆☆		☆	☆	☆	
Establish energy management center and increase management capacity	☆	☆☆	☆	☆		☆☆	☆
More advanced coke oven	☆	☆		☆	☆☆	☆☆	☆☆☆
More advanced blast furnace with TRT		☆☆☆		☆☆	☆☆☆	☆☆☆	☆☆☆
Adjust ratio of iron/steel	☆	☆☆		☆☆	☆	☆☆	☆☆
Apply dry coke quenching	☆☆☆			☆		☆	☆☆☆
More advanced sinter machine	☆	☆		☆		☆	☆☆
More advanced direct steel rolling machine		☆☆		☆	☆	☆	☆
Apply smelt reduction iron-making process	☆	☆☆☆		☆☆	☆	☆☆	☆☆
More advanced oxygen blown converter for steel-making		☆		☆	☆	☆	☆
More advanced electric furnace for steel-making		☆		☆	☆	☆	☆

Note: More☆ means specific mitigation option will produce more co-benefit

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Appendix: Main technical structure change within production process under different scenarios

Process	Plants Classification		Base year	Scenario 1			Scenario 2			Scenario 3		
			2000	2010	2020	2030	2010	2020	2030	2010	2020	2030
Coke Making	Small		8.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Large		41.8	33.0	29.0	23.2	22.0	26.0	23.0	7.0	13.5	19.0
	Domestic advanced		41.4	49.0	52.0	55.0	60.0	55.0	54.0	71.0	61.5	53.0
	International advanced		7.9	18.0	19.0	21.8	18.0	19.0	23.0	22.0	25.0	28.0
Coke quenching	Dry coke quenching		6.0	25.0	42.0	67.0	40.0	65.0	91.0	45.0	80.0	100
Sintering	Small		35.5	23.0	21.0	15.0	19.0	15.0	9.0	11.0	5.0	2.0
	Large		56.5	61.0	59.0	58.0	60.0	57.0	58.0	61.0	56.0	44.0
	International		8.0	16.0	20.0	27.0	21.0	28.0	33.0	28.0	39.0	54.0
Iron making	Blast furnace	Share of total iron/%	100	90	82.7	81.2	90.0	80.0	78.0	90.0	77.0	73.0
		Small	51.9	42.0	35.0	29.0	22.0	19.0	14.0	15.0	11.0	2.0
		Large	18.6	20.0	17.0	13.0	19.0	13.0	9.0	17.0	9.0	5.0
		Advanced	20.9	26.0	30.0	35.0	44.0	45.0	47.0	44.0	46.0	53.0
		International advanced	8.6	12.0	18.0	23.0	15.0	23.0	30.0	24.0	34.0	40.0
	Short process - smelt reduction	Share of total iron/%	0	10.0	17.3	18.8	10.0	20.0	22.0	10.0	23.0	27.0
		DIOS		50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
		COREX		50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Steel making	BOF	Share of total steel/%	84.1	81.0	79.0	77.0	80.0	75.0	71.0	75.0	73.0	67.0
		Normal	13.9	9.0	7.0	5.0	7.0	4.0	2.0	1.0	0.0	0.0
		Large	76.7	68.0	69.0	70.0	75.0	73.0	63.0	72.0	65.0	49.0
		advanced	9.4	23.0	24.0	25.0	18.0	23.0	35.0	27.0	35.0	51.0
	EAF	Share of total steel/%	15.9	19.0	21.0	23.0	20.0	25.0	29.0	25.0	27.0	33.0
		Normal	49.7	29.0	21.0	17.0	25.0	15.0	11.0	11.0	5.0	2.0
		large	41.3	53.0	60.0	62.0	53.0	60.0	57.0	54.0	53.0	47.0
		advanced	9.0	18.0	19.0	21.0	22.0	25.0	32.0	35.0	42.0	51.0
Casting	Normal		17.5	5.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
	Continuous		67.5	72.0	71.0	65.0	74.0	69.0	62.0	71.0	62.0	44.0
	Advanced continuous		15.0	23.0	28.0	35.0	25.0	31.0	38.0	29.0	38.0	56.0
Steel rolling	Normal		7.7	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Large		59.0	45.0	42.0	37.0	46.0	40.0	34.0	36.0	28.0	19.0
	Direct rolling		20.3	33.0	35.0	37.0	33.0	35.0	37.0	27.0	30.0	32.0
	Advanced direct rolling		13.0	19.0	23.0	26.0	21.0	25.0	29.0	37.0	42.0	49.0
Cool rolling	Normal		42.9	37.0	32.0	28.0	35.0	27.0	20.0	29.0	20.0	12.0
	advanced		57.1	63.0	68.0	72.0	65.0	73.0	80.0	71.0	80.0	88.0

		2010	2020	2030
Fuel price index	Coal	1.1	1.2	1.3
	Electricity	1.2	1.3	1.4
	Natural gas	3	3.5	3.7
	Fuel oil	1.2	1.3	1.5
Exchange rate	1 US. dollar =8.2784 Yuan RMB			
Discount rate	10%			

V. Sector Analysis and Results: Cement

V.A Sector Overview

V.A.1 Summary and explanation of economic statistics

V.A.1.i Total output/production, by plant type if available

Table 5-1.China's Cement sector historical output

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	2000
Production(Mt)	210	252.6	308.2	367.9	421	475.6	491.2	511.7	536	718.3

Much of China's remarkable development over the past few decades rests on cement—the primary ingredient in concrete. The country has constructed millions of new houses and buildings, paved thousands of kilometers of new highways, and built hundreds of large power plants, all requiring enormous quantities of cement.

China's cement industry has grown remarkably since economic reforms began in the late 1970s. At the start of reforms in 1978, China ranked fourth in world cement output and produced about 65 million tonnes of cement a year. By 1985, China had become the world's leading producer, and today produces over one-third of total global output.

V.A.1.ii Role of sector in overall economy as source of inputs to other sectors

Forty percent of China's cement is now used for basic infrastructure construction (an area regularly neglected during the period of heavy central planning.), with about one-third of that used in rural areas. Twenty-five percent is used for maintenance activities.

China's transport sector uses cement in road construction rather than asphalt. As China lacks an adequate national highway system and its rail network is so overburdened, investment can be expected in highways over the medium term.

V.A.1.iii Role in exports, international trade

China is the second leading cement exporter in the world, accounting for about 17 percent of total world cement trade. Exports of cement dramatically exceed imports, about 5 million tones v. 200 thousand tonnes, respectively in 2000. Shaft kiln cements of #425 and #525 comprise 60–70 percent of total exports. A share of this is from foreign owned companies or joint ventures, which themselves account for about 25 percent of exported cement. Major exporting regions include Shandong, Jiangsu, Guangdong, Liaoning, Guangxi, and Hebei provinces. The largest exporting companies include Daewoo Shandong Metal and Minerals Import/Export (with sales of about 2 million tonnes); and Taiheiyo Cement (with sales of about 1.8 million tonnes). The United States is the largest market for Chinese cement, accounting for 42 percent of trade in 1998.

V.A.2 Quantitative and qualitative characterization of sector

V.A.2.i <u>Table with breakdown of facilities by type</u>

Table 5-2.Distribution of China's Cement Plants in Clinker Production Process in 2000

		Average Age (Year)*a	No. of plants*a	Share*a	Unit Investment (USD/T)*b
shaft kiln	Mechanical Shaft Kiln	15	7904	83.98%	72.5
	ordinary shaft Kiln	15	347	3.69%	36.2
	Other	15	-	-	
	Subtotal		8251	87.66%	
rotary kiln	dry process plain kiln	15	421	4.47%	72.5
	rotary kiln with waste heat for power generation	15	88	0.93%	72.5
	rotary kiln with cyclone preheater	15	348	3.70%	
	stand-tube preheating kiln	15	-	-	
	kiln operated with off-kiln decomposition	20	86	0.91%	120.8
	Lepol kiln	15	199	2.11%	84.6
	Wet-process Rotary kiln	15	19	0.20%	78.5
	Subtotal		1161	12.34%	
	Total		9412	100%	

Data resource: HU Xiulian, JIANG Kejun, XU Huaqing, et al. Evaluation of Technology and Countermeasure for Greenhouse Gas Mitigation in China[M].Beijing: China Environmental Science Press, 2001. (in Chinese). *a Data in 1995;*b: data in 1995, discounted to 2000 value.

V.A.2.ii Table with breakdown of facilities by range of average CO2 intensity

Table 5-3. Facilities of cement industry

		Energy consumption (Mcal/T)	Coal consumption (kgce/T))*a	Gasoline consumption (kg/T)*a	Electricity consumption (kWh/T)*a	CO2 Intensity (TCO2/T)*b	total CO2 emissions (MTCO2)*c	Share of CO2 emissions*c
shaft kiln	Mechanical Shaft Kiln	1154	144	2.4	141	0.822	257.61	61.84%
	ordinary shaft Kiln	1596	218	3.4	98	0.949	82.84	19.89%
	Subtotal						340.45	81.73%
rotary kiln	dry process plain kiln	1896	249	3.81	133	1.023	6.06	1.45%
	rotary kiln with waste heat for power generation	1229	156	2.43	133	0.842	63.06	15.14%
	rotary kiln with cyclone preheater							
	stand-tube preheating kiln							
	kiln operated with off-kiln decomposition	748	87	1.81	140	0.711	2.29	0.55%
	Lepol kiln	1117	139	2.22	140	0.812	0.85	0.20%
	Wet-process Rotary kiln	1435	184	2.87	140	0.899	3.84	0.92%
	Subtotal						76.1	18.27%
	Total						416.55	100%

*a,*b: HU Xiulian, JIANG Kejun, XU Huaqing, et al. Evaluation of Technology and Countermeasure for Greenhouse Gas Mitigation in China[M].Beijing: China Environmental Science Press, 2001. (in Chinese).data in 1990;*b:emissions from process emissions, fuel combustion and electricity generation;*c: data from LEAPChina model, CO2 emission from fuel combustion and electricity generation

V.A.2.iii Table with breakdown of facilities by range of production capacity

Table 5-4. Distribution of China's cement facilities by production capacity.

		average plant Capacity (MT)*a	Annual Production (MT)*b	Share of Production
shaft kiln	Mechanical Shaft Kiln	0.1	418.0	58.22%
	ordinary shaft Kiln	0.05	116.4	16.21%
	Other	-	64.6	9.00%
	Subtotal		599	83.43%
rotary kiln	dry process plain kiln	0.1	7.9	1.10%
	rotary kiln with waste heat for power generation	0.04	99.9	13.91%
	rotary kiln with cyclone preheater			
	stand-tube preheating kiln			
	kiln operated with off-kiln decomposition	0.5	4.3	0.60%
	Lepol kiln	0.3	1.4	0.19%
	Wet-process Rotary kiln	0.2	5.7	0.79%
	Subtotal		119	16.58%
	Total		718	100%

Data resource:*a:HU Xiulian, JIANG Kejun, XU Huaqing, et al. Evaluation of Technology and Countermeasure for Greenhouse Gas Mitigation in China[M].Beijing: China Environmental Science Press, 2001;*b: assumption in LEAPChina model in 2000 baseline year

V.A.2.iv In-depth discussion and explanation of above breakdowns

The simplified process for cement making can be described as kiln feed preparation, clinker production and finish grinding. Clinker production is the most energy-intensive stage in cement production, accounting for over 90% of total industry energy use, and virtually all of the fuel use. The estimated number of Chinese cement plants ranges from 8,000 to 9,500, although the actual number is uncertain due to the fragmented nature of the industry, the small size of many plants, the fact that some plants exist illegally, and data reliability issues. The cement industry in China is dominated by shaft kilns.

In 2000, about 8500 shaft kilns account for almost 85% of total cement production. These plants account for over 80% of total cement CO2 emissions.

The cement industry is very energy intensive and China relies almost exclusively on coal to produce cement. Energy accounts for roughly 40 percent of the total manufacturing cost of cement in China. Mechanical Shaft Kiln is the largest single source of cement CO2 emissions, accounts for 61.84% of China's total CO2 emissions from cement.

V.A.2.v Ownership patterns of sector

In 2000 and 2001, the Chinese government decentralized its industrial ministries, and the organizational structure of the cement industry remains in a state of flux. The Ministry of Building Materials has been changed, first to a State Administration of Building Materials Industry (SABMI), and earlier in 2001 to a small, quasi-governmental Cement Association. Changes in top officials have occurred and provincial authorities now exert more control over the industry.

A shrinking number of cement companies (now about 24 percent) remain state-owned, while a growing number (about 3 percent) are foreign invested enterprises (FIEs). Collective enterprises account for over 50 percent of companies while 10 percent are privately owned. There also is a trend toward consolidation, as evidenced by the 1999 formation of China United Cement Company, a large state-owned holding company.

V.B Emissions Overview of Sector

Background and discussion of emissions, main sources/causes/drivers, trends
The cement industry is very energy intensive and China relies almost exclusively on coal to produce cement. Energy accounts for roughly 40 percent of the total manufacturing cost of cement in China. Unlike some industrialized countries, China has not yet moved to alternative energy sources in its cement kilns, although that may become an option.

Cement plants are responsible for over 40 percent of total industrial particulate (dust) emissions. Chinese cement plants are also responsible for about 6 to 8 percent of the country's energy consumption. These emissions are produced in roughly equal parts from fuel combustion and the liberation of carbon dioxide from limestone at high temperature. Carbon dioxide emissions from small Chinese plants are two or more times higher than plants in industrialized nations (because of poor efficiencies requiring more fuel use, etc.). Increasing the efficiency of cement kilns is one way to reduce carbon dioxide emissions.

V.B.1 Annual GHG emissions inventory for a recent year

V.B.1.i Percent share of emissions by source (pie chart)

Main sources of CO2 emission from cement sector is fossil fuel combustion, self industrial process and a relative small portion of indirect electrical consumption.

Table 5-5.CO2 emissions in 1990s (MtCO2)

	Energy utilization*	Share of total	industrial process	Share of total	Total
1990	82.4	51.83%	76.5	48.17%	158.9
1991	97.8	51.47%	92.2	48.53%	190.0
1992	116.1	50.78%	112.5	49.22%	228.5
1993	146.8	52.59%	132.3	47.41%	279.1
1994	156.8	50.48%	153.7	49.52%	310.5
1995	174.6	50.13%	173.7	49.87%	348.4
1996	183.1	50.48%	179.6	49.52%	362.7
1997	188.2	50.13%	187.1	49.86%	375.3

Data resource: Chinese energy statistics year book 1998.
* emission include fuel combustion and electricity generation

V.B.2 Historical annual fuel consumption and GHG emissions trends over time by fuel type

Table 5-6.China's cement sector historical annual fuel consumption

	Coal (Mt)	Electric (Twh)	Oil (Mt)	Total (MTce)	Unit consumption (kgce/T)
1990	32.08	21.37	0.15	40.71	194.13
1991	38.1	24.63	-	48.05	190.21
1992	45.21	30.57	-	57.57	186.79
1993	57.19	36.2	-	67.11	185.18
1994	61.07	42.1	-	78.09	185.40
1995	68.05	47.6	-	87.28	183.38
1996	71.34	49.2	-	91.21	185.34
1997	73.32	49.3	-	93.21	181.78

Data resource: HU Xiulian, JIANG Kejun, XU Huaqing, et al. Evaluation of Technology and Countermeasure for Greenhouse Gas Mitigation in China[M].Beijing: China Environmental Science Press, 2001

V.B.3 Relative contribution of each sector in 2000

V.B.3.i <u>total national energy consumption and emissions</u>

Table 5-7. Sector's share of total energy consumption

Target Sectors	Electricity	Iron &Steel	Cement	Pulp &Paper
Share of China's total energy consumption (2000)	8.56%*	9.95%	7.86%	1.67%
CO2 Emission (MtCO2)(2000)	256.65*/1199	351.53	678.4	62.67

Asterisk implies emissions from electricity that is consumed at the same site or plant where it is generated, and not transmitted across the local grid.

V.B.3.ii <u>total world sector emissions</u>

Table 5-8.Share of China in cement and limestone

Cement & Limestone			
Countries	$MtCO_2$	% of Developing Country	% of World
China	678.4	56%	36%

V.C Background Assumptions for Sector Analysis

V.C.1 Baseline with policies adopted before 2000

V.C.1.i <u>Policies under Consideration</u>

- Elimination of small illegal cement plants

In 1999 and 2000, and continuing into 2001, China reportedly closed hundreds of small, illegal cement plants. In 1999, cement plants with a total production capacity of 42 million tonnes were closed. The measures where taken to reduce pollution and to remove excessive production capacity. In June 2000, the Beijing Municipal Environmental Protection Bureau closed several cement factories in the Beijing area for violating environmental standards.
Implementation of technical retrofit

Since the middle of the 1980s, the government has made extensive efforts to technical retrofit plants in the cement industry and introduced New Suspension Heater (NSP) kiln technology for the first time with government budgets, public bonds, bank loans. The distinct characteristics of this technical retrofit are "wet process to dry process" and "large-scale options". The government also made guidelines of technical retrofit and outlines of technical development, and shut down small-scale cement plants in order to encourage the development and adoption of energy conservation technologies. All the following points are confirmed in "Policy Outlines of Energy Conservation Technologies", enacted in 1984 and revised in 1996.

- Declaration of energy conservation

According to the "Policies Outlines of Energy Conservation Technologies", the principle of recovering and utilizing the heat from kilns is to use the waste heat firstly for pre-warming the inputs of kilns such as air, fuel and raw materials.

In the August of 1995, an agreement was signed to demonstrate the operation of using low temperature heat for power generation among NEDO (New Energy and Industrial Technology Development Organization of Japan), SDPC (State Development and Planning Commission of P. R. China) and State Construction Material Bureau. Japan side donated a whole set of power generation

system that was installed at a cement plant in China. The government will promote active adoption of using low temperature heat for power generation at cement industry according to "The China Medium and Long Term Energy Conservation Plan".

It should indicate in the new version of "Energy Conservation of People's Republic of China" or correlative regulations to be implemented that public utilities must be prescribed unconditionally to allow the power plants using waste heat and exhaust energy to connect to the power grid. There should be some discounts in the tariff in order to encourage using power generated by waste heat and exhaust energy.

V.C.1.ii Assumptions about the Effectiveness of Policies

The micro-policies mainly direct the way how China's cement industry take its renovation. Big issues China emphasized before 2000 focused on technical retrofit and energy conservation, which can be realized through technology advancement. A number of effective measures can be taken through cement production process, which can be classified as raw materials preparation, clinker production, finish grinding, products change and some general measures such as energy management control.

The recent baseline scenario employed here is a conservative projection of China's cement industry future that closely tracks previous Chinese forecasts. The scenario assumes that sector's relative policies will not change radically, although some technologies are projected to improve gradually.

V.C.2 Baseline with policies adopted between 2000 and 2005

V.C.2.i Policies under Consideration

- *Improvement of both production capacity and product quality*

Chinese planners project that cement output will increase by 3.4 percent annually during the Tenth Five-Year Plan (2001–2005) and by 2.9 percent during the Eleventh Five-Year Plan. They anticipate producing 660 million tonnes by 2005, 750 million tonnes by 2010, and 800 million tonnes by 2015. In peer review, it is said the actual data indicates that cement production in 2005 was 1064 Mt, and projects it to rise to 1250 in 2010.[38] So the outputs projection has the same problem as electricity sector. We make modest assumptions between the above two opinions.

- *Management organization reformation*

In 2000 and 2001, the Chinese government decentralized its industrial ministries, and the organizational structure of the cement industry remains in a state of flux. The Ministry of Building Materials has been changed, first to a State Administration of Building Materials Industry (SABMI), and earlier in 2001 to a small, quasi-governmental Cement Association. Changes in top officials have occurred and provincial authorities now exert more control over the industry.

- *Energy efficiency enhancement*

Provinces and cities given priority investment during the Tenth Five-Year Plan include Xinjiang, Ningxia, Qinghai, Shaanxi (including Xian), Gansu, Sichuan, Tibet (Xizang), Chongqing, Guizhou, and Yunnan (including Kunming). Eastern provinces should not expect new plants but will receive technology upgrades.

- *Market system renovation*

[38] Prof Cui Yuan-sheng, VP of Institute of Technical Information for Building Materials Industry of China, CBMIA, *Status Quo of the Chinese Cement Industry in 2005 and Future Prospect*. Presentation, MidEast & North Africa Cement Conference, Dubai, United Arab Emirates, March 20-21, 2006.

Foreign investment is expected to play a key role in growth in the cement industry during the 10th Five-Year Plan (2001–2005).[16] These financing sources are expected to be guided toward large cement production lines in central and western China and other less economically developed areas.

- *Environmental protection issues*

In many relatively wealthy urban areas, public pressure plays an important role in government planning and environmental enforcement. Enforcement of existing environmental regulations will become stricter in major urban areas, especially Beijing.

Chinese Government strengthens to supervise and inspect environmental protection. With the standard further improvement of environmental protection increasingly, increasing the investment in environmental protection is inevitable. Because of the constant rise of prices of oil, coal, natural gas, electricity, etc., it impels the enterprises to carry on the technological innovation transformation, take energy-conserving and environmental protection as the center and meet present development situation. According to experts' estimation, energy shortage and energy rising price will continue in the Chinese economy for a long time, and have especially caused the enormous existent pressure for cement enterprises. Therefore saving-energy and reducing consumption are the important rules for cement enterprise to reduce operation cost, to raise productivity effect and to be on the way of sustainable development.

V.C.2.ii Assumptions about the Effectiveness of Policies

Here we can tell the policies adopted through 2000~2005 still pay great attention to technical development. China strive for making market system renovation and policies to introduce investment to promote technology upgrades. Compared to the policies adopted before 2000, environmental protection issues become more and more perspective.

In this scenario, we will evaluate projected emissions using combination of measures in place before the end of 2005. Taking regards of Report of 16th Party Congress, Tenth Five-Year Plan as well as relative industrial long term development policies and plans. The policy takes more consideration for environmental protection and sustainable development.

V.D Baseline (business-as-usual) Forecasts for sectors

V.D.1 Production/output forecast

It is said China's GDP in 2020 will quadruple above 2000 levels in the Considering the Report of 16th Party Congress. We refer to series of literatures on Chinese energy and carbon scenarios[39] and assume China's GDP will keep the fast growth in 1990s, the annual growth rate is set to be 7.5% during 2000 to 2010. Then the growth speed will slow down, and the annual growth rate is set to be 6.5% from 2010 to 2020, and 5.5% after 2020. And cement sectoral production is projected consistent with economy development, see Table 5-9. The projection trend is shown in Fig 5-1.

Table 5-9. China's GDP and Cement Production Assumptions in the Analysis

year	2000	2005	2010	2015	2020	2025	2030
Annual growth ratio	7.50%			6.50%		5.50%	
GDP（billion dollar）	1081	1552	2227	3096	4181	5465	7142
Sectoral production (MT)	718.3	881.5	1045	1132	1220	1324	1427

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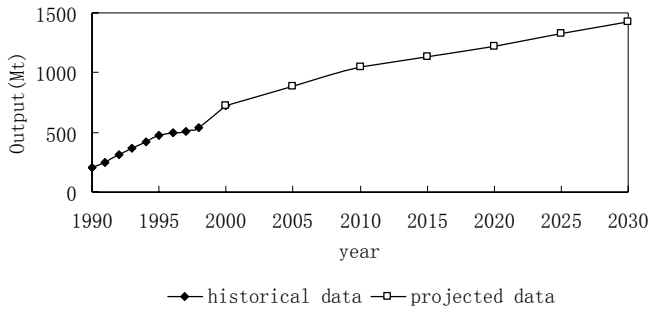

Fig 5-1 Output projection for cement sector in the analysis

V.D.2 Energy and fossil fuel consumption (by type) forecast

Table5-10 Energy consumption under 2000 baseline scenario(Unit:PJ)

Year	Total Fuel Consumption (PJ)				Energy Intensity (GJ / metric ton)
	Coal	Electricity	Gasoline	All Fuels	
2000	3285.8	338.5	87.7	3712.0	5.17
2005	4070.3	413.0	110.3	4593.6	5.21
2010	4868.7	486.7	133.8	5489.2	5.25
2015	5254.3	525.0	144.3	5923.7	5.23
2020	5636.5	563.1	154.7	6354.3	5.21
2025	6090.3	608.0	167.1	6865.4	5.19
2030	6540.1	652.4	179.3	7371.8	5.16

Table 5-11 Energy consumption under 2005 baseline scenario(Unit:PJ)

Year	Total Fuel Consumption (PJ)				Energy Intensity (GJ / metric ton)
	Coal	Electricity	Gasoline	All Fuels	
2000	3285.8	338.5	87.7	3712.0	5.17
2005	3862.4	420.5	106.3	4389.2	4.98
2010	4375.8	504.5	124.3	5004.6	4.79
2015	4571.1	546.6	131.2	5249.0	4.64
2020	4740.0	588.7	137.6	5466.3	4.48
2025	5012.3	639.7	146.8	5798.8	4.38
2030	5264.1	690.9	155.6	6110.6	4.28

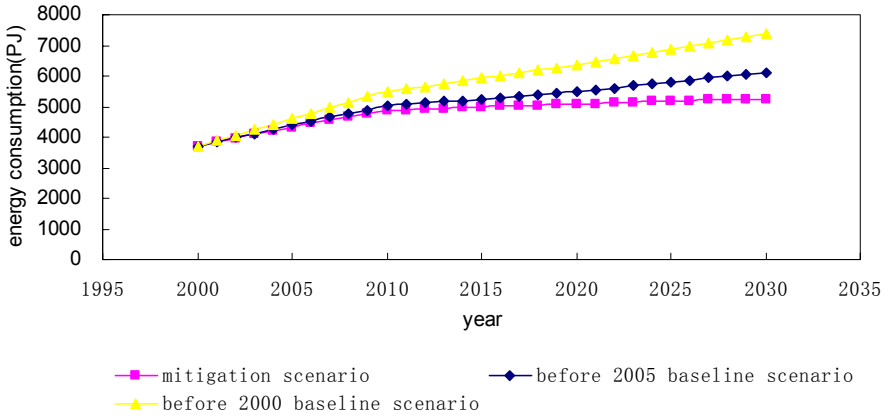

Fig 5-2 energy consumption for cement sector under three scenarios

V.D.3 Annual GHG forecast

V.D.3.i Total GHG emissions

The corresponding CO2 emissions related to fuel combustion are calculated, see table.

Table 5-12. CO2 emission for China's cement sector by fuel type under 2000 baseline scenario (MMtCO2)

	2000	2005	2010	2015	2020	2025	2030
Gasoline	4.3	5.4	6.6	7.1	7.6	8.3	8.9
Electricity	35.9	43.9	51.7	55.8	59.8	64.6	69.3
Coal	299.9	371.5	444.4	479.6	514.5	555.9	596.9
Total	340.2	420.8	502.7	542.5	581.9	628.7	675.1
Process	338.2	418.5	497.6	532.7	576.3	624.5	660.1
Total	678.4	839.3	1000.3	1075.2	1158.2	1253.2	1335.2
Emission intensity* (kgCO2/kg)	0.944	0.952	0.957	0.950	0.949	0.947	0.936

* emission from energy utilization and industrial process

Table 5-13. CO2 emission for China's cement sector by fuel type under 2005 baseline scenario (MMtCO2)

	2000	2005	2010	2015	2020	2025	2030
Gasoline	4.3	5.2	6.1	6.5	6.8	7.2	7.7
Electricity	35.9	44.7	53.6	58.1	62.5	67.9	73.4
Coal	299.9	352.5	399.4	417.2	432.6	457.5	480.5
Total	340.2	402.4	459.1	481.8	502.0	532.7	561.5
Process	338.2	398.5	447.4	478.2	497.3	525.6	554.5
Total	678.4	800.9	906.5	960.0	999.3	1058.3	1116
Emission intensity*(kgCO2/kg)	0.944	0.909	0.867	0.848	0.819	0.799	0.782

* emission from energy utilization and industrial process

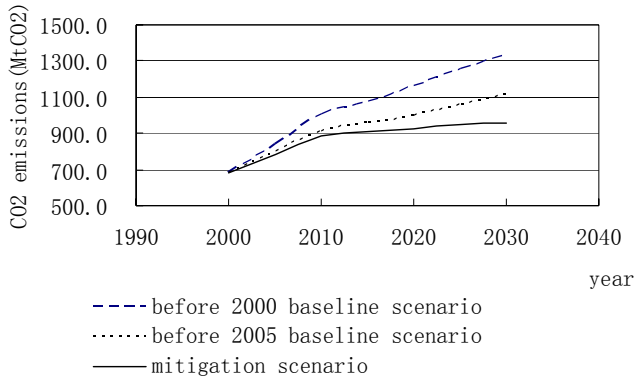

Fig 5-3 Emissions projection for cement sector under three scenarios

V.E GHG Mitigation Options and Costs

V.E.1 Selection criteria for consideration of mitigation options

First of all, technologies and measures listed in this section have been tested by many developed countries. They can virtually reduce the energy intensity (i.e. the electricity or fuel consumption per unit of output) of the various process stages of cement production. Second, implementation of such

technologies and measures are compatible with China's cement industry policies focus on energy efficiency improvement and sustainable development.

V.E.2 Overview of each mitigation option evaluated

V.E.2.i Description, including technologies required

Measures generally fall into 4 classes:

Technology structure Adjustment and process management
Wide variation exists in equipment used to produce cement in China. The gap between proportions of modern rotary kilns vs. inefficient mechanical shaft kilns, new dry process rotary kilns vs. old rotary kilns is great. There is obvious energy efficiency contrast between large scale and small scale companies. China has less efficiency than the developed countries' even as the same production process. Table 5-16.

Table 5-14. China's cement production heat consumption comparison with international advanced level

	Internal average level		External advanced level		Internal/External
Kiln	Heat consumption (kJ/kg)	Thermal efficiency (%)	Heat consumption (kJ/kg)	Thermal efficiency (%)	(%)
kiln operated with off-kiln decomposition	3553	49.4	2888	60.9	123.0
rotary kiln with cyclone preheater	4182	42	3056	57.8	136.9
stand-tube preheating kiln	4700	37.3	3600	48.8	130.6
Lepol kiln	4605	38.2	3349	52.5	137.5
rotary kiln with waste heat for power generation	6100	28.8	5232	33.6	116.6
Wet-process Rotary kiln	6145	30.0	5232	33.6	117.5
Mechanical Shaft Kiln	4887	36.5	2990	60	163.4

Data resource: Hu Xiulian, Comparison of national and international production unit energy consumption. 1997.(in Chinese)

Active improvement of technology structure and enhancement of industrial monitoring and management are the key elements for CO2 emission reductions through energy utilization in this sector. Some detailed measures are as follows:

Process management and Control: Heat from the kiln may be lost through non-optimal process conditions or process management. Improved process control will also help to improve the product quality, e.g. reactivity and hardness of the produced clinker, which may lead to more efficient clinker grinding. Process control systems also include the use of on-line analyzers that permit operators to instantaneously determine the chemical composition of raw materials being processed in the plant, thereby allowed for immediate changes in the blend of raw materials. A uniform feed allows for more steady kiln operation, thereby saving ultimately on fuel requirements. Energy savings from such process control systems may vary between 2.5% and 10%, and the typical savings are estimated at 2.5-5%.

High-Efficiency Motors and Drives: Motors and drives are used throughout the cement plant to drive fans (preheater, cooler, alkali bypass), rotate the kiln, transport materials and, most importantly, for grinding.

Preventative Maintenance: Preventative maintenance involves training personnel to be attentive to energy consumption and efficiency. Successful programs have been launched in many industries.

Raw Material Preparation

Efficient transport systems: Transport systems are required to transport powdered materials such as raw meal, kiln dust, and cement throughout the plant. These materials are usually transported by means of either pneumatic or mechanical conveyors. While mechanical conveyors use less power than pneumatic they can have higher capital costs than pneumatic.

High-efficiency roller mills: Traditional ball mills used for grinding certain raw materials (mainly hard limestone) can be replaced by high-efficiency roller mills, by ball mills combined with high pressure roller presses, or by horizontal roller mills. The use of these advanced mills saves energy without compromising product quality.

High-efficiency Powder Classifiers: A recent development in efficient grinding technologies is the use of high-efficiency classifiers or separators. Classifiers separate the finely ground particles from the coarse particles. The large particles are then recycled back to the mill. Standard classifiers may have a low separation efficiency, which leads to the recycling of fine particles, leading to extra power use in the grinding mill.

Introduction for advanced clinker making technology
Theoretical heat consumption of raw material is 1759kJ/kg. Pre-decomposition invented in 1970s together with pre-heating system improvement make it down to 2929kJ/kg, with the thermal efficiency of 60%, which is very close to theoretical value. To improve the cement clinker making efficiency, some substantial measures are described as follows:

Combustion System Improvement: Fuel combustion systems in kilns can be contributors to kiln inefficiencies with such problems as poorly adjusted firing, incomplete fuel burn-out with high CO formation, and combustion with excess air.

Kiln Shell Heat Loss Reduction: There can be considerable heat losses through the shell of a cement kiln, especially in the burning zone. The use of better insulating refractories can reduce heat losses.

Use of Waste Derived Fuels: Waste fuels can be substituted for traditional commercial fuels in the kiln. Waste derived fuels may replace the use of commercial fuels, and are hence accounted as energy savings. The carbon dioxide emission reduction depends on the carbon content of the waste derived fuel, as well as the alternative use of the waste and efficiency of use (e.g. incineration with or without heat recovery).

Conversion to Multi-stage pre-heater kiln: Installing multi-stage suspension preheating (i.e. four- or five-stage) may reduce the heat losses and thus increase efficiency. By installing new preheaters, the productivity of the kiln will also increase, due to a higher degree of pre-calcination (up to 30-40%) as the feed enters the kiln.

Development for Finish Grinding technology, exploitation of additives
Active Additives. 1 ton cement contains 620 kg calces, and 750 kg raw materials are needed when producing 1 ton cement in China. Increasing the output of raw material is essential for cement production. Blending additives as fly ash, pozzolans, blast furnace slag, silica fume, volcanic ash with various proportions in to inter-grinding of clinker will increase the output of cement greatly. The use of blended cements is a particular attractive efficiency option since the inter-grinding of clinker with other additives not only allows for a reduction in the energy used (and carbon emissions) in clinker production, but also corresponds to a reduction in carbon dioxide emissions in calcination as well.

Composite Cement: Chinese national standard GB12958-91 defines composite cement as being made of silicate cement raw material, two or more than two appointed mixtures, some hydraulic cementitious materials from gypsum grinding. Composite cement is fast developed new product for it's quite compatible with our nation's status, and composite cement can be produced from whatever kind of kilns or processes.

V.F Analysis of GHG mitigation scenarios

V.F.1 Marginal abatement cost curve

Theoretically, the marginal cost for each measure should be calculated through its mitigation effect compared to its situation in 2000 baseline year. Actually, there is no such systemic data strictly complied with options classification in our mitigation scenario. So we find the marginal cost for similar measures in America[40]. Also, we do adjustments by checking the Chinese cement sector related literature of disperse marginal abatement cost data for mitigation measures[41,42].

V.F.1.i 2010

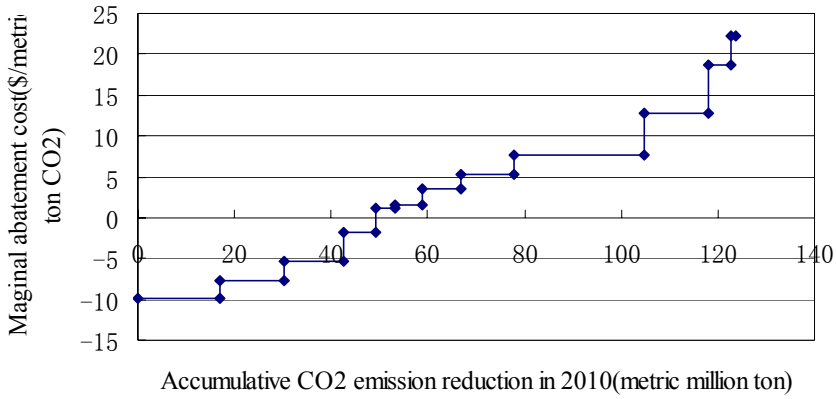

Figure 5-4.Marginal abatement cost curve of China's cement sector in 2010

Table 5-15. Cost of mitigation options and relevant emission reduction in 2010

No.	Measures	Marginal mitigation cost (U.S.Dollar/ tCO2)	Total Emission Reduction (MMt CO2)	Total Cost (million $)	Cumulative Emission Reduction* (MMT CO_2e)	Cumulative Net Cost (million $)	Average Cumulative Cost Effectiveness ($/metric ton CO_2e)
1	Preventative Maintenance	-9.8	16.8	-164.6	16.8	-164.6	-9.8
2	Process management and Control	-7.72	13.5	-104.2	30.3	-268.9	-8.9
3	Use of Waste Derived Fuels	-5.28	12.3	-64.9	42.6	-333.8	-7.8
4	Kiln Shell Heat Loss Reduction	-1.76	6.71	-11.8	49.31	-345.6	-7.0
5	High-Efficiency Motors and Drives	1.07	3.9	4.2	53.2	-341.4	-6.4
6	Active Additives	1.6	5.61	9	58.8	-332	-5.7
7	Composite Cement	3.55	7.87	27.9	66.7	-305	-4.6
8	Combustion System Improvement	5.34	11.2	59.8	77.9	-245	-3.1
9	Conversion to Multi-stage pre-heater kiln	7.6	26.9	204.4	104.8	-40	-0.4
10	High-efficiency roller mills	12.7	13.1	166.4	117.9	126	1.1
11	High-efficiency Powder Classifiers	18.6	4.93	91.7	122.8	218	1.8
12	Efficient transport systems	22.2	1.03	22.9	123.9	241	1.9

* emission from energy utilization and industrial process

[40] Nathan Martin, Ernst Worrell, and Lynn Price. Energy Efficiency and Carbon Dioxide Emissions Reduction Opportunities in the U.S. Cement Industry. 1999.
[41] Mason H. Soule, Jeffrey S. Logan, and Todd A. Stewart.Trends, Challenges and opportunities in China's Cement Industry. 2002.
[42] HU Xiulian, JIANG Kejun, XU Huaqing, et al. Evaluation of Technology and Countermeasure for Greenhouse Gas Mitigation in China[M].Beijing: China Environmental Science Press, 2001.

V.F.1.ii **<u>2015</u>**

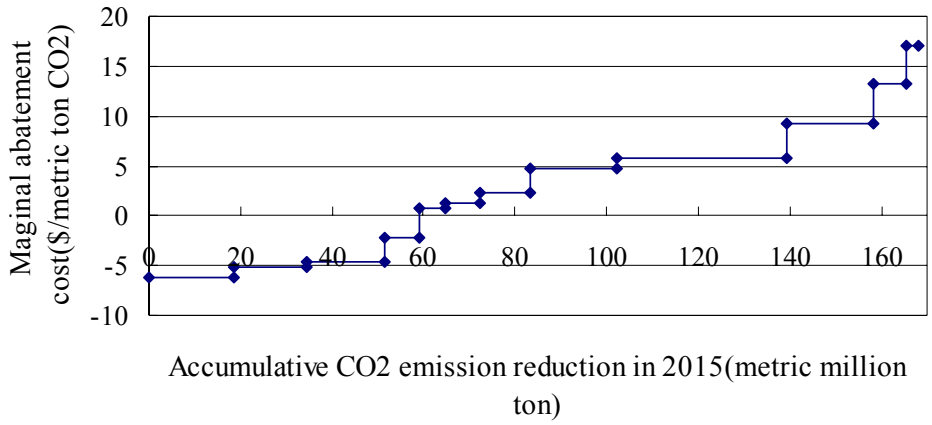

Figure 5-4.Marginal abatement cost curve of China's cement sector in 2015

Table 5-16. Cost of mitigation options and relevant emission reduction in 2015

No.	Measures	Marginal mitigation cost (U.S.Dollar/tCO2)	Total Emission Reduction (MMtCO2)	Total Cost (million $)	Cumulative Emission Reduction* (million metric tons CO_2e)	Cumulative Net Cost (million $)	Average Cumulative Cost Effectiveness ($/metric ton CO_2e)
1	Preventative Maintenance	-6.12	18.7	-114.4	18.7	-114.4	-6.1
2	Process management and Control	-5.23	15.6	-81.6	34.3	-196.0	-5.7
3	Use of Waste Derived Fuels	-4.58	17.1	-78.3	51.4	-274.4	-5.3
4	Kiln Shell Heat Loss Reduction	-2.24	7.79	-17.4	59.19	-291.8	-4.9
5	High-Efficiency Motors and Drives	0.75	5.46	4.1	64.7	-287.7	-4.5
6	Active Additives	1.24	7.79	10	72.4	-278	-3.8
7	Composite Cement	2.39	10.9	26.1	83.3	-252	-3.0
8	Combustion System Improvement	4.78	18.7	89.4	102.0	-163	-1.6
9	Conversion to Multi-stage pre-heater kiln	5.72	37.4	213.9	139.4	51	0.4
10	High-efficiency roller mills	9.23	18.7	172.6	158.1	224	1.4
11	High-efficiency Powder Classifiers	13.3	7.47	99.4	165.6	323	2.0
12	Efficient transport systems	17.1	2.33	39.8	167.9	363	2.2

* emission from energy utilization and industrial process

V.F.1.iii 2020

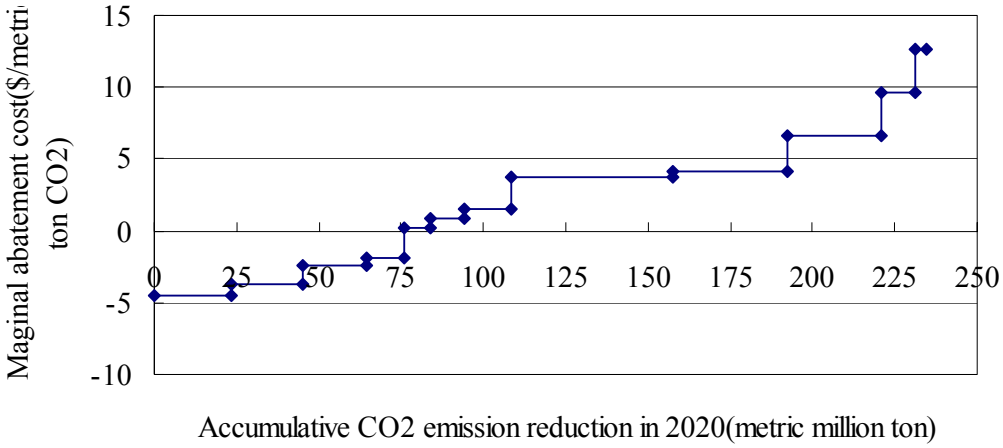

Figure 5-4.Marginal abatement cost curve of China's cement sector in 2020

Table 5-17. Cost of mitigation options and relevant emission reduction in 2020

No.	Measures	Marginal mitigation cost (U.S.Dollar/tCO2)	Total Emission Reduction (MMt CO2)	Total Cost (million $)	Cumulative Emission Reduction* (million metric tons CO_2e)	Cumulative Net Cost (million $)	Average Cumulative Cost Effectiveness ($/metric ton CO_2e)
1	Preventative Maintenance	-4.53	23.5	-106.5	23.5	-106.5	-4.5
2	Use of Waste Derived Fuels	-3.75	21.5	-80.6	45	-187.1	-4.2
3	Process management and Control	-2.44	19.5	-47.6	64.5	-234.7	-3.6
4	Kiln Shell Heat Loss Reduction	-1.89	11.3	-21.4	75.8	-256.0	-3.4
5	High-Efficiency Motors and Drives	0.22	8.17	1.8	84.0	-254.2	-3.0
6	Active Additives	0.87	10.2	9	94.2	-245	-2.6
7	Composite Cement	1.54	14.3	22.0	108.5	-223	-2.1
8	Conversion to Multi-stage pre-heater kiln	3.79	49.1	186.1	157.6	-37	-0.2
9	Combustion System Improvement	4.14	34.8	144.1	192.4	107	0.6
10	High-efficiency roller mills	6.59	28.6	188.5	221.0	295	1.3
11	High-efficiency Powder Classifiers	9.67	10.2	98.6	231.2	394	1.7
12	Efficient transport systems	12.69	3.67	46.6	234.8	441	1.9

* emission from energy utilization and industrial process

V.G Analysis of GHG mitigation scenarios

V.G.1 Advanced Options (Mitigation) Scenario #1: All Zero- or Negative Cost Mitigation Options

This mitigation scenario includes Preventative Maintenance, Use of Waste Derived Fuels, Process management and Control, and Kiln Shell Heat Loss Reduction.

V.G.1.i Results from the mitigation scenario

Table 5-18. Annual fuel consumption, emissions and intensity forecast for cement sector

Year	Total Production (Mt cement)	Total Fuel Consumption					Total Energy (PJ, fuel+ electricity)	CO2 emissions (million tones)	Fuel Intensity (GJ/tonne cement)	Energy Intensity (GJ/tonne cement)	Emissions Intensity (tonne CO2 / tonne cement)
		Coal	Gasoline	Natural Gas	All Fuels	Electricity (PJ)					
2000	718.3	3286	87.7		3374	338	3712	678.4	4.70	5.17	0.94
2005	881.5	3967	106.9		4074	415	4489	814.6	4.62	5.09	0.92
2010	1044.8	4623	125.7		4749	492	5241	950.7	4.55	5.02	0.91
2015	1132.3	4887	133.7		5021	530	5551	1008	4.43	4.90	0.89
2020	1219.8	5132	141.3		5273	568	5841	1064	4.32	4.79	0.87
2025	1323.6	5423	150.5		5573	618	6191	1129	4.21	4.68	0.85
2030	1427.4	5691	159.1		5850	668	6518	1181	4.10	4.57	0.83

Table 5-19. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)			
	Coal	Oil	Electricity	Process
2000	299.9	4.30	35.9	338.2
2005	362.1	5.03	41.4	406.1
2010	422.0	6.02	49.5	473.2
2015	446.1	6.52	55.0	500.5
2020	468.4	6.90	59.1	529.9
2025	495.0	7.39	63.7	562.5
2030	519.4	7.83	69.0	585.1

V.G.2 Advanced Options Scenario #2: All Mitigation Options costing less than $5 per metric ton

This mitigation scenario includes 3 additional mitigation options to Advanced Options Scenario #1 "All Zero- and Negative-cost Mitigation Options": High-Efficiency Motors and Drives, Active Additives, and Composite Cement.

V.G.2.i **Results from the mitigation scenario**

Table 5-20. Annual fuel consumption, emissions and intensity forecast for cement sector

Year	Total Production (Mt cement)	Total Fuel Consumption					Total Energy (PJ, fuel+ electricity)	CO2 emissions (million tones)	Fuel Intensity (GJ/tonne cement)	Energy Intensity (GJ/tonne cement)	Emissions Intensity (tonne CO2 / tonne cement)
		Coal	Gasoline	Natural Gas	All Fuels	Electricity (PJ)					
2000	718.3	3286	87.7		3374	338.5	3712	678.3	4.70	5.17	0.94
2005	881.5	3928	105.6		4034	415.9	4450	805.3	4.58	5.05	0.91
2010	1044.8	4531	122.6		4654	493.6	5148	932.1	4.45	4.93	0.89
2015	1132.3	4749	129.7		4879	532.2	5411	982.9	4.31	4.78	0.87
2020	1219.8	4942	136.3		5079	570.5	5649	1029.0	4.16	4.63	0.84
2025	1323.6	5172	144.2		5317	621.7	5938	1081.7	4.02	4.49	0.82
2030	1427.4	5373	151.5		5524	673.4	6198	1123.5	3.87	4.34	0.79

Table 5-21. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)			
	Coal	Oil	Electricity	Process
2000	299.9	4.30	35.9	338.2
2005	358.5	4.89	40.5	401.5
2010	413.6	5.80	48.6	464.1
2015	433.5	6.30	54.7	488.4
2020	451.1	6.64	58.8	512.4
2025	472.1	7.05	63.4	539.2
2030	490.4	7.43	68.8	556.9

V.G.3 Advanced Options Scenario #3: All Mitigation Options costing less than $10 per metric ton

This mitigation scenario includes 1 additional mitigation option to Advanced Options Scenario #2 "All Mitigation Options costing less than $5 per metric ton": Conversion to Multi-stage pre-heater kiln

V.G.3.i **Results from the mitigation scenario**

Table 5-22. Annual fuel consumption, emissions and intensity forecast for cement sector

Year	Total Production (Mt cement)	Total Fuel Consumption					Total Energy (PJ, fuel+ electricity)	CO2 emissions (million tones)	Fuel Intensity (GJ/tonne cement)	Energy Intensity (GJ/tonne cement)	Emissions Intensity (tonne CO2 / tonne cement)
		Coal	Gasoline	Natural Gas	All Fuels	Electricity (PJ)					
2000	718.3	3286	87.7		3374	338.5	3712	678.3	4.70	5.17	0.94
2005	881.5	3850	103.0		3953	417.5	4371	786.8	4.48	4.96	0.89
2010	1044.8	4348	116.5		4464	497.4	4961	895.0	4.27	4.75	0.86
2015	1132.3	4474	121.7		4596	536.1	5132	932.6	4.06	4.53	0.82
2020	1219.8	4564	126.2		4690	574.5	5264	958.6	3.84	4.32	0.79
2025	1323.6	4672	131.7		4804	629.2	5433	988.2	3.63	4.10	0.75
2030	1427.4	4736	136.4		4872	684.9	5557	1008.1	3.41	3.89	0.71

Table 5-23. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)			
	Coal	Oil	Electricity	Process
2000	299.9	4.3	35.9	338.2
2005	351.4	4.6	38.6	392.2
2010	396.8	5.4	47.0	445.8
2015	408.4	5.9	54.1	464.2
2020	416.6	6.1	58.2	477.6
2025	426.4	6.4	62.7	492.7
2030	432.3	6.6	68.6	500.6

V.G.4 Advanced Options Scenario #4: All feasible mitigation options

V.G.4.i **Results from the mitigation scenario**

Table 5-24 Annual fuel consumption, emissions and intensity forecast for cement sector

Year	Total Production (Mt cement)	Total Fuel Consumption					Total Energy (PJ, fuel+ electricity)	CO2 emissions (million tones)	Fuel Intensity (GJ/tonne cement)	Energy Intensity (GJ/tonne cement)	Emissions Intensity (tonne CO2 / tonne cement)
		Coal	Gasoline	Natural Gas	All Fuels	Electricity (PJ)					
2000	718.3	3285.8	87.7		3712	338.5	4050.5	678.3	5.17	5.64	0.94
2005	881.5	3811.7	101.7		4331.7	418.3	4750.0	777.5	4.91	5.39	0.88
2010	1044.8	4255.6	113.5		4868.3	499.3	5367.6	876.4	4.66	5.14	0.84
2015	1132.3	4336.3	117.7		4992.2	538.1	5530.3	907.4	4.41	4.88	0.80
2020	1219.8	4374.4	121.2		5072.1	576.5	5648.6	923.3	4.16	4.63	0.76
2025	1323.6	4421.5	125.5		5179.9	633.0	5812.9	941.5	3.91	4.39	0.71
2030	1427.4	4417.5	128.8		5236.9	690.6	5927.5	950.4	3.67	4.15	0.67

Table 5-25. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)			
	Coal	Oil	Electricity	Process
2000	299.9	4.30	35.9	338.2
2005	347.9	4.48	37.6	387.5
2010	388.4	5.15	46.1	436.7
2015	395.8	5.65	53.9	452.1
2020	399.3	5.85	58.0	460.2
2025	403.6	6.03	62.4	469.4
2030	403.2	6.23	68.4	472.5

V.G.5 Co-Benefits

Mitigation Option	Water quality improvements	Increased economic productivity and competitiveness	Job creation	Technology development and transfer	Infrastructure development	Enhanced energy security and independence	Air quality improvement
Preventative Maintenance		☆☆☆☆		☆	☆☆☆		
Process management and Control	☆	☆☆☆		☆	☆☆	☆	☆☆
Use of Waste Derived Fuels	☆☆	☆☆☆		☆☆	☆☆	☆	
Kiln Shell Heat Loss Reduction		☆☆		☆	☆☆	☆	☆
High-Efficiency Motors and Drives		☆☆		☆	☆		
Active Additives	☆	☆		☆			
Composite Cement	☆	☆					
Combustion System Improvement	☆☆	☆		☆☆	☆	☆☆	☆☆
Conversion to Multi-stage pre-heater kiln	☆	☆☆		☆☆☆	☆	☆☆	☆☆☆
High-efficiency roller mills	☆	☆		☆☆	☆	☆	
High-efficiency Powder Classifiers		☆		☆	☆	☆	
Efficient transport systems		☆		☆	☆☆	☆	

VI. Sector Analysis and Results: Pulp and Paper

VI.A Sector Overview

Total annual output and consumption of paper in China has kept rising starting from 1990. Over the past 20 years, the annual paper production capacity in the China has increased significantly, from 5.56 million tonnes in 1980 to 27.44 million tonnes in 1997, representing an average increase of 1.21 million tonnes or 10.1% per year, higher than the 6.7% global growth rate during the period. Paper production in China grew at an annual rate of 15.4% during the 10-year period from 1991 to 2000. In 2001, total paper production in China was 30.50 million tonnes. In 2000, China was the world's third largest paper producer, after the United States and Japan (Now, China is the second largest paper producer only after USA).

There is about 5 million metric tons gap between consumption and production. Paper consumption in China represented approximately 10% of the world's total consumption in 2000. In 2000, China surpassed Japan as the world's second largest and Asia's largest paper consumer. However, per capita paper products consumption in China was only approximately 28 kilograms per year in 2000 whereas per capita consumption in most developed countries such as the United States and Japan was more than 200 kilograms per year.

It is obvious that total consumption of paper products in China will increase further due to continuing development of China's economy following the increase of the country's living standard.

Table 6-1. Annual output and consumption of China's paper industry

Year	Paper pulp output(10000 metric tons)	Paper and paperboard(1000 metric tons)				Consumption per capital(kilogram per capita per year)
		Total output	Import	Export (1000 metric tons)	Total consumption	
1990	834.96	1391.87	96.20	25.20	1462.87	2.79
1991	860.59	1498.69	133.90	23.30	1609.29	13.89
1992	1031.81	1745.10	251.60	23.00	1973.70	16.86
1993	823.28	1820.00	245.00	22.20	2042.80	17.24
1994	1006.69	2136.00	318.00	27.00	2427.00	20.25
1995	1143.69	2400.00	302.90	53.00	2649.90	21.70
1996	1211.79	2600.00	449.00	22.00	3027.00	24.70
1997	1147.79	2733.00	552.00	27.00	3258.00	26.40
1998		2800.00	577.00	30.00	3347.00	26.80
1999	918.43	2900.00	652.30	13.80	3525.00	27.80
2000	1048.72	3050.00	597.10	71.80	3575.00	28.00

At present, according to industrial experts, the Chinese paper industry's major problems revolve around the fact that many Chinese factories are poorly equipped in regard to both facilities and technology. Chinese paper mills are either equipped with facilities produced 40 or 50 years ago or those very advanced imported ones. Due to poor equipment, most Chinese paper factories are continuing to produce paper out of non-wood fibre, such as straw fibre. Foreign countries now mainly produce high value-added paper out of wood fibre. Last year, China imported a large amount of this type of paper.

The industry structure, including enterprise scale and use of raw materials, leads to higher energy consumption and more pollutants in China's pulp and paper industry.

The following table show energy efficiency in China's pulp and paper industry comparing with Japan. The data is out of date and the energy efficiency gap between China and Japan at present already shortened. But the general technology level of China's pulp and paper has been at low level.

Table 6-2.Energy efficiency in China's pulp and paper industry comparing with Japan

	Units	China,19995	Japan,1993	Comparing with Japan
Paper and paperboard output	million metric tons	27.80	27.67	100.4%
Energy consumption	Million metric tce	21.38	17.81	119%
Energy consumption per unit production	Metric tce/t	1.57	0.65	241%
thereinto:				
Sulphate pulp bleaching	Metric tce/t	0.714	0.391	210%
Mechanical pulp	Metric tce/t	0.278	0.166	167%
Printing paper	Metric tce/t	0.36	0.363	174%

In order to produce higher quality paper and paperboard and to reduce pollution, China's paper manufacturers are turning away from traditional fibres such as wheat straw, bamboo and bagasse and now use increasing amounts of wood pulp and recycled wood fibres in the manufacture of paper products. In 2002, Non-wood pulp accounts for 32% of total pulp and only 30% in 2003.

Table 6-3.China's paper grade fiber consumption

	2002	Share of total %	2003	Share of total %	Change %
Total	34700.00	100	39100.00	100	12.68
Wood pulp	7400.00	21	8200.00	21	10.81
Waste paper	16200.00	47	19200.00	49	18.52
Non-wood pulp	11100.00	32	11700.00	30	5.41

Data source: China Paper Association

Total employee in China's pulp and paper industry is 806.7 thousand and physical labor productivity keeps rising.

Table 6-4.Work force and physical labor productivity of pulp and paper industry

Year	Work force(10000 people)		Physical labor productivity(metric ton per capita per year
	Total employee	technician	
1990	80.73	3.17	17.07
1991	83.29	3.37	18.06
1992	84.32	3.45	19.62
1993	78.74	3.71	20.68
1994	79.28	3.63	21.89
1995	81.66	3.99	21.04
1996	80.03	4.00	21.40
1997	76.35	4.05	22.05
1998	52.20		23.52
1999	86.42		25.00
2000	80.67		30.83

Most paper production facilities in China are state-owned enterprises. Many of these facilities have yet to meet international standards, in terms of quality and product variety, and are of a scale much smaller than international operators. In order to compete more effectively with foreign paper imports, China is actively undergoing restructuring with a view to expedite the development of its paper industry. These restructuring measures include encouraging plant automation of state-owned enterprises with a view to improve product quality and diversity, promoting merger and acquisition activities within the industry, encouraging foreign investments in forming equity or cooperative joint venture in pulp and paper production in China and suspending the production of smaller producers, particularly those that cause severe pollution.

According to China Paper Association, there were approximately 4,000 paper factories in China in 2001. Of this number, 2,620 paper factories had an annual sales of RMB 5 million and their combined production accounted for approximately 82% of the country's total.

In 2003, the number of the companies whose individual sales over RMB 5 million per year rose to 2766, 14.06% were owned or majority held by the state, down 3.74% from 2002, 9.04% were under Sino-foreign JV or 100% foreign ownership, up 0.94% and 76.90% were collectively or privately owned, up 2.8% from 2002.

By revenue, 29.23% came from state-owned or state-held companies, down 2.17% from 2002, 31.18% from joint venture or 100% foreign owned operations, up 0.88% from 2002 and 39.59% from collectively or privately owned companies, up 1.29% from 2002.

This confirmed the changes in equity structure in the industry. Although JV and foreign owned companies only accounted for 9.04% in number, they took up more than 30% of industry sales, earnings before interest and tax and net earnings respectively. Their progress in production, product development and market shares enabled them remarkable economic returns.

China Government regulates those industries that produce waste water such as the pulp and paper industry. Under the "People's Republic of China Environmental Protection Law", the environmental protection administration departments under the State Council are responsible for the overall regulation and management of environmental protection in China, whereas the various provincial environmental protection administration departments are delegated the powers to regulate and manage environmental protection of the relevant provinces. Waste water is produced in pulp and paper production and the quality of waste water produced by such manufacturers is subject to the monitoring of environmental protection bureau in their respective provinces and must meet the waste water effluent standard in terms of chemicals discharged set by China Government for the paper industry. Along with water pollution abatement, there will also co-benefits from energy conservation. In pulp and paper industry the scale of facilities is the main factor influencing energy efficiency and environmental performance.

VI.B Emissions Overview of Sector

VI.B.1 Background and discussion of emissions, main sources/causes/drivers, trends

Greenhouse gas emissions in pulp and paper sector are primarily the result of burning fossil fuels during the production. In 2000, pulp and paper industry accounts for 1.67% of country's total energy consumption. The following table is the historical annual fuel consumption and GHG emission. During all fuel consumption of pulp and paper industry, share of coal is more than 90%.

Table 6-5.Historical annual fuel consumption and GHG emissions

Year	Total Annual Fuel Consumption, all Fuels (PJ)	Annual GHG Emissions ($MMTCO_2e$)
1990	496.48	45.31
1991	508.49	46.41
1992.	555.39	50.69
1993	566.23	51.68
.1994	580.59	52.99
1995	626.61	57.19
1996	644.78	58.85
1997	645.36	58.90
1998.	561.54	51.25
1999	569.45	51.98
2000	679.34	62.67

VI.C Background Assumptions for Sector Analysis

Prevention and control of water pollution is the focus of pulp and paper industry, rather than energy conservation.

There are many difficulties in the evaluation of mitigation option's cost and reduction potential in pulp and paper industry. Because the industry structure rather than some one specific technology is the most important in energy conservation.

In order to simplify our analysis and gain some results, we establish three kinds of scenarios named baseline pre 2000, baseline between 2000 and 20005, mitigation scenario.

In the scenario analysis of pulp and paper, differences between these three scenarios is the output proportion of enterprises with different scale.

The following figure shows the analytical framework and data structure for pulp and paper industry.

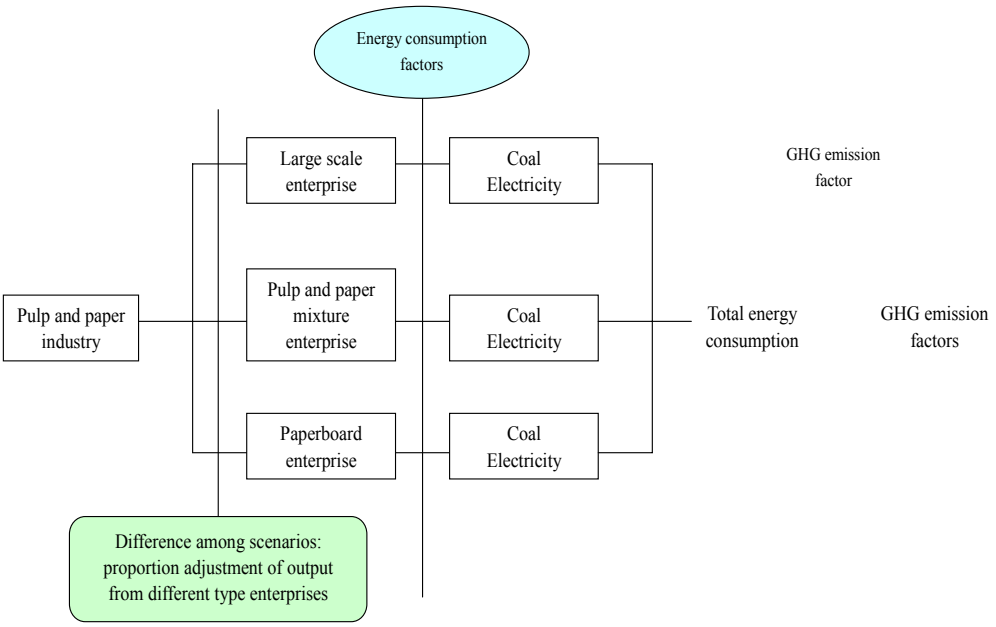

Figure 6-1. Analytical framework and data structure for pulp and paper industry

VI.D Baseline (Business-As-Usual) Forecasts for Sectors

VI.D.1 Production/output forecast

In China, per capita paper products consumption is at lower level and obviously in the future following the increase of people's living standard, per capita paper products consumption will rise and total consumption then will increase further.

The following figure is the output forecast of paper and paperboard in China's pulp and paper industry from 2000 to 2003.

Output of paper products will keep rising and reach 48.28 million tonnes at 2010,76.42 million tonnes at 2020 and 120.98 million tonnes at 2030.

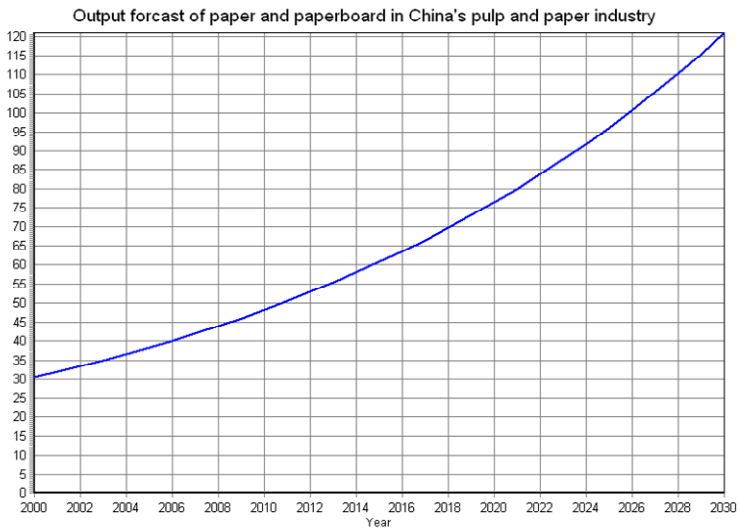

Figure 6-2. Output forecast of paper and paperboard in China's pulp and paper industry

VI.D.2 Energy and fossil fuel consumption (by type) forecast

Along with the increasing of output of paper products, energy consumption and GHG emission will also keep rising, just as the following figure shows.

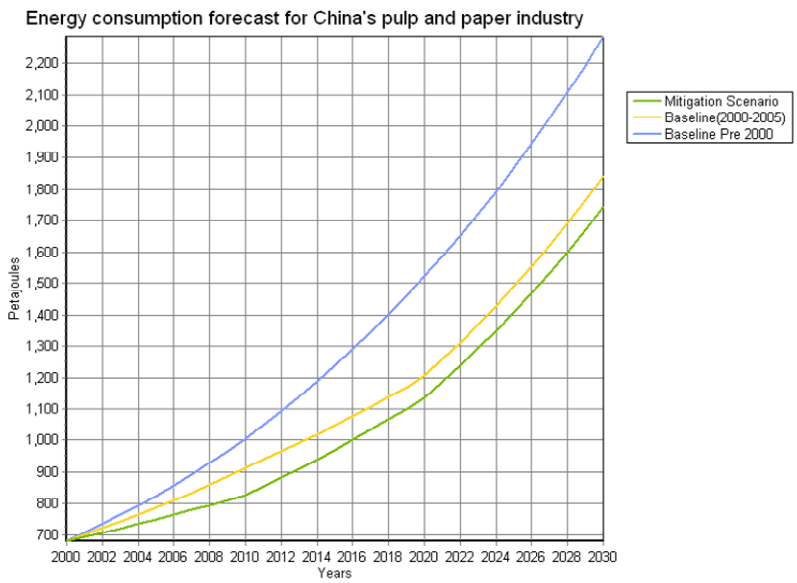

Figure 6-3. Energy consumption forecast for China's pulp and paper industry

VI.D.3 Annual GHG forecast

CO2 emission has the similar trend with energy consumption forecast. Compared with two baseline scenarios, mitigation scenario will have much emission reduction potential. In the mitigation scenario, more paper products are produced by larger scale enterprises. These enterprises will have wood resource owned by themselves and then produce wood pulp, produce paper and different paperboard.

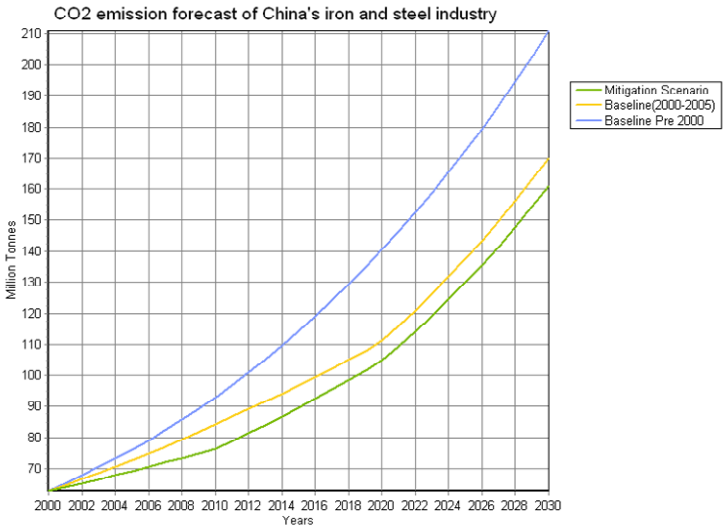

Figure 6-4. CO2 emission forecast for China's pulp and paper industry

Compared with baseline pre 2000, other two scenarios have emission reduction potential. The accumulative emission reduction between two baselines is 41.77 million metric tons at 2010,233.19 million metric tons at 2020 and 588.69 million metric tons at 2030.

The accumulative emission reduction between mitigation scenario and baselines pre 2000 is 82.11 million metric tons at 2010,343.27 million metric tons at 2020 and 776.06 million metric tons at 2030. Finally, the accumulative emission reduction between mitigation scenario and baselines 2000-2005 is 40.34 million metric tons at 2010,110.07 million metric tons at 2020 and 187.37 million metric tons at 2030.

Taking into account the exiting rapid technology advancement in China's pulp and paper industry, which has be boosted by some new industry policies promulgated between 2000 and 2005, emission reduction potential between mitigation scenario and baseline 2000-2005 will have more significance for mitigation policy in this industry.

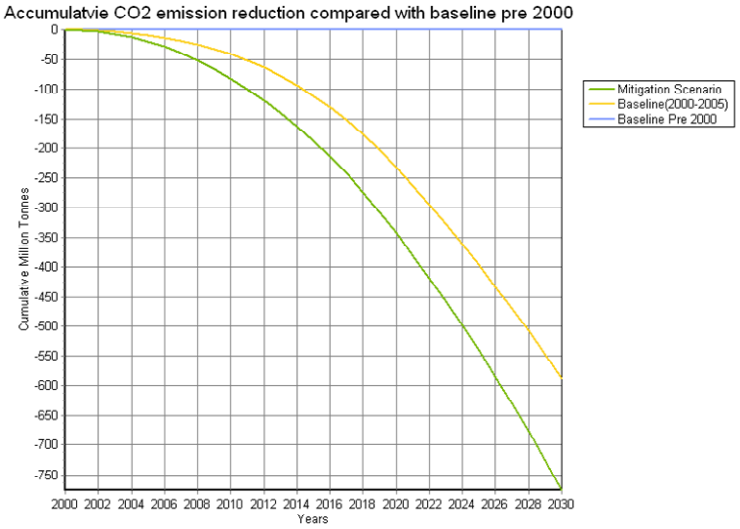

Figure 6-5. Accumulative CO2 emission reduction compared with baseline pre 2000

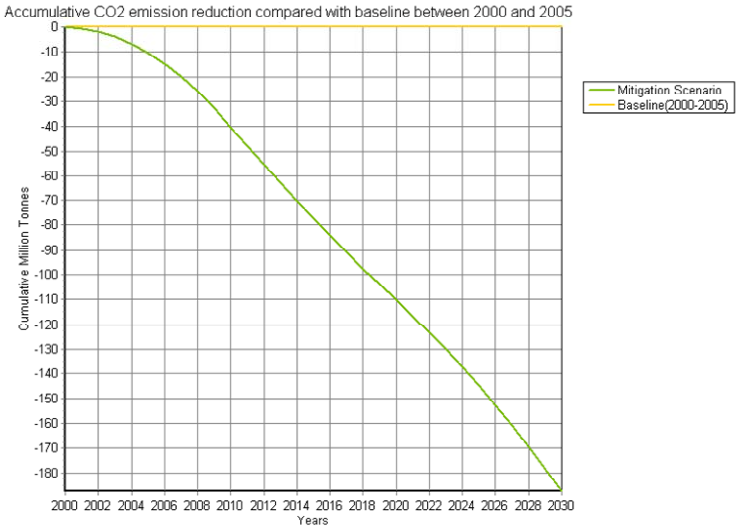

Figure 6-6. Accumulative CO2 emission reduction compared with baseline between 2000 and 2005

The following tables show the consolidated results of this sector's scenario analysis.

From these results, several conclusions can be gained.

The first, along with the rising of total production, total fuel consumption and total GHG emissions keep on rising in all scenarios.

The second, because of the industry's restructure and technology advancement, energy intensity and emission intensity, in all scenarios, keep on descending.

The third, because of stronger structure adjustment and technology advancement, the energy and emission intensities' descending will be fastest and then the increase of total fuel consumption and total GHG emission will be slower than the other two baseline scenarios.

Finally, difference of total energy consumption and GHG emission between mitigation scenario and baseline 2000-2005 will be smaller than the difference between two baselines.

VI.D.4 Energy intensity and CO2 intensity forecast (per unit of output)

Table 6-6. Annual Fuel Consumption, Emissions and Intensity Forecast (Baseline Pre 2000)

Year	Total Production (million metric tons)	Total Fuel Consumption (PJ)			Total GHG Emissions (MMTCO2e)	Energy Intensity (GJ/metric ton)	Emissions Intensity (metric tons CO2e/metric ton output)
		electricity	coal	All fuels			
2000	30.50	44.30	635.04	679.34	62.67	22.27	2.05
2005	38.37	53.79	771.11	824.90	76.09	21.50	1.98
2010	48.28	65.51	938.96	1004.47	92.66	20.81	1.92
2015	60.74	80.72	1156.99	1237.71	114.18	20.38	1.88
2020	76.42	99.42	1425.02	1524.44	140.63	19.95	1.84
2025	96.15	121.80	1745.69	1867.49	172.27	19.42	1.79
2030	120.98	149.11	2136.96	2286.07	210.88	18.90	1.74

Table 6-7 Annual Fuel Consumption, Emissions and Intensity Forecast (Baseline 2000 to 2005)

Year	Total Production (million metric tons)	Total Fuel Consumption (PJ)			Total GHG Emissions (MMTCO2e)	Energy Intensity (GJ /metric ton)	Emissions Intensity (metric tons CO2e/metric ton output)
		electricity	coal	All fuels			
2000	30.50	44.30	635.04	679.34	62.67	22.27	2.05
2005	38.37	51.35	736.04	787.39	72.63	20.52	1.89
2010	48.28	59.50	852.86	912.37	84.16	18.90	1.74
2015	60.74	68.27	978.48	1046.75	96.56	17.23	1.59
2020	76.42	78.53	1125.37	1203.90	111.06	15.75	1.45
2025	96.15	97.17	1392.48	1489.65	137.42	15.49	1.43
2030	120.98	120.21	1722.51	1842.72	169.99	15.23	1.41

Table 6-8. Annual Fuel Consumption, Emissions and Intensity Forecast (Advanced Options/Mitigation Scenario)

Year	Total Production (million metric tons)	Total Fuel Consumption (PJ)			Total GHG Emissions (MMTCO2e)	Energy Intensity (GJ /metric ton)	Emissions Intensity (metric tons CO2e/metric ton output)
		electricity	coal	All fuels			
2000	30.50	44.30	635.04	679.34	62.67	22.27	2.05
2005	38.37	48.82	699.76	748.59	69.05	19.51	1.80
2010	48.28	54.03	774.37	828.40	76.42	17.16	1.58
2015	60.74	63.27	906.64	969.91	89.47	15.97	1.47
2020	76.42	74.18	1062.82	1137.00	104.89	14.88	1.37
2025	96.15	91.87	1316.15	1408.02	129.89	14.64	1.35
2030	120.98	113.76	1629.44	1743.20	160.81	14.41	1.33

VII. Sector Analysis and Results: Transportation

VII.A Sector Overview

VII.A.1 Summary and explanation of economic statistics

Transport sector is one of the fundamental sectors in national economy and plays the role of transferring freight and passengers. Along with the booming economy and the improving living condition in China, transport sector has also been experiencing a rapid development.

VII.A.1.i Total output/production

Table 7-1 shows the development of passenger and freight traffic in China from 1990 to 2000. The volume of passenger traffic had almost doubled, and the freight traffic volume in 2000 was 1.4 times of the 1990 level.

Table 7-1 Statistics of Passenger Traffic and Freight Traffic in China, 1990-2000

Year	Passenger Traffic (million people-trips)	Freight Traffic (million tons)	Activity Level of Passenger Traffic (billion persons-km)	Activity Level of Freight Traffic (billion tons-km)
1990	7727	9706	562.9	2621
1991	8061	9858	617.8	2799
1992	8609	10459	694.9	2922
1993	9966	11159	785.8	3053
1994	10929	11804	859.1	3328
1995	11726	12349	900.2	3591
1996	12447	12984	914.3	3659
1997	13261	12782	1006	3839
1998	13787	12674	1064	3809
1999	13944	12930	1130	4057
2000	14786	13587	1226	4432

Data source: China Statistic Yearbook
Note: Passenger traffic data includes national railways, local railways, highways, marine transport and civil aviation. Freight traffic data includes national railways, local railways, highways, marine transport, civil aviation and petroleum and gas pipelines.

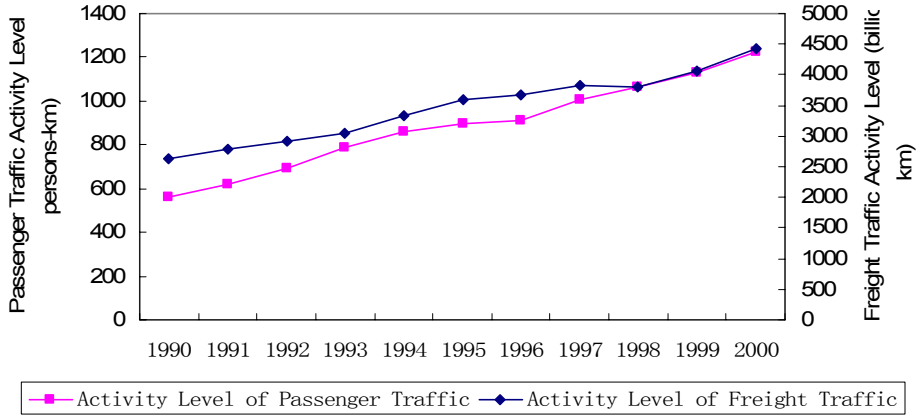

Figure 7-1 Activity level of passenger and freight traffic in China from 1990-2000

Figure 7-1 displays a steadily growing activity level of passenger and freight traffic in China from 1990-2000. It is a normal reflection of China's booming economy and people's higher demand for travel and freight delivery.

VII.A.1.ii Employment

Table 7-2 shows that the number of staff and workers engaged in transport sector from 1996 to 2002 had been declining all the time. And it remained for all these years along that around 60% of staff worked in railway and highway transport.

Table 7-2 Number of Staff and Workers Engaged in Transport Sector 1996-2002 (thousand persons)

Year	Railway Transport	Highway Transport	Pipeline Transport	Marine Transport
1996	2214	2063	36.0	757.0
1997	2238	2000	26.0	723.0
1998	1934	1395	33.0	513.0
1999	1852	1290	29.0	443.0
2000	1811	1200	22.0	388.0
2001	1789	1090	17.9	326.2
2002	1758	1016	50.9	281.5
Year	Air Transport	Transport Subsidiary Trades	Other Transports	Total
1996	108.0	1516	46.0	6740
1997	116.0	1521	40.0	6664
1998	112.0	1478	20.0	5485
1999	125.0	1512	25.0	5276
2000	117.0	1477	19.0	5034
2001	121.5	1457	21.5	4824
2002	120.5	1409	18.7	4655

Data Source: China Statistic Yearbook

Besides, in 2003, people worked in auto industry (only people working at vehicle manufacturing plants, components and auto-related industries excluded) reached 33 million, which was 1/7 of the urban employees. This data didn't include those people working in component supply industries and auto-related industries. (Miao. 2004)

VII.A.1.iii Revenues, share of GDP

We can tell from Table 7-3 that from 1990 to 2000, the revenues of transport sector had quadrupled, while its share of GDP remained almost the same during this period.

Table 7-3 Revenue of Transport, Storage, Postal & Telecommunications Services and its share of GDP

	Revenue (billion US$)[a]	GDP (billion US$)[a]	Share of GDP
1990	13.9	224.3	6.20%
1991	17.0	261.4	6.52%
1992	20.3	322.1	6.31%
1993	25.6	418.7	6.12%
1994	32.5	565.4	5.75%
1995	37.0	707.1	5.23%
1996	42.2	820.9	5.14%
1997	45.9	884.4	5.20%
1998	49.8	930.7	5.35%
1999	53.9	974.4	5.53%
2000	65.4	1067	6.13%

Data source: China Statistic Yearbook

[a] in year 2000 US$ Exchange rate of USD: RMB=1:8.27

It should be noted that due to statistical caliber in China, revenue of transport sector is not available. Here we use revenue of transport, storage, postal & telecommunications services for reference.

VII.A.1.iv Role of transport sector in overall economy as source of inputs to other sectors

Transport has always played a supportive role for other sectors' development. According to a research, the annual new job opportunities directly created by transport sector from 2001 to 2004 reached 10 million, and the number is rising by 1.7 million per year. And the induced job opportunities by transport investment had reached about 25 million, which was 13% of the new job opportunities national-wide for the same period. (Cen, 2004) The development in transport sector would bring market demand for manufacturing, marketing, maintenance, financial service, storage sector, environmental protection and etc. Besides, a well-designed transport system would increase the efficiency of other sectors' material purchase and merchandise selling, which indirectly increases the sectors' net income. For the auto industry especially, according to the experience in developed countries, each dollar added by the auto industry would bring in 0.65 dollar to the upper industries (such as component manufacturing industries) and 2.63 dollars to the subsequent industries (such as carwash industries) (Zhao. 2003).

VII.A.2 Quantitative and qualitative characterization of sector

Patterns of the development of total fuel consumption and fuel economy vary significantly among different transport facilities, such as railway, road, waterway, air, and pipeline. Here, we focus on the fuel consumption of road transport for the following reasons: 1) road transport took up over 50% of the total gasoline and diesel consumption in the whole transport sector and is experiencing a rapid consumption growth rate—nearly 12.6% per year, which is higher than all the other transport ways except air transport (Zhou et al. 2003); 2) the mitigation potential of road transport is larger than that of other transport modes; 3) the data and research in road transport are much more available than the others. Taking all these factors into consideration, we focus all the following characters and analysis on road transport.

VII.A.2.i Breakdown of vehicles in Analysis

In road transport, facilities could be divided into truck, bus, car and motorcycle. Truck refers to freight carrier or towing vehicle. Bus refers to vehicle which can carry more than 9 people, with rectangular carriage, mainly for passengers and their taken-with baggage. Car refers to small passenger vehicle which can carry 2 to 8 people, with four wheels, including taxi. Motorcycle refers to 2-wheel or 3-wheel vehicle. Each type contains vehicles for both commercial and personal use. Furthermore, truck could still be categorized into heavy (HT), medium(MT), light(LT) and mini(MiniT) by gross vehicle weight, and bus into the similar categories (HB, MB, LB and MiniB) by total vehicle length[43].

Table 7-4 shows the number of different types of vehicles in China in 2000. The total vehicle ownership (excluding motorcycle) in 2000 had reached 15.72 million, in which truck, bus and car took up 46%, 26% and 28% respectively. The total motorcycle ownership in 2000 was 37.7 million. The most recent data shows that in 2004, the vehicle ownership in China reached 27.42 million (motorcycle excluded) (NSB, 2005). And from 1990-2003, the average annual growth rate of vehicle ownership was 12%. And the average annual growth rate of private vehicle ownership reached 31% in the same period (Shen, 2005), which aligned with the encouragement policy in China for vehicles' private ownership.

43 Heavy truck (HT): 14.0 tons<gross vehicle weight (GVW)
Medium truck (MT): 6.0 tons <GVW<14.0 tons
Light truck (LT): 1.8 tons<GVW<6.0 tons
Mini truck (MiniT): GVW<1.8tons
Heavy bus (HB): 10.0 meters<total vehicle length (TVL)
Medium bus (MB): 7.0 meters<TVL<10.0 meters
Light bus (LB): 3.5 meters<TVL<7.0 meters
Mini bus (MiniB): TVL<3.5 meters

Table 7-4 Number of entire fleet of vehicles by type in China (million units), data in 2000

Truck	Bus	Car	Motorcycle
7.18	4.14	4.40	37.7

Data Source: Huo Hong (2002)

Table 7-5 and 7-6 show the composition of new trucks and buses sold in China in 2000. In 2000, new light truck took up more than 50% of the total new truck sales and new mini bus took up nearly 60% of the total new bus sales.

Table 7-5 Percentage of HT, MT, LT and MiniT in total new trucks in China, data in 2000

HT	MT	LT	MiniT
10.7%	21.1%	51.2%	17.0%

Data Source: Huo Hong (2002)

Table 7-6 Percentage of HB, MB, LB and MiniB in total new buses in China, data in 2000

HB	MB	LB	MiniB
1.3%	5.0%	35.0%	58.7%

Data Source: Huo Hong (2002)

Gasoline and diesel are the main vehicle fuels in China. And most light vehicles are using gasoline. Table 7-7 shows the percentage of gasoline vehicle in different types of fleet-wide vehicles in China in 2000.

Table 7-7 Percentage of gasoline vehicle in different types of vehicles in China, data in 2000

HT	MT	LT	MiniT	Car
2.00%	35.00%	40.00%	99.50%	100.00%
HB	MB	LB	MiniB	
8.00%	45.00%	67.00%	100.00%	

Data Source: China Automotive Industry Yearbook (2001)

Table 7-8 shows the annual average traveled kilometers of each class of vehicle in China in 2000.

Table 7-8 Annual vehicle kilometers traveled (VKT) of each type of vehicle in China (thousand kilometers), data in 2000

HT	MT	LT	MiniT	Car
67.4	25	20.9	43.2	26.4
HB	MB	LB	MiniB	MC
52	52	34	35	9

Data source: Huo Hong (2002)

By 2000, there has been no officially published fuel economy statistics of each class of vehicles in China. However, in 1998, Department of Mechanics and Industry had released a New Vehicle Technology Handbook, which demarcated the tested fuel economy of vehicles at that time. European NEDC test cycle is used to measure tested fuel economy. See Table 7-9.

Table 7-9 Tested fuel economy of new vehicles (km/L) in 1998 in China

HT		MT		LT		MiniT		Car	
Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
3	4.42	3.98	5.71	7.87	8.7	15.38	18	14.71	20
HB		MB		LB		MiniB		MC	
Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel		
2.94	4.03	3.57	4.21	10.03	11.76	15.87	19	49.02	

Data Source: New Vehicle Technology Handbook (1998)

Up till 2000, there has been no fuel efficiency data or limits published. Therefore, we intend to use the above 1998 data to reflect the situation in 2000. Furthermore, an adjustment factor is introduced here to transform the tested fuel economy to the on-road fuel economy. This factor takes other important factors influencing fuel economy into consideration, such as the kilometers the vehicle had traveled, average travel speed, driver's personal habits, fuel quality and road conditions etc. We set this adjustment factor 75% in the research (Huo Hong, 2002). Take heavy truck for example. The fuel economy of new heavy truck in 1998 was 3 km/L, so that the real fuel economy of new heavy truck was 3×75%, that was 2.25 km/L. Table 7-10 shows the on-road fuel economy of new vehicles (km/L) in 2000 in China. It should be noted that for the fuel economy of cars, we choose to refer to a research on regulations and policies on Chinese vehicles' fuel economy (CATARC, 2003), which mentioned the cars' fuel economy reality in 2000 (it says phase I of the newly published Maximum Limits of Fuel Economy for Passenger Cars would help cars and LDVs to increase their fuel economy by 5% to 10% in the 10th five-year period, so we use the limits to educe the fuel economy reality. We also assume there is no fuel economy difference between gasoline and diesel cars.).

Table 7-10 On-road fuel economy of new vehicles (km/L) in 2000 in China

HT		MT		LT		MiniT		Car	
Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
2.25	3.32	2.99	4.28	5.90	6.53	11.5	13.5	6.17	6.17
HB		MB		LB		MiniB		MC	
Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel		
2.21	3.02	2.68	3.16	7.52	8.82	11.90	14.25	36.77	

VII.A.2.ii Brief and general comparisons with rest of the world

Figure 7-2 shows the comparison of fuel economy of Chinese vehicle models (red dots) and the European models (black triangles) in 2004. Obviously, Chinese vehicles models are lighter but less efficient.

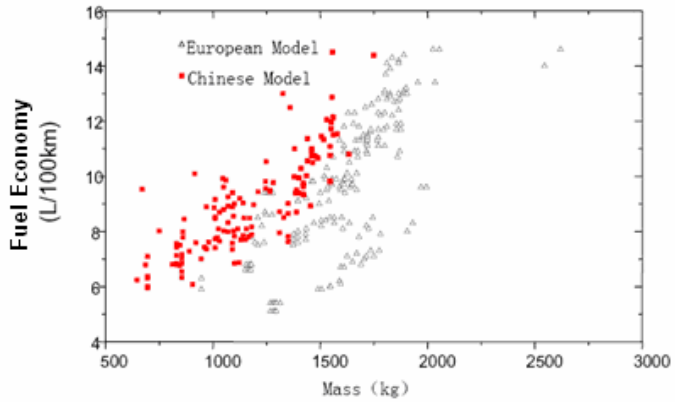

Figure 7-2 Comparison of fuel economy of Chinese and European vehicle models in 2004
Source: Feng An (2004)

VII.A.2.iii Ownership patterns of sector

Car ownership in China in 2005 is very low. The total number is about 9 cars per 1000 people, as compared to over 700 per 1000 people in US. However, it is growing at impressive rates as China's urban middle class embraces the automobile just as Americans did in the 1930s (Wei. 2005).

VII.B Emissions Overview of Sector

VII.B.1 Background and discussion of emissions

Road transport emissions keep growing these years. Although the current advanced technology has greatly improved fuel efficiency, the booming vehicle ownership, the more and more severe traffic congestion, and people's higher desire for comfort have resulted in the higher emission share of road transport in total national emissions.

VII.B.2 Annual GHG emissions inventory for a recent year

VII.B.2.i Total emissions by source

In 2000, the CO2 emission of road transport sector in China reached 213 million tons. Table 7-11 shows the CO2 emission by vehicle type in road transport sector.

Table 7-11 CO2 emission of road transport sector in China, data in 2000 (million tons)

HT		MT		LT		MiniT		Car	
Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
1.45	22.70	14.34	22.62	9.98	17.96	11.94	0.012	43.2	0
HB		MB		LB		MiniB		MC	Total
Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel		
0.16	2.21	5.62	7.03	13.55	5.86	13.22	0	21.19	213.0

Data source: Huo Hong (2002)

VII.B.2.ii Percent share of emissions by source

From Figure 7-3, it is obvious that in China in 2000, emission from truck took up nearly half of the total road transport emissions, followed by bus (22%), car (20%) and motorcycle(10%).

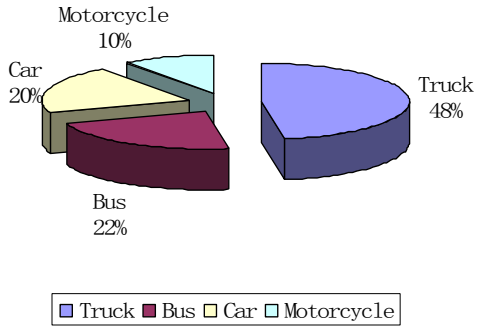

Figure 7-3 Percent share of emission by vehicle type, data in 2000

VII.B.3 Historical annual fuel consumption and GHG emissions trends by fuel type (1990--2000)

Due to statistical restrictions, we could only use energy consumption in transport, storage, postal & telecommunications Services to roughly show the trends and share of road transport sector. See Table 7-12 and Figure 7-4.

Table 7-12 Energy consumption of Transport, Storage, Postal & Telecommunications Services and its share in total energy consumption

	1995	1996	1997[b]	1998	1999	2000	2001	2002	2003
Energy Consumption of Transport, Storage, Postal&Telecommunications Services(billion GJ)[a]	1.59	1.63	1.84	2.05	2.51	2.70	2.79	3.02	3.47
Total Energy Consumption (billion GJ)	35.7	37.8	37.7	37.6	35.4	35.4	36.7	40.3	46.5
Share	4.47%	4.31%	4.89%	5.46%	7.10%	7.61%	7.60%	7.48%	7.45%

Data: China Statistic Yearbook

[a]1 tce=27.2 GJ (ZBEPB(Zibo Environmental Protection Bureau))

[b]The 1997 data is not available from China Statistic Yearbook. The data here is the average of value in 1996 and 1998.

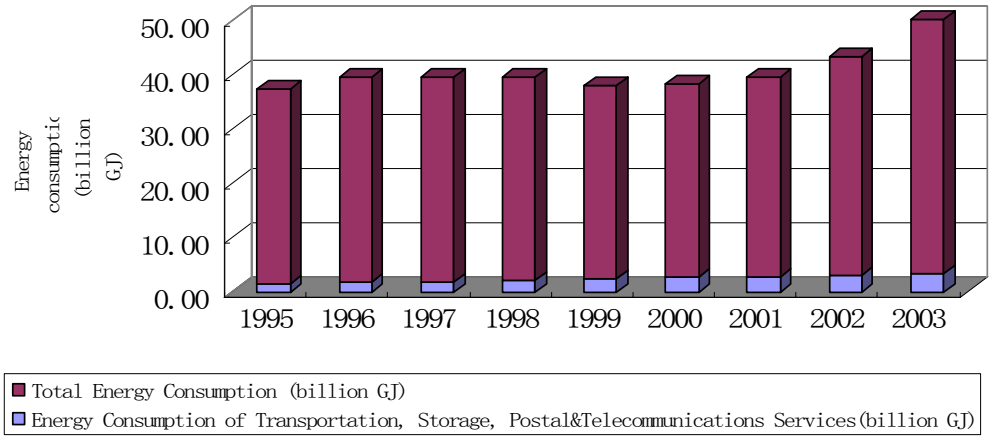

Figure 7-4 Energy consumption of Transport, Storage, Postal & Telecommunications Services (billion GJ) and its share in total energy consumption

The sector had experienced a continuous growth in energy consumption from 1996 to 2003; with its share gradually increase in total energy consumption. This aligns with the global trend that transport would become one of the main sectors that consume most of the energy.

VII.B.4 Relative contribution of each sector in 2000

VII.B.4.i <u>to total national energy consumption and emissions</u>

As we can see from the tables above, transport sector takes up about 7% of the national energy consumption. As road transport sector takes up 50% (Zhou et al, 2003) of the energy consumption in transport sector, then the relative contribution of road transport would be roughly 3.5-4%.

VII.C Background Assumptions for Sector Analysis

VII.C.1 Baseline with policies adopted before 2000

VII.C.1.i <u>Policies under Consideration</u>

Policies related to road transport sector adopted before 2000 include:

In 1986 <Law on Fuel Saving Management in Transport Sector> focused on ways to improve management structure and enhance management efficiency.

In April 1986, <The seventh five-year plan of national economy and social development in the People's Republic of China> listed auto-manufacturing industry as one of the key industries in China, and since that time there has been a booming automobile industry.

In 1994 <Policies on Auto Industry> mentioned that the government would gradually adjust the current public-owned consumption mode in auto industry and greatly encourage individuals auto buyers. Meanwhile, it was referred that the government would enhance the reformation and investment centralization in auto industry.

In 1997, the government renewed the 1986 < Standards for the Scrapping of Motor Vehicles >and since then, two major adjustments had been made to it in 1998 and 2000. The most updated scrapping standards mainly are: Commercial-use vehicles (including taxis) have a legally required scrapping time – 8 years. Among non-commercial-use vehicles, passenger vehicles (including cars and SUVs) with no more than 9 seats have a suggested scrapping time – 15 years. Passenger vehicles with more than 9 seats have a suggested scrapping time – 10 years. Yet they do not need to pass any inspection to get the permission to extend their life-span, however they need to have two inspections each year (compared to only one inspection for normal vehicles). Heavy buses have a suggested scrapping time of 10 years and needs to pass inspection to get the permission to extend the life-span. Mini trucks have a legally required scrapping time of 8 years. Light truck, medium truck and heavy truck can drive for 10 years and needs to apply and pass the inspection if wanting to extend the life-span, yet the maximum life-span extension should not be longer than 10 years. Motorcycles have a suggested scrapping time of 9 years yet the maximum life-span extension should not be longer than 3 years. No inspection is needed for motorcycles to extend its life-span.

<Measurement method of fuel saving technology for automobiles> was published in 1994, and <Rules for the Publication of Energy Conservation Products of Automobiles and Vessels> in 1995, and <Decision on modifying highway law> in 1999.

And before 2000, another important technology handbook should be referred here. It was the < New Vehicle Technology Handbook> published by Department of Mechanics and Industrial. In the following sector analysis, we refer most of the fuel efficiency data in this handbook as the real fuel economy of new vehicles of vehicles in China in 2000.
Almost no policies directly related to reducing automobile fuel consumption and GHG emissions had been adopted before 2000.

VII.C.2 Baseline with policies adopted between 2000 and 2005

VII.C.2.i <u>Policies under Consideration</u>

In 2000, <Detailed Rules on the Implementation of Energy Conservation Law in the Transport Industries> implemented Energy Conservation Law from managerial perspective. And it encouraged adjusting vehicle structure and road planning and carrying out research on aspects such as fuel consumption limits, new fuel substitutes and lower friction.

In Mar. 2001 <Summary of the tenth five-year plan of national economy and social development> referred in official documents for the first time that ordinary families were encouraged to own autos. However, this policy has always been accompanied by fierce debate on its effects to urban transport and energy consumption.

In 2004, new <Policies on Auto Industry> was published to align with WTO regulations and added more market-oriented factors into the management system. Besides the policies that aimed at improving the market competency of home auto companies, companies were also induced and encouraged to develop energy-saving and environmental friendly automobiles, some with new types of fuel as well. The new policy had emphasized the harmony between auto industry development and the environment.

Also in 2004, the government had set up limits of fuel consumption level for two periods, for cars with different complete mass -- <Maximum Limits of Fuel Consumption (L/100-km) for Passenger Cars >.

The limits are applicable to vehicles which 1) are equipped with ignition engine or compression ignition engine; 2) have the maximum designed vehicle speed no less than 50km/h; 3) have the maximum designed mass no more than 3500 kg; 4) are passenger vehicles that have no more than 9 seats (including the driver seat). Obviously these limits are only applicable to cars in this research.

European NEDC test cycle is used to measure the fuel economy. These limits are tested fuel economy and are weight based. Standards for gasoline and diesel vehicles are identical. There are two separate sets of standard, one for passenger cars with manual transmission, and another for those with automatic transmission, SUVs and MPVs (Multi-Purpose Vehicles – vehicles with functions of cars, wagons, vans) with 3+ rows (all transmission types). Moreover, there are differences between the standard implementation timeline between the new registered vehicles and in-production vehicles. For new registered vehicles, phase I to implement these limits start from July 2005 and phase II starts from Jan 2008; for in-production vehicles, the corresponding two dates to start implementation are both one year behind the new registered vehicles. The limits in phase I could ensure the realization of goal in the 10th five-year plan (the oil consumption per 100 kilometers of cars and light duty vehicles could decrease 5% to 10% compared to the current oil consumption level) and the limits in phase II could ensure the realization of goal in the 11th five-year plan (a 15% decrease compared to current oil consumption level)

One fact is that most vehicles in China are manual. To simplify the following calculation and analysis, here we neglect the limits for auto/SUV and those in-production vehicles. The detailed limits information is shown in table below.

Table 7-13 Maximum Limits of Fuel Consumption for Passenger Car (L/100km)

Complete Mass (CM) (kg)	Stage I	Stage II
CM≤750	7.2	6.2
750 < CM≤865	7.2	6.5
865 < CM≤980	7.7	7
980 < CM≤1090	8.3	7.5
1090 < CM≤1205	8.9	8.1
1205 < CM≤1320	9.5	8.6
1320 < CM≤1430	10.1	9.2
1430 < CM≤1540	10.7	9.7
1540 < CM≤1660	11.3	10.2
1660 < CM≤1770	11.9	10.7
1770 < CM≤1880	12.4	11.1
1880 < CM≤2000	12.8	11.5
2000 < CM≤2110	13.2	11.9
2110 < CM≤2280	13.7	12.3
2280 < CM≤2510	14.6	13.1
2510 < CM	15.5	13.9

Data Source: Limits of Fuel Consumption for Passenger Car (GB19578-2004), 2005

In Nov 2004, <Mid- and Long-term Specific Plan on Energy Conservation> encouraged developing diesel vehicles and public transport. For passenger cars, the average on-road fuel economy should reach 8.2~6.7 liters per 100 km in 2010, compared 9.5 liters per 100 km in 2000. This plan greatly promoted the energy conservation action for all society.

VII.D Baseline (business-as-usual) Forecasts

The GHG emission in road transport sector is dependent on three factors: 1) vehicle fleet mix; 2) VKT of each type of vehicle; 3) fuel economy of each type of vehicle. This research only tracks tailpipe CO2 emissions from vehicles but does not account for non-CO2 tailpipe (such as e.g., CH4, N2O) and direct GHG emissions from air-conditioning coolant leaks.

VII.D.1 Production/output forecast

Projections on vehicle fleet mix and VKT are identical for both baseline scenarios (the 2000 policies and the 2005 policies).

VII.D.1.i Vehicle fleet mix

Since the late 1970s, the vehicle ownership in China has grown extremely rapidly, increasing about 10-fold during the past two decades. By the end of 2000, the total number of vehicles had reached nearly 16 million (motorcycles excluded). The following table shows the vehicle ownership by class in China from 1997 to 2000.

Table 7-14 Vehicle ownership in China from 1997 to 2000 (million units)

	Truck	Bus	Car	Total (Motorcycle excluded)	Motorcycle
1997	6.01	2.42	3.38	11.8	20.2
1998	6.28	2.88	3.67	12.8	25.2
1999	6.77	3.29	4.11	14.2	26.2
2000	7.18	4.14	4.4	15.7	37.7

Data source: Huo Hong (2003)

Elasticity factor method is used here to estimate the future vehicle ownership in China. According to Huo 2002, it is assumed that the growth rate of GDP in China is 8.0% from 2000 to 2010, 7% from 2010 to 2020, and 6.0% from 2020 to 2030, and the elasticity factor of vehicle ownership to GDP growth is 1.2 from 2000 to 2010, 1.15 from 2010 to 2020 and 1.1 from 2020 to 2030. The elasticity factor of motorcycle ownership to GDP growth is assumed to gradually decrease. In 2000-2006, it is stable at 2.5 and starts to decrease by 0.5 every year since 2006. It is stable at 0.5 in 2010-2015, and starts to decrease 0.1 every year since 2015. And since 2020, it is assumed that the elasticity factor turns down to 0. In 2030, China will have about 160 million vehicles, among which 60% are cars. Here we assume that the average scrapping time is 15 years.

In 1999, the proportion of trucks, buses, and cars in the total vehicle ownership was 48.9%, 20.3%, and 30.8% (motorcycle excluded) (Huo. 2002). As mentioned in the policies before year 2000, we see an industrial policy which was to encourage the development of cars and the improvement of people's quality of life. Therefore, this report assumes that the proportion of cars will increase greatly in the future 30 years. Although the number of buses and truck will also increase greatly, but their growth rate is much slower than that of cars. Therefore, their proportion in the total vehicle ownership will decrease gradually, as shown in Table 7-15.

Table 7-15 Projection of proportion of new trucks, buses, and cars in the total ownership, till 2030

Year	Truck	Bus	Car
2000	46%	23%	31%
2005	30%	28%	42%
2010	24%	30%	46%
2015	20%	30%	50%
2020	15%	30%	55%
2025	10%	30%	60%
2030	10%	30%	60%

It is projected that in 2020, there will be 85.1 million vehicles and an extra 175.6 million motorcycles in China, as is shown in Table 7-16. Figure 7-5 shows the growth trend of vehicle ownership in China, from 2000 to 2030, from which we find a comparatively more rapid growth of cars. It should be noted that this projection result is based on the 2000 baseline and is developed upon our own assumptions.

That is why the data in Table 7-16 has some differences with the reality of vehicle population described in the paragraph preceding Table 7-4.

Table 7-16 Vehicle ownership and motorcycle ownership forecast in China, 2000-2030 (million units)

Year	Truck	Bus	Car	Total (Motorcycle excluded)	Motorcycle
2000	7.18	4.14	4.40	15.7	37.7
2005	6.98	7.36	10.3	24.6	89.6
2010	8.93	12.1	17.9	38.9	133.3
2015	11.0	17.6	28.6	57.3	158.1
2020	13.0	25.8	46.3	85.1	175.6
2025	12.0	35.3	69.6	116.8	169.3
2030	16.3	48.4	95.8	160.5	173.9

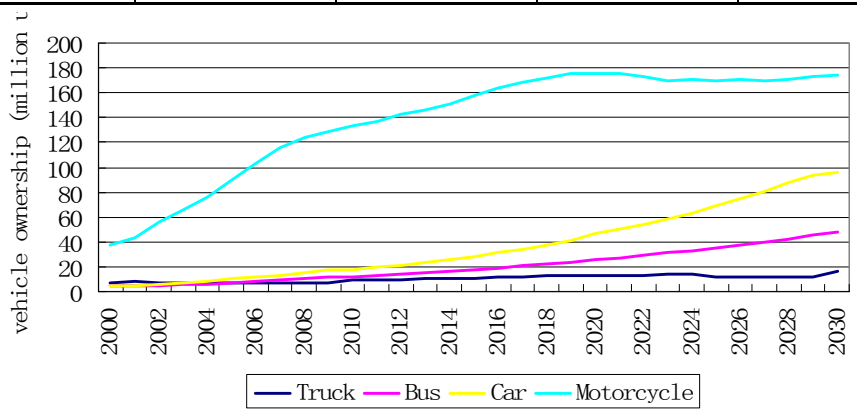

Figure 7-5 Vehicle ownership and motorcycle ownership forecast in China, 2000-2030 (million units)

The CHINA AUTOMOTIVE INDUSTRY YEARBOOK displayed the proportion of each vehicle type in new vehicles fleet during 1989 and 1999. The future structure of new fleet is projected based on these historical data, the Chinese policy to promote light duty vehicles and related research (Huo, 2002), as shown in Table 7-17.

Table 7-17 Projection of structure of new fleet till 2030

Year	HT	MT	LT	MiniT	HB	MB	LB	MiniB
2000	10.7%	21.1%	51.2%	17.0%	1.3%	5.0%	35.0%	58.7%
2005	25.0%	10.0%	50.0%	15.0%	1.3%	5.5%	32.5%	60.7%
2010	26.5%	7.5%	52.0%	14.0%	1.3%	6.0%	30.0%	62.7%
2015	28.0%	5.0%	55.0%	12.0%	1.2%	7.0%	30.0%	61.9%
2020	30.0%	4.0%	58.0%	8.0%	1.0%	8.0%	30.0%	61.0%
2025	30.0%	4.0%	62.0%	4.0%	1.0%	8.0%	30.0%	61.0%
2030	30.0%	4.0%	65.0%	1.0%	1.0%	8.0%	30.0%	61.0%

The China Automobile Industry Yearbook had included the proportion of the vehicles fueled with gasoline and diesel in each vehicle type during 1995 and 1999. At present, most of the light duty vehicles are fueled with gasoline. Given the recent policy to encourage diesel vehicles and related research (Huo, 2002), we assume that the proportion of diesel vehicles in light vehicles will increase a little during the future 30 years. For the heavy duty vehicles, the proportion of gasoline vehicles is very large at present. Considering the high efficiency of diesel vehicles and the policy direction of Chinese government, we assume that the proportion of diesel vehicles in large duty vehicles will growth greatly and will be 100% in 2030, as shown in Table 7-18.

Table 7-18 Projection of the proportion of gasoline in each vehicle type, till 2030

Year	HT	MT	LT	MiniT	HB	MB	LB	MiniB	Car	MC
2000	2.0%	35.0%	40.0%	99.5%	8.0%	45.0%	67.0%	100.0%	100.0%	0.0%
2005	1.5%	32.5%	37.5%	97.3%	6.5%	42.5%	66.0%	97.5%	97.5%	0.0%
2010	1.0%	30.0%	35.0%	95.0%	5.0%	40.0%	65.0%	95.0%	95.0%	0.0%
2015	0.5%	25.0%	32.5%	92.5%	2.5%	37.5%	62.5%	92.5%	92.5%	0.0%
2020	0.0%	20.0%	30.0%	90.0%	0.0%	35.0%	60.0%	90.0%	90.0%	0.0%
2025	0.0%	15.0%	25.0%	90.0%	0.0%	32.5%	60.0%	90.0%	90.0%	0.0%
2030	0.0%	10.0%	20.0%	90.0%	0.0%	30.0%	60.0%	90.0%	90.0%	0.0%

Table 7-19 and 7-20 show the projection of vehicle ownership of vehicles with different fuels.

Table 7-19 Total vehicle ownership for gasoline vehicle of each type (million units) till 2030

Year	HT	MT	LT	MiniT	HB	MB	LB	MiniB	Car	MC
2000	0.02	0.75	1.23	1.39	0.00	0.13	1.31	1.96	4.40	0
2005	0.02	0.46	1.22	1.15	0.01	0.20	1.94	3.97	10.1	0
2010	0.02	0.34	1.60	1.39	0.01	0.29	2.63	7.12	17.0	0
2015	0.03	0.28	1.97	1.42	0.01	0.43	3.54	10.4	26.5	0
2020	0.02	0.21	2.34	1.50	0.01	0.67	4.88	14.8	41.7	0
2025	0.01	0.14	2.09	1.11	0.00	0.94	6.46	19.7	62.6	0
2030	0.00	0.10	2.47	0.69	0.00	1.26	8.74	26.6	86.2	0

Table 7-20 Total vehicle ownership for diesel vehicle of each type (million units) till 2030

Year	HT	MT	LT	MiniT	HB	MB	LB	MiniB	Car	MC
2000	0.40	1.39	2.01	0.00	0.05	0.15	0.55	0.00	0.00	37.7
2005	0.87	1.32	1.91	0.01	0.09	0.25	0.86	0.04	0.26	89.6
2010	1.87	0.89	2.79	0.03	0.15	0.41	1.34	0.19	0.89	133.3
2015	2.89	0.66	3.72	0.07	0.21	0.64	1.93	0.52	2.15	158.1
2020	3.62	0.55	4.67	0.10	0.29	1.11	2.90	1.14	4.63	175.6
2025	3.42	0.45	4.66	0.09	0.37	1.73	4.12	1.93	6.96	169.3
2030	4.85	0.56	7.60	0.07	0.49	2.57	5.77	2.89	9.58	173.9

VII.D.1.ii VKT

There has been no publicized vehicle kilometer traveled (VKT) data in China. Thus researchers usually turn to field surveys or models to estimate the VKT. See Table 7-21. There have been few changes in annual average traveled kilometers from 1997 to 2000.

Table 7-21 Annual VKT per vehicle (thousand km), from 1997 to 2000

Year	HT	MT	LT	MiniT	HB	MB	LB	MiniB	Car	MC
1997	73.6	25.0	24.5	36.3	68.9	68.0	35.2	35.0	27.2	10.0
1998	75.6	25.0	23.3	39.5	67.3	66.5	34.9	35.0	27.3	10.0
1999	72.0	25.0	22.0	44.8	58.6	57.8	36.0	35.0	26.4	10.0
2000	67.4	25.0	20.9	43.2	52.0	52.0	34.0	35.0	26.4	9.0

Data Source: Huo Hong (2002)

Projected VMT in the future 30 years is estimated based on Huo's research in 2002, as shown in Table 7-22. Here we assume new vehicles have the same VKT as older vehicles.

Table 7-22 Projection of annual average traveled mileage, till 2030 (Th. Km)

Year	HT	MT	LT	MiniT	HB	MB	LB	MiniB	Car	MC
2000	67.4	25.0	20.9	43.2	52.0	52.0	34.0	35.0	26.4	9.0
2005	50.0	24.0	19.5	35.6	51.1	46.8	32.1	32.1	24.0	9.0
2010	50.0	24.0	18.3	30.4	52.4	42.9	29.7	29.7	21.0	9.0
2015	50.0	24.0	16.5	25.2	53.7	38.9	27.4	27.4	18.0	9.0
2020	50.0	24.0	15.3	21.0	54.7	35.0	25.5	25.5	15.0	9.0
2025	50.0	24.0	15.3	21.0	54.7	35.0	25.5	25.5	15.0	9.0
2030	50.0	24.0	15.3	21.0	54.7	35.0	25.5	25.5	15.0	9.0

Data Source: Huo Hong (2002); Note: It is assumed that in one class of vehicles, there is no difference in the annual average traveled mileages between gasoline and diesel.

As the growth rate of vehicle ownership outpaces the growth rate of passenger and freight traffic and people's travel demand, the VKT in China generally has a decline tendency. Because most of the medium and heavy trucks and buses are commercial-used and the need for commercial use traffic would not vary too much, the decline of VKT is comparatively slow. Along with the rapid development of private-owned and non-commercial-use LDV, those vehicles are taking up a larger and larger percentage in the total fleet wide. The VKT of these LDVs is projected to have a faster decline speed. (Huo Hong, 2002)

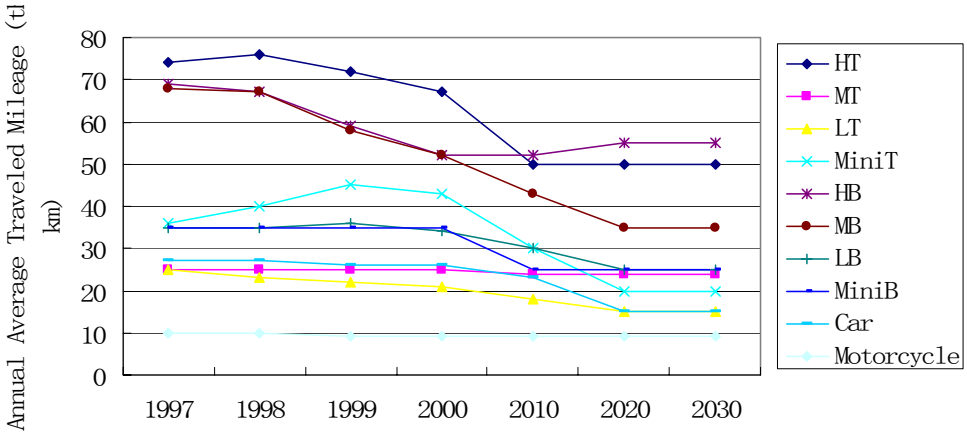

Figure 7-6 Projection of annual average traveled mileage, till 2030 (Th. Km)

VII.D.2 Energy and fossil fuel consumption (by type) forecast

VII.D.2.i <u>Fuel Economy</u>

The fuel economy differs between the scenarios of year 2000 policies and the year 2005 policies. For year 2000 policies, we assume that almost no policies would be published to affect the fuel economy of fleet wide. Therefore, the future fuel economy from 2000-2020 is assumed to remain as the year 2000 level. The on-road fuel economy of new vehicles under 2000 policies is shown as Table 7-10.

For year 2005 polices, we mainly take into account the Mid- and Long-term Plan on Energy Conservation. This plan has pointed out the average on-road fuel economy goal for passenger cars to reach in 2010. We assume that this plan will be fully implemented. And for the other types of vehicles, as there is no fuel economy improvement policy for them, we assume that their fuel economy would remain as the year 2000 level. It should be noted that Maximum Limits of Fuel Consumption (L/100-km) for Passenger Cars, compared to the Mid- and Long-term Plan, has a more detailed fuel economy goals for each category of passenger cars. However, as we are lack of car ownership data of each category of passenger cars, we cannot deduce the average fuel economy from it. Therefore, we mainly utilize the Mid- and Long-term Plan on Energy Conservation.

For the fuel economy of cars in 2010, we simply take the average value of goal range (8.2-6.7 L/100km)– 7.45 L/100km, which is 13.4 km/L, as the average of on-road fuel economy of cars. For years between 2000 and 2010, we assume that the fuel economy of cars will increase by a certain absolute amount each year. For years between 2010 and 2020, although the Mid- and Long-term Plan on Energy Conservation mentioned that fuel conservation will continue in auto industry, there is no text showing to what exact extent the fuel economy would improve, thus we simply assume that the fuel economy of cars would remain at the 2010 level. We also assume there is no difference of fuel economy between gasoline cars and diesel cars.

Table 7-23 shows the actual average fuel economy of fleet wide under 2005 policies. Except for cars, the adjustment factor is introduced to adjust the demarcated fuel economy to the on-road fuel economy of other vehicles. Moreover, the average fuel economy of all vehicles excluding cars is derived from the weighted average of real fuel economy of new vehicles of last 15 years (we assume in this research that the average scrapping time for vehicles in China is 15 years).

Table 7-23 Actual average fuel economy of fleet wide (km/L) under 2005 policies

	HT		MT		LT		MiniT		Car	
	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
2000	2.25	3.32	2.99	4.28	5.90	6.53	11.54	13.50	10.5	10.5
2005	2.25	3.32	2.99	4.28	5.90	6.53	11.54	13.50	11.95	11.95
2010	2.25	3.32	2.99	4.28	5.90	6.53	11.54	13.50	13.4	13.4
2015	2.25	3.32	2.99	4.28	5.90	6.53	11.54	13.50	13.4	13.4
2020	2.25	3.32	2.99	4.28	5.90	6.53	11.54	13.50	13.4	13.4
2025	2.25	3.32	2.99	4.28	5.90	6.53	11.54	13.50	13.4	13.4
2030	2.25	3.32	2.99	4.28	5.90	6.53	11.54	13.50	13.4	13.4
	HB		MB		LB		MiniB		MC	
	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel		
2000	2.21	3.02	2.68	3.16	7.52	8.82	11.90	14.25	36.77	
2005	2.21	3.02	2.68	3.16	7.52	8.82	11.90	14.25	36.77	
2010	2.21	3.02	2.68	3.16	7.52	8.82	11.90	14.25	36.77	
2015	2.21	3.02	2.68	3.16	7.52	8.82	11.90	14.25	36.77	
2020	2.21	3.02	2.68	3.16	7.52	8.82	11.90	14.25	36.77	
2025	2.21	3.02	2.68	3.16	7.52	8.82	11.90	14.25	36.77	
2030	2.21	3.02	2.68	3.16	7.52	8.82	11.90	14.25	36.77	

VII.D.2.ii Energy Consumption

Functions to calculate fuel consumption and CO2 emissions in transport sector are shown below.

$$\mathrm{GasolineCon_i} = \sum_{j^G} \left(\mathrm{Tr_{i,j^G}} \times \mathrm{VP_{i,j^G}} / \mathrm{FE_{i,j^G}} \right) \times \mathrm{Den_i^G}$$

$$\mathrm{DieselCon_i} = \sum_{j^D} \left(\mathrm{Tr_{i,j^D}} \times \mathrm{VP_{i,j^D}} / \mathrm{FE_{i,j^D}} \right) \times \mathrm{Den_i^D}$$

$$CO_{2i} = \left(GasolineCon_i \times Carbon_i^G + DieselCon_i \times Carbon_i^D \right) \times 44/12$$

Note:
In this function,
i – year
j^G -- vehicle type that uses gasoline
j^D—vehicle type that uses diesel
$GasolineCon_i$—the vehicle gasoline consumption in year *i* (million tons)
$DieselCon_i$—vehicle diesel consumption in year *i* (million tons)
FE_{i,j^G} -- the aveage fuel econmy of j^Gin year *i* (km/L)
FE_{i,j^D} -- the average fuel economy of j^Din year *i* (km/L)
Tr_{i,j^G} -- average vehicle traveled kilometer of j^G in year *i* (thousand kilometers)
Tr_{i,j^D} -- average vehicle traveled kilometer of j^D in year *i* (thousand kilometers)
VP_{i,j^G} -- total vehicle ownership of j^G in year *i* (million units)
VP_{i,j^D} -- total vehicle ownership of j^D in year *i* (million units)
Den_i^G—density of vehicle gasoline in year *i* (kg/L)

Den_i^D—density of vehicle diesel in year *i* (kg/L)
$Carbon_i^G$—the percent of carbon in vehicle gasoline in year *i*
$Carbon_i^D$ – the percent of carbon in vehicle diesel in year *i*
CO_{2i}—the total vehicle CO2 emission in year *i* (million tons)

Assumption:
Density and the percent of carbon in fuel is constant. The density of vehicle gasoline is 0.732 kg/L, and the percent of carbon in it is 85.5%; the density of vehicle diesel is 0.875 kg/L, and the percent of carbon in it is 87%.

Projection of total oil consumption by year 2000 policies and year 2005 policies is shown in Table 7-24, Table 7-25 and Figure 7-7. After comparing the projected oil consumption of 2000 policies and 2005 policies, the implementation of 2005 policies has produced a total oil saving of 10.7 million tons in 2020. And the cumulative oil savings through 2020 would reach 108.5 million tons, of which 99.6 are gasoline and 8.88 are diesel.

Table 7-24 Total oil consumption by year 2000 policies and year 2005 policies (million tons)

	Gasoline consumption - Year 2000 Policies	Diesel consumption - Year 2000 Policies	Total fuel consumption - Year 2000 Policies	Gasoline consumption - Year 2005 Policies	Diesel consumption - Year 2005 Policies	Total fuel consumption - Year 2005 Policies
2000	37.3	24.6	61.8	37.3	24.6	61.8
2005	58.1	30.9	89.0	56.0	30.9	86.9
2010	81.6	48.7	130.3	76.2	48.4	124.6
2015	101.6	69.3	170.9	94.4	68.6	163.0
2020	124.1	90.1	214.2	114.6	88.9	203.5
2025	157.2	101.4	258.6	143.1	99.5	242.6
2030	201.7	145.6	347.3	182.2	143.0	325.2

Table 7-25 Gasoline and diesel consumption by year 2000 policies and year 2005 policies (billon liters)

	Gasoline consumption -Year 2000 Policies	Diesel consumption - Year 2000 Policies	Gasoline consumption - Year 2005 Policies	Diesel consumption - Year 2005 Policies
2000	50.9	28.1	50.9	28.1
2005	79.4	35.3	76.6	35.3
2010	111.5	55.7	104.1	55.3
2015	138.8	79.2	129.0	78.4
2020	169.5	103.0	156.6	101.5
2025	214.8	115.9	195.5	113.7
2030	275.6	166.4	248.9	163.4

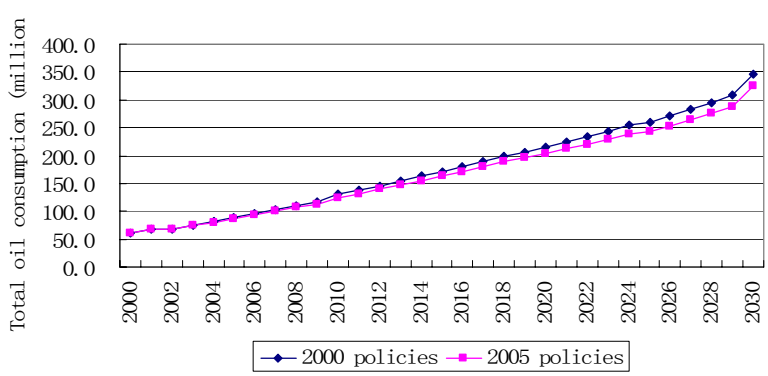

Figure 7-7 Total oil consumption of 2000 policies and 2005 policies

VII.D.3 Annual GHG forecast

In 2020, under year 2000 and year 2005 policies, the CO2 emission in road transport sector in China would reach respectively 674.4 and 642.9 million tons.

Table 7-26 Annual CO2 emission forecast (million tons), till 2030

Vehicular CO2 emission	Year 2000 Policies			Year 2005 Policies		
	By Gasoline	By Diesel	Total	By Gasoline	By Diesel	Total
2000	116.8	78.4	195.2	116.8	78.4	195.2
2001	126.7	89.9	216.5	125.9	89.9	215.8
2002	135.4	81.9	217.4	133.6	81.9	215.5
2003	147.6	89.5	237.1	144.6	89.4	234.0
2004	161.1	97.6	258.7	156.7	97.5	254.2
2005	182.1	98.7	280.8	175.7	98.5	274.2
2006	198.4	105.3	303.7	190.1	105.0	295.1
2007	215.0	112.3	327.4	204.7	111.9	316.6
2008	230.5	118.9	349.3	217.8	118.2	336.0
2009	244.7	124.7	369.4	229.5	123.8	353.3
2010	255.8	155.4	411.2	238.9	154.3	393.3
2011	266.9	167.9	434.8	249.0	166.7	415.6
2012	279.1	180.9	460.1	260.2	179.5	439.7
2013	290.6	194.8	485.4	270.6	193.1	463.7
2014	304.1	209.9	514.0	283.0	208.0	490.9
2015	318.6	221.0	539.6	296.1	218.8	514.9
2016	332.6	236.4	569.0	308.9	233.9	542.8
2017	346.2	250.4	596.6	321.2	247.6	568.9
2018	359.7	264.9	624.6	333.5	261.7	595.3
2019	373.5	279.6	653.1	346.0	276.1	622.1
2020	389.0	287.4	676.4	359.4	283.4	642.9
2021	407.5	299.4	707.0	375.6	295.1	670.7
2022	425.9	311.4	737.3	391.4	306.8	698.2
2023	444.8	323.4	768.2	407.6	318.3	726.0
2024	467.8	335.1	802.9	427.7	329.7	757.3
2025	493.0	323.5	816.4	448.5	317.5	766.0
2026	519.3	334.6	853.9	471.4	328.2	799.5
2027	546.4	345.3	891.7	494.7	338.4	833.1
2028	576.6	355.6	932.2	520.9	348.1	868.9
2029	609.4	365.5	974.8	549.3	357.4	906.7
2030	632.4	464.4	1096.7	571.2	456.1	1027.3

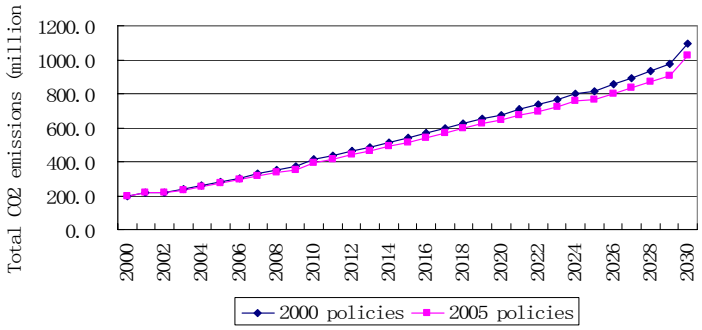

Figure 7-8 Total CO2 emissions of 2000 policies and 2005 policies

After comparing the projected oil consumption and CO2 emission of 2000 policies and 2005 policies, the implementation of 2005 policies has produced CO2 emission reduction of 33.5 million tons in 2020. And the cumulative CO2 emission reduction through 2020 could reach 340.5 million tons, in which 312.2 are from reduced gasoline consumption and 28.3 are reduced diesel consumption.

VII.E GHG Mitigation Options and Costs

Mitigation options and costs are the basis of mitigation scenarios analysis. In this section, we will give an overview of each appropriate mitigation option, characteristic of each mitigation option, their costs, their emission reduction potential etc.

VII.E.1 Selection criteria for consideration of mitigation options

There are many options for reaching GHG mitigation goals in transport sector, such as improve transport conditions, adjust vehicle structure and improve its components, utilize substitute fuels, encourage public transport, enhance transport management system, etc.
Selection criteria for consideration of mitigation options include capital costs, operating costs, carbon dioxide emissions abatement performance, traffic noise, traffic congestion, quality of life, public acceptability, practicality and etc.

VII.E.2 Overview of each mitigation option evaluated

VII.E.2.i Description, including technologies required

Fuel economy of vehicles is mainly a function of three factors, which are vehicle, fuel and travel demand. Vehicle related options include improving engine technologies, transmission technologies, vehicle technologies (rear to front) and engine-transmission-vehicle technologies. The following table will imply more details. Fuel related factors include renewable fuels and more clean fuels substitution, such as switching from gasoline and diesel to liquefied petrol gas (LPG) and compressed natural gas (CNG), etc. Travel demand factors include urban planning, Bus Rapid Transit (BRT), improve road conditions, etc.

In vehicle related options, among all possible technologies, hybrid electric engines[44], direct injection gasoline/diesel engines and variable valve lift and timing have the most remarkable fuel efficiency improvement effect[45] (Gallagher, 2006).
Commercially available hybrid-electric vehicles contain both a conventional gasoline engine and a battery-driven electric motor. The electric motor and the internal combustion engine work together during acceleration – the engine is downsized from the engine in a normal vehicle, so the electric motor provides additional power when needed. The fuel savings are mostly derived from utilizing more efficient electric motors in stop-and-go urban driving, capturing wasted energy from braking, converting it into electricity, and storing it for later use by the electric-drive motor in a battery. Hybrid-electric vehicles vary in the degree to which they actually utilize the electric motor, but all hybrids take advantage of the main innovation – the combined use of electric and gasoline motors together to power the automobile (Gallagher, 2006).

In traditional gasoline or diesel engines, fuel is injected into a port before it enters the combustion chamber. The use of a port gives the fuel time to evaporate and mix uniformly with the air that it will be burnt with. However, this is not ideal because it provides little control over the air and fuel mixture. Direct Injection gasoline/diesel engines do not inject fuel into a port. These engines inject the fuel directly into the combustion chamber instead. This approach gives control over the air/fuel mixture and reduces fuel evaporation to enhance the fuel efficiency.

Poppet valves are used in gasoline and diesel engines to control the intake and exhaust of air passing through the engine. When the intake valves open, fuel and air are both drawn into the engine cylinder. After the fuel has been burnt, the exhaust valves then open to let it leave. In conventional engines, the

[44] According to previous researches, the technology of hybrid electric engines had been classified as engine-related technology in some cases and fuel-related option in others. In this research, we define hybrid electric engines as engine-related technology.
[45] Gallagher (2006) indicated that China's Ministry of Science and Technology (MOST), believe that the technologies that China should consider adopting are hybrid-electric or fuel-cell vehicles. However, FCVs are still in the research and development stage, and are not yet available commercially.

poppet valves open and close at a constant speed. Their timings do not depend on how fast the engine is running. At high engine speeds [e.g. when overtaking a slower vehicle], this starts to become a problem. Large amounts of air are required by the engine at higher speeds. However, the intake valves may close before all the air has been given a chance to flow in. On the other hand, if the valves were calibrated to remain open for longer periods of time, problems start to occur at the lower engine speeds. In these situations, un-burnt fuel may exit from the engine since the valves are still open. This leads to lower engine performance and increased emissions. Around the early 1990s, Variable Valve Lift and Timing started to become popular on gasoline passenger cars. Using this technique, engine manufacturers are able to control the extent and duration for which the poppet valves are open. In addition, the opening and closing of the valves can also be varied depending on the crank angle. With variable valve lift and timing, a sensor is used to detect the engine's speed. An electronic system then uses this information to adjust the valve opening and closing timings accordingly. This avoids the problems mentioned earlier and allows for maximum torque at all engine speeds (Bong, 2002).

Bus Rapid Transit (BRT) can be broadly defined as "a permanent system of facilities, services and amenities that collectively improve the speed, reliability and identity of bus transit" (Levinson et.al., 2002). BRT systems provide a roadway-based rapid transit alternative that combines high levels of service, intelligent transport systems (ITS) and low emission vehicle technologies. For example, as a full BRT system, TransMilenio of Bogota provides several different sources of emission reductions, including the following (Wright and Fulton, 2005):

- Increasing the share of public transport ridership by dramatically improving the quality of service (in terms of travel time, comfort, security, cleanliness, etc.).
- Constructing segregated busways that permit uninhibited bus movements without delays from mixed traffic.
- Using pre-board fare-collection systems that reduce dwell times.
- Replacing four to five smaller buses with a larger articulated vehicle.
- Requiring the destruction of four to eight older buses for every new articulated vehicle introduced into the system.
- Managing the fleet through global positioning satellite (GPS) technology and thus allowing the optimization of demand and supply during peak and nonpeak periods.
- Encouraging transit-oriented development around stations and along corridors.
- Requiring minimum-emission standards for vehicles (currently Euro II vehicles are employed with a future schedule requiring eventual Euro III/IV compliance).

Currently, the possible fuel switch options for fossil fuels include LPG, CNG, hydrogen fuel-cell and electric motors, etc, of which LPG and CNG are comparatively market-ready.

VII.E.2.ii <u>Background on use of option in country to date, future potential of option</u>

Vehicle related option packages can be summarized to those improving engine technologies, improving transmission technologies, vehicle (rear-to-front) technologies and engine-transmission-vehicle technologies, and some options in those packages have been used widely in China, especially those that have comparatively lower costs and comparatively better efficiency. China already has some small-scale BRT systems in Beijing, Kunming, Shenyang, Shijiazhuang and Taipei (Xu, 2003). In Kunming for instance, the first modern bus-only road had been built in April 1999 and in their city planning, it is referred that a BRT system with 63 km network size would be finally built in Kunming (KIUT, 2004). It is expected to have a promising future in China's transport system (Xu, 2003). For fuel transition from diesel/gasoline to LPG and CNG, it had been widely implemented in some big cities in China, such as Beijing. LPG is much more popular in mass and public transport sector (and a forecast (Jiang, 2003) shows that Beijing will have clean fuel occupy 90% of the public transport market), however, in private transport part, gasoline still takes the leading role.

In China, a notice about the clean vehicles actions mentioned that the major technology option to reduce vehicle emissions and pollution near term is to promote the clean fossil fuel vehicles and

promote the gas vehicles (MOST & SEPA, 1999). LPG and CNG vehicles are experiencing a rapid development in China. Take Beijing for Example. Till the end of 2001, there had been 86 gas stations all around Beijing, among which 62 are LPG gas stations and 24 are CNG gas stations. Number of Gasoline-LPG bi-fuel taxis reached 32 thousand, and the number of CNG and LPG bus reached 5 thousand. In 2003, Beijing had newly imported 600 single-fuel (LPG) taxis (CSDTP, 2004). Similar tendency is happening in other cities in China, although which one is more preferred, LPG or CNG, depends mainly on its resource. Although hydrogen fuel-cell, methanol and ethanol are in hot discussion these days, they still have a long way to go for commercial use.

VII.E.3 Marginal abatement cost curve

Here are some explanation on how marginal abatement cost curves are developed here and what those assumptions in the development process are.

Vehicle related options

, light duty vehicles (LDVs) have long been considered the pivot of fuel consumption control. In this research, LDV refer specifically to cars, light bus and mini bus. In China, those LDVs take up large proportion in road transport fuel consumption (29.87% in 2000 (Huo, 2002)). Huo (2003) has summarized the current possible technologies to utilize in vehicles. They vary in their costs, fuel economy improvement rates, and also the expansion potential. Benefits and cost of those technologies are shown in Table 7-28.

Table 7-28 Benefit and cost of the efficiency technologies

Technologies	FE improvement (%)	Cost (Year 2000 US$)
1 Engine technology		
1.1 Improve the mechanical efficiency		
1.1.1 better optimize engine operations		
Multi-valve, overhead camshaft	5	135.4
Variable valve timing	5	135.4
Variable valve lift and timing	10	203.1
Intake valve throttling	6	399.0
Camless valve actuation	10	544.1
1.1.2 reduce the friction of engine		
Low-friction lubricants	1	10.9
Reduce the friction of components (such as bearing, oil seal)	3	72.6
Roller cylinder (rocker)	2	72.6
1.1.3 reduce friction of accessory		
Improve engine accessory by increasing the technical skills of suppliers	2	108.8
1.2 Improve the work process of engine		
Improve compression ratio +0.5	1.5	12.1
Cylinder deactivation	6	241.8
Variable compression ratio engine	6	483.7
1.3 Other engine technologies		
Engine downsizing and supercharging	7	544.1
Direct injection gasoline engine	20	556.2
Direct injection diesel engine	35	725.5
Hybrid Electric Vehicles	30*	2418.4*
2 Transmission technologies		
4 and 5 speed manual transmission	3	48.4
Automatic Transm. with aggressive shift logic	3	67.7
4 and 5 speed automatic transmission	3	145.1
Automatic Shift Manual Transmission	5	278.1
Continuously variable transmission	8	362.8
5 and 6speed automatic transmission	2	362.8
Advanced Continuously variable transmission	2	822.2
Automatic transm replace manual transm.	-7	1813.8
3 Vehicle technologies (rear to front)		
Aerodynamic improvement	2	145.1
Low-resistance tires	1.5	54.4
42 volt electricity system	2	278.1
Integrated starter-generator	7	362.8
Electric power steering system	2.5	145.1
Safety enhancing weight reductions	4	338.6
4 Engine-Transmission-Vehicle technologies		
Engine-Transmission-Vehicle matching technologies	1.5	120.9

Data source: Huo Hong (2002)

It should be noted here that:

*Huo does not include Hybrid Electric Vehicles in the technology list. However, after analyzing from related governmental attitudes towards HEV, we think it is necessary to add it into the list. And the FE improvement and cost information of HEV is from http://www.qyev.com/chinesenew/jsmt/index.htm.

Ccst information in Table 7-28 all refers to cost per vehicle.

All the cost data in this form reflects only the operational data of those technologies. The cost for R&D, technology trade, managerial cost and etc are not included, because there is little research on this area and it is far too complex to estimate.

In Hong's paper, she designed three schemes (high, medium and low). High scheme implies the best of factory's managerial level, employees' skills and the fuel efficiency improvement effects when utilizing one technology. And in our research, we assume that it is under the high scheme background. And the table above just presents the detailed data of the high scheme.

Table 7-29 shows the possible starting period of each technology (Huo, 2003). Technology with * means it will start utilizing in China since a certain period. Some technologies which have never been involved in any term of technology package (such as 4 and 5 speed manual transmission) have been omitted in this table.

In Huo (2003), she explains near-term, mid-term and long-term as follows:

- Near term technologies are those which have been widely used internationally, and could be totally commercialized in the near 5 years;
- Mid term technologies are those which have begun to be used internationally and could possibly be totally commercialized in the near 10 years;
- Long term technologies are those in the process of commercialization and would possibly be completely commercialized in 20 years.

In this research, we simply assume that the near term technologies represent the period from 2006-2010, the mid term technologies represent the period from 2011-2015, and the long-term technologies represent the period from 2016-2020. We also make an assumption that once a technology is starting to be used, it is used by all corresponding vehicles. For example, we see from Table 7-29 that hybrid electric vehicles are going to be utilized in cars since 2016. In the research, we assume that there is not any hybrid electric vehicle in 2015; however from 2016, all the new and old cars will become hybrid electric vehicles.

In Table 7-29, it should also be noted that in Huo's paper that some vehicles are installed with variable valve timing and variable compression ratio engine. However, as variable valve lift and timing and improve compression ratio +0.5 are incompatible with them and are both more widely used, we assume that no vehicles will use variable valve timing and variable compression ratio engine.

From Table 7-29, we could get the costs and fuel saving rates for engine technologies, transmission technologies, vehicle technologies, engine-transmission-vehicle matching technologies, in different periods, for cars and for LB and MiniB respectively, as is shown in Table 7-30(a) and 7-30(b)(c).

It should be noted that the fuel saving rate is different from FE improvement rate. The fuel efficiency improvement rate x% is changed into the fuel saving rate y by y=x/(100+x). For example, if an option has a 100% fuel efficiency improvement rate, then its corresponding fuel saving rate is 100/(100+100)=50%; and multi-valve, overhead camshaft has a 5% fuel efficiency improvement rate, then its corresponding fuel saving rate is 5/(100+5)=4.76%. And when calculating the fuel saving rate of a technology package (such as engine technologies package), we accumulate the fuel saving rate of each option one by one. If one option has been utilized in one vehicle and has an x fuel saving rate, when another option with y fuel saving rate is added into the same vehicle, then the cumulative fuel saving rate is z=1-(1-x)*(1-y); if another option with k fuel saving rate is added, then the new cumulative fuel saving rate is 1-(1-z)*(1-k). This process keeps going until all options are included in the package they should belong to. The cost of the package is the cumulative cost of each option included.

Table 7-29 Starting period of each technology

		Engine Technologies															
Mitigation Option		Low-friction lubricants	Improve compression ratio +0.5	Reduce the friction of components	Roller cylinder (rocker)	Improve engine accessory by increasing the technical skills of suppliers	Multi-valve, overhead camshaft	Variable valve lift and timing	Engine downsizing and supercharging	Direct injection gasoline engine	Hybrid Electric Vehicles	Cylinder deactivation	Intake valve throttling	Camless valve actuation	Direct injection diesel engine	Variable compression ratio engine	Variable valve timing
For Cars	Near term	*	*	*	*	*	*	*									
	Mid term	*	*	*	*	*	*	*	*								
	Long term	*	*	*	*	*	*	*	*	*	*						
For LB and Mini Bus	Near term	*	*	*	*	*	*										
	Mid term	*	*	*	*	*	*	*	*								
	Long term	*	*	*	*	*	*	*	*	*	*						

		Transmission Technologies		Vehicle Technologies						Engine-Transmission-Vehicle matching technologies
Mitigation Option		Automatic Transm. with aggressive shift logic	continuously variable transmission	Low-resistance tires	Aerodynamic improvement	Electric power steering system	42 volt electricity system	Safety enhancing weight reductions	Integrated starter-generator	Engine-Transmission-Vehicle matching technologies
For Cars	Near term			*	*			*		*
	Mid term			*	*		*	*		*
	Long term		*	*	*	*	*	*	*	*
For LB and Mini Bus	Near term			*	*					*
	Mid term			*	*		*	*		*
	Long term		*	*	*	*	*	*	*	*

Table 7-30(a) Fuel Saving Rate of different terms and different technology packages

			Engine Technologies Fuel Saving Rate	Transmission Technologies Fuel Saving Rate	Vehicle Technologies Fuel Saving Rate	Engine-Transmission-Vehicle matching technologies Fuel Saving Rate	Total Fuel Saving Rate
For Cars	2006－2010	near term	21.19%	0%	7.12%	1.48%	29.79%
	2011－2015	mid term	26.34%	0%	8.95%	1.48%	36.77%
	2016－2020	long term	52.78%	7.41%	16.98%	1.48%	78.65%
For LB and MiniB	2005－2010	near term	13.31%	0%	3.41%	1.48%	18.19%
	2011－2015	mid term	26.34%	0%	8.95%	1.48%	36.77%
	2016－2020	long term	52.78%	7.41%	16.98%	1.48%	78.65%

Table 7-30(b) Cost per vehicle (US$) in different terms

			Engine Technologies	Transmission Technologies	Vehicle Technologies	Engine-Transmission-Vehicle matching technologies
For Cars	2006－2010	near term	615.5	0	538.1	120.9
	2011－2015	mid term	1159.6	0	816.2	120.9
	2016－2020	long term	4134.2	362.8	1324.1	120.9
For LB and MiniB	2005－2010	near term	412.4	0	199.5	120.9
	2011－2015	mid term	1159.6	0	816.2	120.9
	2016－2020	long term	4134.2	362.8	1324.1	120.9

Table 7-30(b) displays the cost per vehicle in different terms; however, Table 7-30(c) displays the cost per vehicle per year in US$ in 2000. Cost of implementing vehicle related technologies has been distributed to a 15-year lifetime. So the cost per vehicle per year is the corresponding cost per vehicle divided by 15, then the result has been discounted back to the value in year 2000, by a discount rate of 10%. Costs in different years per vehicle are the same, however, when discounted, the costs may vary according to how far it is to year 2000.Table 7-30(c) only lists costs in 2010, 2015 and 2020. So the cost per vehicle per year in 2010 using engine technologies, after discounted back to year 2000, is (615.5/15)*((1-10%)^10)=14.3.

Table 7-30(c) Cost per vehicle per year (US$ in 2000) in 2010, 2015 and 2020

		Engine Technologies	Transmission Technologies	Vehicle Technologies	Engine-Transmission-Vehicle matching technologies
For Cars	2010	14.3	0	12.5	2.81
	2015	15.9	0	11.2	1.65
	2020	33.5	2.94	10.7	0.98
For LB and MiniB	2010	9.59	0	4.64	2.81
	2015	15.9	0	11.2	1.65
	2020	33.5	2.94	10.7	0.98

Multiplying the cost per vehicle in US$ 2000 by vehicle population in a certain year could get the total cost in US$ 2000 in that year. Multiplying the fuel saving rates by the original oil consumption could get the oil savings and the corresponding oil saving benefits in that year. After the discount rate is taken into consideration, we could get the oil saving value in US$ 2000. The net cost is the total cost minus the oil saving benefits. And the cost effectiveness is the net cost divided by CO2 emission reduction in that year.

BRT

In this section, we intend to tell the amount of CO2 emission reduction by the construction of all BRT systems in China and the corresponding CO2 emission reduction cost.

The evaluation of CO2 emission reduction effects of constructing BRT systems in China is based on the analysis of difference BRT cases. We assume that there will only be three types of network size in BRT in China – 100 km, 200 km and BRT package (BRT package is characterized by its pedestrian upgrades and cycleway investment). We assume that the BRT package in China contains a 200 km BRT (costing $2,500,000 per km), a 400 km footpath (costing $150,000 per km), a 500 km cycleway (costing $100,000 per km) and a promotional campaign (costing $10,000,000)(Costing information is from Wright and Fulton, 2005). The main difference between the three types of BRT systems is the change in travel mode share. Based on the current development situation of BRT in China, we assume that before the end of 2010, all BRT programs will be under construction and since 2011, there will be twelve 100 km BRT, six 200 km BRT and two BRT packages becoming effective in twenty large cities in China, which means the emission reduction effects from BRT only comes into being since 2011. The total emission reduction achieved by BRT is a simple sum of the emission reduction from these 20 BRT systems. Costs will mainly come from infrastructures; however, BRT systems could also bring in oil saving benefits due to the travel mode change introduced in the city by BRT. Infrastructures costs have been evenly split into year 2011-2020, the duration where also oil saving benefits is.

IMI Consumer Behavior and Living Conditions Yearbooks (from 1995-2005) had summarized the travel mode share of several important cities in China from late 1990s to the early 2000s; however, the current travel mode share national-wide is developed in a simplified manner with no assumed difference between the several important cities and the whole country, and no assumed change between the current mode share and the mode share in 2010. Clearly, this static assumption will not be the case. We can tell from the IMI yearbook that along with the quick economic development in China, taxi, buses and automobiles are taking more and more shares and the shares of bicycles and walking are quickly shrinking. However, this assumption makes the result more conservative since any baseline growth in private vehicle emissions will make the reductions even greater. For the 100 km BRT, 200 km BRT and BRT package case, we have changed the mode share according to the characteristics of each case and some previous research (Wright, 2005). Table 7-31 shows the settings of mode share in different cases.

The emission reduction effect of each BRT system is educed from the comparison of reference case and the BRT system. We assume the current mode shares and total number of trips per day (10 million) (according to Wright 2005) are appropriate for a common city in China in 2000. The known travel mode share will tell us trips per day for each kind of travel mode. However, different years will have different total trips due to the change in vehicle population, VKT, and fuel efficiency. The total trips are in direct ratio with the oil consumption in pre-2000 baseline. In year 2015, for example, after comparing oil consumption in 2000 and in 2015 in the pre-2000 baseline, we deduce the total trips in 2015 to input into the cases. From the total trips data and the mode share data, we could tell the trips per day for each mode. For the passenger/vehicle-km data, we refer to Wright 2005 and then educed the distance traveled per day for each mode (Distance traveled per day is equal to trips/day divided by passengers/vehicle-km). By entering the projected fuel economy data in 2010, we could educe the oil consumption per year and then the CO2 emission per year (we have also adjusted the CO2 emission per liter of fuel according to the reality in China). By comparing the CO2 emission between the reference case and different BRT cases, the emission reduction effect of BRT system is gained. See Table 7-32 and Table 7-33. The CO2 emission reduction for implementing a 50 km BRT system in a city in 2015 is (1887.2-1845.5)×1000=41700 tonnes. As we know there are twelve 100km BRT, six 200km BRT and 2 BRT packages in China in 2015, and we can tell the amount of CO2 emission reduction of each type of BRT system, we could add them up to the total emission reduction effect of BRT systems in 2015.

As said above, the cost of BRT systems will mainly come from the infrastructure. We can tell the total cost of infrastructure by adding up the cost for each BRT system. The cost has been split evenly into year 2011-2020, to compare with the oil saving income. In 3), by comparing the reference case to the BRT case, we can tell the amount of oil savings in a specific year. By multiplying the price of oil in

that year (in this research, we assume that oil price in China would be constant at a price of $0.55 per liter), we can tell the monetary value oil savings. All the costs and incomes have been discounted back to year 2000 by a discount rate of 10%. The net cost is the infrastructure cost in that year minus the oil saving income.

Net cost divided by total CO2 emission reduction in a specific year will tell us the cost per ton of CO2 emission reduction in that year.

It should be noted that the CO2 emission factor of gasoline in China is assumed to be 3172 kg CO2/ton gasoline; the CO2 emission factor of diesel in China is assumed to be 3188 kg CO2/ton diesel (Zhu, 2004). As the density of gasoline and diesel is assumed to be 0.732kg/L and 0.875kg/L, the CO2 emissions for each liter of gasoline and diesel are respectively 2.32kg and 2.79kg.

As the vehicle category mini-bus in Wright and Fulton refers to all non-BRT buses, so the fuel consumption used for mini-bus is the weighted average of HB, MB, LB and MiniB on-road fuel economy in 2000. We assume no change would happen to the fuel consumption for mini-bus during 2000-2020. The on-road fuel economy (km/L) of HB-Gasoline, HB-Diesel, MB-Gasoline, MB-Diesel, LB-Gasoline, LB-Diesel, MiniB-Gasoline, MiniB-Diesel is 2.21, 3.02, 2.68, 3.16, 7.52, 8.82, 11.9 and 14.25. And the vehicle ownership (million) for the corresponding types of vehicles is 0.003, 0.046, 0.126, 0.153, 1.306, 0.545, 1.959, and 0.000. So the fuel consumption for 'mini-bus' in BRT is 9.40 km/L, which is 10.64 liters/100km.

Table 7-31 Transport mode share in different cases

Mode Share (%)	Automobile	Motorcycle	Taxi	Mini-bus	BRT	Walking	Bicycle
Reference Case	5	7	3	40	0	15	30
100 km BRT	4	7	3	36	5	15	30
200 km BRT	3	7	2	33	10	15	30
BRT Package	3	6	2	24	10	20	35

Note: Reference case refers to the projected mode share in 2010 in China. And the other cases reflect the refreshed mode share when different size of BRT network is utilized.

Table 7-32 Reference case (city with no BRT system)

Mode	Mode Share (%)	Trips/day (000s)	Passengers / vehicle-km	Distance travelled / day (km, 000s)	Fuel Consumption (litres / 100km)	litres/yr (000s)	CO2 (kg) / litre	CO2 / yr (tonnes, 000s)
Automobile	5	1382	0.15	9,213	7.46	214,426	2.32	497.5
Motorcycle	7	1935	0.105	18,425	2.72	156,364	2.79	436.3
Taxi	3	829	0.15	5,528	7.46	128,656	2.32	298.5
Mini-bus	40	11055	1.3	8,504	10.64	282,305	2.32	654.9
BRT	0	0	5.2	0	64.1	0	2.32	0
Walking	15	4146	1	150	0	0	0	0
Bicycle	30	8291	1	8,291	0	0	0	0
Sum	100	27638						1887.2

Table 7- 33 100 km BRT case (city with a 100 km BRT system)

Mode	Mode Share (%)	Trips/day (000s)	Passengers / vehicle-km	Distance travelled / day (km, 000s)	Fuel Consumption (litres / 100km)	litres/yr (000s)	CO2 (kg) / litre	CO2 / day (tonnes, 000s)
Automobile	4	1106	0.15	7,370	7.46	171,541	2.32	398.0
Motorcycle	7	1935	0.105	18,425	2.72	156,364	2.79	436.3
Taxi	3	829	0.15	5,528	7.46	128,656	2.32	298.5
Mini-bus	36	9950	1.3	7,654	10.64	254,075	2.32	589.5
BRT	5	1382	5.2	266	64.1	53,148	2.32	123.3
Walking	15	4146	1	150	0	0	0	0
Bicycle	30	8291	1	8,291	0	0	0	0
Sum	100	27638						1845.5

As the BRT systems in China become effective since 2011, there will be a corresponding cost effectiveness value since that year too. The cost effectiveness of BRT systems in 2015 and 2020 are respectively 17.9 US$/per tonne and 2.64 US$/per tonne.

For Fuel Switch

Fuel switch in this research includes both gasoline and diesel to both LPG and CNG, for buses only. There has been few research related to the cost of fuel switch in China. Wright (2005) indicated that fuel switch from a EURO II diesel bus with a ten-year, 750,000 mile lifetime would educe an estimated cost of 442 US$/ tonne CO2. As in research, China has a similar emission criteria and VKT, and the biggest difference is the emission reduction rate – 25% (as mentioned in Jiang, 2003), we roughly estimate that the cost in China would be 442/(25%/10%), about 176.8 US$/tonne CO2 in 2000. We also assume the fuel switch from gasoline and diesel into LPG and CNG in China would cost the same. When we are estimating the CO2 emission per vehicle, we take the VKT and FE data from mini Bus because its share in all buses is the biggest. Considering that Beijing plans to have 90% buses use clean energy in 2020 (CSDTP, 2004), we assume that China will start fuel switch in 2010, and in 2010, 10% of buses would use CNG or LPG, in 2015, 30% of buses would use CNG or LPG, and in 2020 in China, the percentage for buses to use CNG or LPG would reach 50%.

The 25% emission reduction rate would tell us the amount of emission reduction for each bus per year. Take year 2010 for example. By multiplying the emission reduction amount per year by the bus population, we could deduce the total emission reduction in 2010. And the fuel switch cost in 2010 is 176.8, however, when discounted back to year 2000 with a discount rate 10%, the value changed to 61.6 US$ per tonne CO2.

After these researches and assumptions, we generated the marginal abatement cost curve of road transport in China in 2010, 2015 and 2020. The corresponding graphs and tables are listed below.

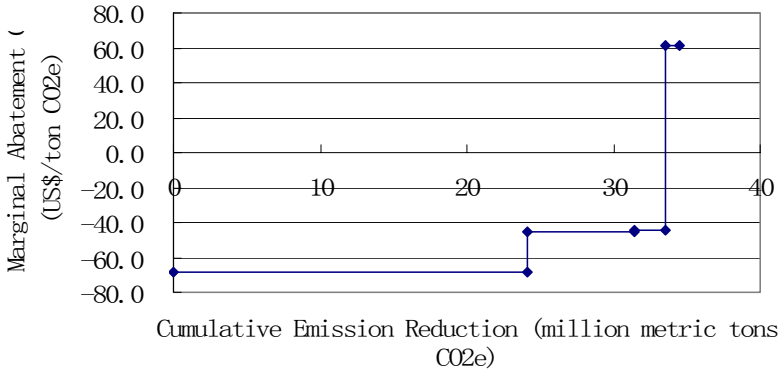

Figure 7-9 Marginal abatement cost curve of transport sector at 2010

Table 7-34 Cost of mitigation options and relevant emission reduction in 2010

Mitigation Option	Cost Effectiveness ($/metric ton CO_2e)	Total Emission Reduction (million metric tons CO_2e)	Total Cost (million $)	Cumulative Emission Reduction (million metric tons CO_2e)	Cumulative Net Cost (million $)	Average Cumulative Cost Effectiveness ($/metric ton CO_2e)
Engine Technologies	-68.5	24.1	-1654	24.1	-1654	-68.5
Vehicle Technologies	-45.7	7.3	-333.1	31.4	-1987	-63.2
Engine-Transmission-Vehicle Technologies	-44.8	2.1	-94.7	33.5	-2082	-62.1
Fuel Switch	61.6	0.9	58.4	34.5	-2023	-58.7

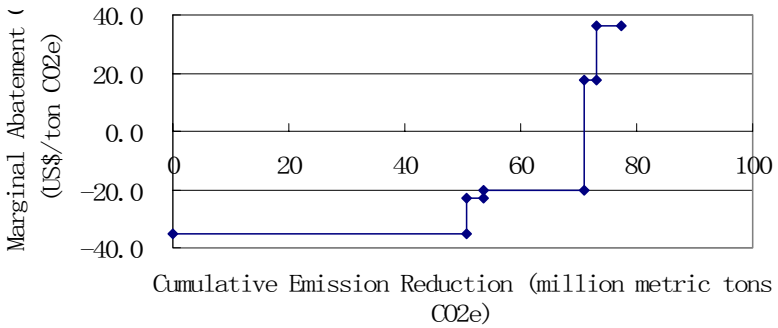

Figure 7-10 Marginal abatement cost curve of transport sector at 2015

Table 7-35 Cost of mitigation options and relevant emission reduction in 2015

Mitigation Option	Cost Effectiveness ($/metric ton CO_2e)	Total Emission Reduction (million metric tons CO_2e)	Total Cost (million $)	Cumulative Emission Reduction (million metric tons CO_2e)	Cumulative Net Cost (million $)	Average Cumulative Cost Effectiveness ($/metric ton CO_2e)
Engine Technologies	-35.3	50.8	-1791	50.8	-1791	-35.3
Engine-Transmission-Vehicle Technologies	-23.2	2.8	-66.0	53.6	-1857	-34.6
Vehicle Technologies	-20.2	17.2	-347.6	70.9	-2205	-31.1
BRT	17.9	2.3	40.2	73.1	-2165	-29.6
Fuel Switch	36.4	4.2	152.3	77.3	-2012	-26.0

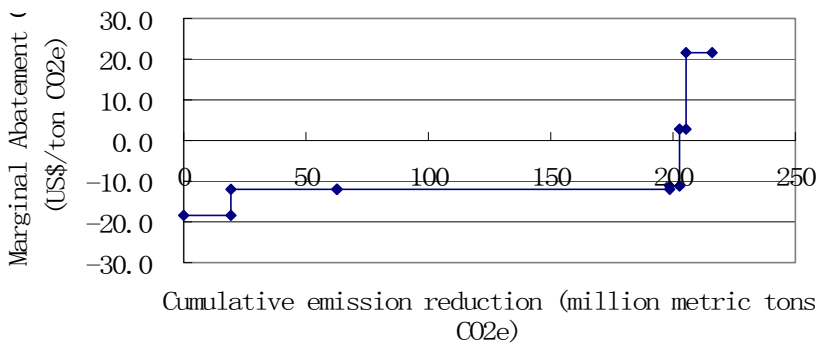

Figure 7-11 Marginal abatement cost curve of transport sector at 2020

Table 7-36 Cost of mitigation options and relevant emission reduction in 2020

Mitigation Option	Cost Effectiveness ($/metric ton CO_2e)	Total Emission Reduction (million metric tons CO_2e)	Total Cost (million $)	Cumulative Emission Reduction (million metric tons CO_2e)	Cumulative Net Cost (million $)	Average Cumulative Cost Effectiveness ($/metric ton CO_2e)
Transmission Technologies	-18.4	19.1	-350.4	19.1	-350.4	-18.4
Vehicle Technologies	-12.0	43.8	-523.7	62.8	-874.1	-13.9
Engine Technologies	-11.9	136.0	-1618	198.9	-2492	-12.5
Engine-Transmission-Vehicle Technologies	-11.1	3.8	-42.4	202.7	-2535	-12.5
BRT	2.6	2.8	7.5	205.5	-2527	-12.3
Fuel Switch	21.5	10.3	220.7	215.8	-2307	-10.7

When we read data in one table, we will easily find that the cost effectiveness of all vehicle related technologies is negative. It shows that within the cost range we have taken into accounts till now, these technologies are highly recommended to use. Each year, the oil saving benefits from installing or renewing certain technologies would exceed the value of apportionment of the total technology expense. However, we should also clarify that for some technologies, these costs are far lower than the cost after taking into account a broader range of potential costs: the fact of technical barriers, the cost of independent or cooperative R&D, the cost of technology transfer, the cost of management and training, and the cost of building other supportive facilities.

Also analyzing from a single table could tell us that the engine technologies are the greatest contributor to the total emission reduction. In 2010, the engine technologies contribute nearly 70% of the total emission reduction. And in 2015 and 2020, the percentage is respectively 66% and 62%. The second contributor is always vehicle technologies. And BRT, as its indirect influence in mitigation (it mainly changes the travel mode), has the least contribution to emission reduction. From the perspective of reaching sheer emission reduction goals, we should certainly first promote these engine technologies.

All these mitigation options are designed in the 2005 policies scenario. In the 2005 policies scenario, the CO2 emission in 2010, 2015 and 2020 is respectively 393.3, 514.9, and 642.9 million tons. So after the implementation of these mitigation options, the emission reduction rate could reach respectively 8.77%, 15.0% and 33.6%. A huge amount of emission has been reduced due to these mitigation options.

From all the three tables above, we can tell that the average cumulative cost effectiveness is all negative, which implies that in transport sector, after considering the oil saving benefits, all the mitigation options, although some with very large initial investment cost, will bring in net benefits.

VII.F Analysis of GHG mitigation scenarios

Six packages of mitigation options for the road transport analysis are discussed here. All vehicle related mitigation options are in the negative-cost range partly due to the limits of cost considered. We classify BRT as the option costing less than $10 per metric tons, and fuel switch costs more than $10. Therefore, we divide these options into three mitigation scenarios in this analysis. Mitigation scenario 1 contains with all zero- or negative-cost mitigation options, mitigation scenario 2 contains mitigation options costing less than $10 per metric tons, and the last scenario – Mitigation scenario contains all feasible mitigation options. See Table 7-37.

Table 7-37 Cost and mitigation effects of three Advanced Options (Mitigation) scenarios

	Mitigation Options Contained	Total Changes in Costs (million US$)	Initial cost (million US$)	Long-term cost (million US$)	Total Emission Reduction (million tons)	The average cost ($ per tonne)
Advanced Options Scenario #1 (zero- or negative-cost mitigation options)	Engine technologies, Transmission Technologies, Vehicle technologies, Engine-transmission-vehicle technologies	8840.6	253.2	-115893	1368.4	-84.7
Advanced Options Scenario #2 (costing less than $10 per metric tons)	Engine technologies, Transmission Technologies, Vehicle technologies, Engine-transmission-vehicle technologies, BRT	13289.2	480.4	-114803	1391.1	-82.5
Advanced Options Scenario #3 (all feasible mitigation options)	Engine technologies, Transmission Technologies, Vehicle technologies, Engine-transmission-vehicle technologies, BRT, fuel switch	22289.4	653.3	-105802	1497.2	-70.7

The time frame taken into accounts in this part is from 2000 to 2020. The vehicle related technologies are starting to be used since year 2006; the BRT systems, though constructing since 2000, are starting to have emission reduction effects since 2011; the fuel switch is starting to be used since 2010. All these mitigation options have emission reduction effects till 2020.

As the emission reduction effects of vehicle related technologies are presented in a percentage form, the emission reduction by vehicle technologies per year is educed by the fuel saving rates and the CO2 emission of target vehicles in the 2005 policies baseline. The oil savings by vehicle related technologies could be educed by the same way. It is obvious that since 2006, we will have the oil saving benefits each year. (Oil price is set to be constant at $0.55 for either gasoline or diesel here.) These oil saving benefits discounted back to year 2000 added together could tell us the total oil saving benefits. Discount rate is 10%. Cost information in Table 7-28 has first been organized to count the cost per vehicle in near term, mid term and long term, then divided by each vehicle's life time – 15 years in this research to get the cost per year. Different years will have different vehicle population. So multiplying the cost per vehicle per year by the vehicle population in that year could educe the cost for a specific year. Discounting the costs from 2006 to 2020 back to 2000 and adding them up together will tell us the total cost. As total cost and oil saving benefits are known now, we can educe the long-term cost (net cost). Divided by the total emission reduction, we can get the average cost for each tonne of CO2 emission reduction.

The infrastructure cost of BRT has been evenly split to years from 2011-2020 where there is CO2 emission reduction. Discounting each year's cost back to year 2000 will give us the total cost information. The CO2 emission reductions in 2011, 2015 and 2020 have been counted, in the way we described in the previous section. And we simply estimate the CO2 emission reduction between the year 2011 and 2015, and the year between 2015 and 2020, assuming that CO2 emission reduction will grow at a constant amount every year. We could also tell the oil saving from the CO2 emission reduction amount each year. Discounting the oil saving benefits every year back to year 2000 and adding them up will give us the total oil saving benefits. Long-term cost could be educed by total costs minus the oil saving benefits. Also divided by the total emission reduction, we can get the average cost for each tonne of CO2 emission reduction.

Emission reduction by fuel switch could easily be educed by the emission reduction rate multiplied with the original emission of target vehicles. Cost by fuel switch per year is educed by multiply the cost per tonne information by the emission reduction amount. Discounted these cost information back to year 2000 will give us the net cost of fuel switch. Divided by the total emission reduction, we can get the average cost for each tonne of CO2 emission reduction.

We define the initial costs as the sum of discounted-back-to-2000 investment cost (no oil saving benefits considered) in the first year when different options begin to have emission reduction effects.

The implementation of mitigation options could certainly bring some co-benefits. The fuel saving reached directly by those mitigation options in transport sector could effectively enhance energy security and independence because China had become one of the most important oil importers in the world nowadays. The CO2 emission reduction and the concomitant reduction in other vehicle-related pollutants would benefit the air quality improvements, increase economic productivity and competitiveness and protect the biodiversity. Besides, the large need in producing new vehicle components with advanced technologies and infrastructure development for BRT would bring more and more job opportunities to the society.

VII.G High Oil Price Sensitivity Analysis Based on Pre-2000 baseline

Crude oil prices and oil products prices have been rising in China since 2000, at a frequency of 3 or 4 times a year. Two rises in oil products happened in China in 2006, one in Mar. 26th and another in May 24th. The May 24th price rising is the biggest one ever since China published her Reformation Plan on Crude Oil and Oil Products Pricing in 1998. It has increased either the gasoline price or the diesel price by 500 RMB per ton, which is nearly 10% higher than their original price. As a result, the price of 93# gasoline has risen from 4.26 yuan (0.515 USD) at the beginning of 2006 to 5.09 yuan (0.615) right now (exchange rate of USD to RMB is assumed to be 1:8.27). Experts also say that the current oil price in China is still comparatively lower than other countries, and there will be space for the further price rising.

Special attention has been paid to the response from vehicles owners and potential vehicle buyers. At the last night before May 24th, a long vehicle queue showed up in the gas station in big cities in China, such as Beijing and Shanghai. Some vehicle owners are considering reducing the usage rate of vehicles, and some are thinking about switching to traveling by bus. According to certain survey, 98% of vehicle owners being interviewed said that they will think about adjusting their travel mode. And a survey carried out by Journal 'Vehicle Observer' shows that price-sensitive consumers are thinking about buying a lower class of vehicles. 80% of the interviewees imply that the rising price has influenced their plan to buy cars, among which 36.6% will delay their purchase. However, some researchers are still very optimistic about the Chinese vehicle market. They believe that the major trend of motorization in China will be very steady and the rise of oil price will mostly influence the composition and the fuel economy of new vehicles.

The key department which decides the oil price in China is the National Development and Reform Committee. Intervention from Chinese government has been playing nearly a decisive role on the oil pricing. And that is why the oil price in China is comparatively stable even when the oil price in the world has been experiencing an unprecedented jump. However, through the several times of oil price rising in China, we could also see the tendency for the oil price in China to gradually approach the average oil price in the world.

In this high oil price sensitivity analysis, we try to figure out how the emission baseline would change if China is under this rising oil price. However, first, it is impossible for China to apply world oil price immediately; there must be a buffering time. We assume that since 2015, China will totally follow the trend of the world oil price change. By 'following the trend', we do not mean that the oil price in China will be identical with the world oil price. Actually nowadays, in other market-economy countries which are very sensitive to world oil price change, they may still vary in the domestic product oil price. So in this research, we assume that China will have an identical rise and fall rate of product oil price with the variance rate of world crude oil price; and between the years 2007 to 2014, China will adjust its own rise and fall rate to gradually follow the trend. In 2004, 2005 and 2006, the rise rate of product oil price in China is respectively 22.94%, 14.58%, 12.21%, which is 0.87, 0.38 and 1.43 times (the average value of the three is 0.89) of the world crude oil price change rate. Assuming that the value of domestic rise and fall rate divided by the international rise and fall rate will grow at a constant value per year until the value reaches 1 in 2015, we can educe the value for years from 2007 to 2014 and then educe the 'actual' rise and fall rate of domestic oil price, and further get the price of product oil price in China. Figure 1 shows the change in world crude oil price and the domestic product oil price in China. It should be noted that we use the price of 90# gasoline to represent the domestic product oil price because the sales of 90# gasoline is the biggest.

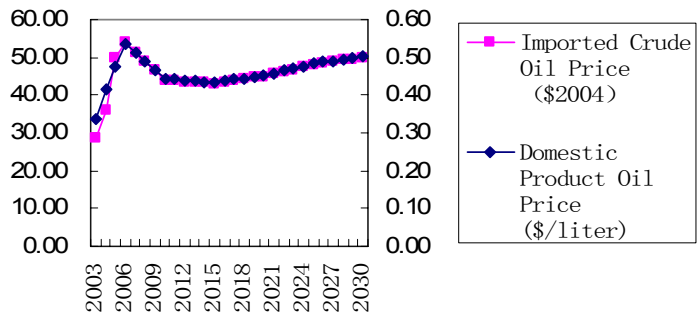

Figure 1 Comparison of world crude oil price and domestic product oil price in China

The product oil price change would influence the VKT and the vehicle population (mainly by influencing the number of new vehicles). In this research, we assume that the oil price change will not affect the FE level, because the FE level is to a large extend closely linked to the specific policy in the country. Table 1 shows our assumption for the new VP and VKT change according to a 100% rise in domestic product oil price. The change rate of new VP and VKT is in direct ratio to the change rate of domestic product oil price change rate.

Table 1 Assumption of influence to new VP and VKT under a 100% rise in domestic product oil price

	New VP	VKT
To HT, MT, HB, MB	-20%	-40%
To other vehicles (except cars)	-25%	-45%
To Cars	-30%	-50%
To Motorcycle	-40%	-60%

Note: HTs, MTs, HBs and MBs are less sensitive due to their commercial characteristics. Cars are more sensitive because the private vehicles are taking up a larger and larger portion in the total vehicle population and the individual buyers are very sensitive to the price. Motorcycles are the most sensitive because motorcycles are in the phasing-out period as the society improves.

By using these assumptions, we could educe a new series of vehicle population and VKT data, from which we can calculate a new version of vehicular oil consumption and CO2 emission. See Table 2 and Figure 2 and 3 below.

Table 2 Comparison of oil consumption and CO2 emission under high oil price scenario and pre-2000 baseline

	Oil consumption (million tons)		CO2 emission (million tons)	
	High Oil Price Scenario	Pre-2000 Baseline	High Oil Price Scenario	Pre-2000 Baseline
2005	82.51	89.01	260.26	280.76
2010	133.61	130.31	421.60	411.19
2015	171.30	170.92	540.86	539.63
2020	213.23	214.19	673.41	676.44

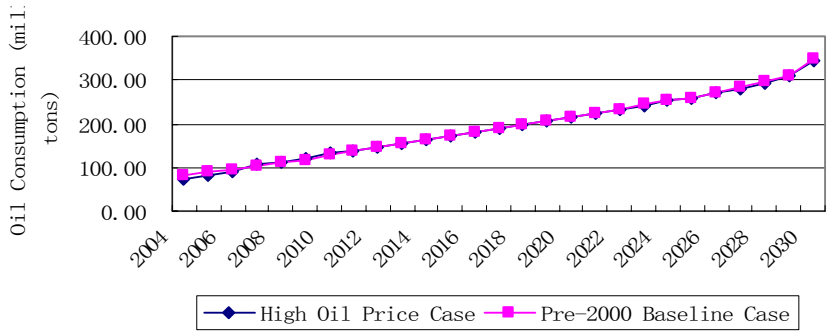

Figure 2 Comparison of oil consumption under high oil price scenario and pre-2000 baseline

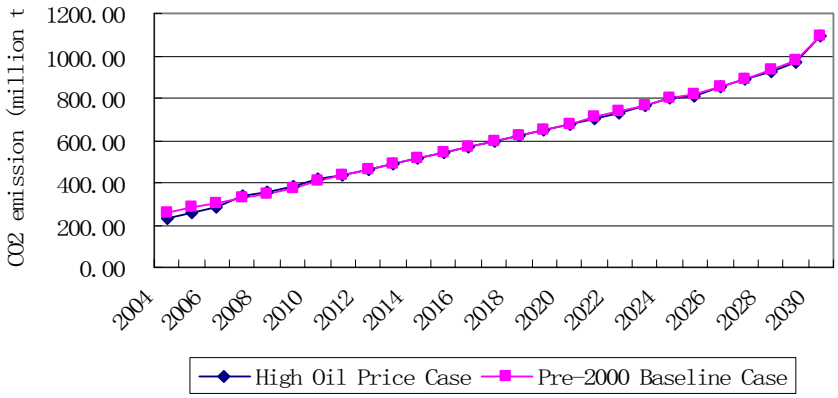

Figure 3 Comparison of CO2 emission under high oil price scenario and pre-2000 baseline

In the several oil price jumping years, China is experiencing its gradual adjustment to meet the global oil price change trend. However, when China is finally meeting the global oil price change trend, the global price seems to follow a quite stable growth tendency. That is one of the reasons that the high oil price case doesn't show a big influence to the baseline change. One big uncertainty exists in the settings of high oil price case – the sensitivity of VP and VKT to the oil price. There have been researches about the effects of high oil price towards Chinese economy, but few has pointed out the qualitative relationship between oil price and vehicle population, and the vehicle kilometers traveled per year. More researches and studies need to be done to calibrate this.

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VIII. Macro-economic Modeling Analysis

VIII.A Scenario Definition for Sectoral Approach

In our above analysis, energy conservation and GHG emission reduction potentials under different scenarios of several sectors were compared and their feasibilities were assessed according to the cost information. Emission reduction technologies with high priority were identified.

The foregoing analysis has some limitation in that the macroeconomic impact of each individual sector's mitigation option cannot be illuminated by a bottom-up analytical framework. Here we introduce a global trade CGE model named GTAP-E. Using this macroeconomic model, we simulate and analyze the macro-economic impacts of single sector's measures on China's gross economic, industry structures and commercial exports. As the space is limited, we take electricity sectoral mitigation policy analysis as example.

From the angles of promoting technology advancement indirectly and enhancing energy efficiency directly, two kinds of categories of scenarios are set up. One is to increase electric generation cost, the other one is to implement mitigation measures. We name them as cost scenarios and measures scenarios separately, and three sub-scenarios contained in each one are given names as Cost scenario 1, 2, and 3 and Measures scenario 1, 2, and 3 for convenience in the following discussion.

Table 8-1 sectoral approach scenarios in "top-down" assessment

	Production cost scenarios	Mitigation option scenarios
Sub-scenario1	Electric generation cost increases 2.5%, paid for by China.	Implementation of all mitigation measures costing less than \$5/metric ton CO_2 in electricity sector, paid for by China.
Sub-scenario2	Electric generation cost increases 5%, paid by China.	Implementation of all mitigation measures costing less than \$10/metric ton CO_2 in electricity sector, paid for by China.
Sub-scenario3	Electric generation cost increases 5%. 2.5% is paid by China, and additional total incremental cost is paid by international community in the form of a direct grant.	Implementation of all mitigation measures costing less than \$10/metric ton CO_2 in electricity sector, 5% is paid for by China. And additional total incremental cost is paid by international community in the form of a direct grant.

VIII.B Development of analytical approach：GTAP-E model

The model used in this research is extended version of the GTAP model called GTAP-E, which allows for the possibility of inter-fuel and inter-factor substitution in the production structure of firms and in the consumption behavior of private households and government sector. GTAP model is developed by Department of Agricultural Economics of PURDUE University. It is a kind of global static computable general equilibrium.

GTAP has been steadily expanding its capability towards facilitating global economic analyses of GHG emissions abatement. GTAP has successfully integrated global energy data sets, in particular, extended energy balances and energy prices and taxes, compiled by the International Energy Agency (IEA), into the GTAP input-output tables and bilateral trade data.

In order to adapt our research needs, we adjusted GTAP-E model and divided the world into 6 regions: EU, USA, Other developed countries, China, India, and Other developing countries.

Twenty sectors: Agriculture, forestry, fisheries, food, textile, manufacturing, pulp and paper, oil refining, chemical industry, metal and metallurgy, construction, trade, transport, services ,other mining, water, coal, oil, natural gas and electricity.

Figure 8-1 offers an overview of economic activity in a simplified version of the GTAP model. At the top of this figure is the regional household. Expenditures by this household are governed by an aggregate utility function that allocates expenditure across three broad categories: private, government, and savings expenditures. The model user has some discretion over the allocation of expenditures across these types of final demand. In the standard closure, the regional household's Cobb-Douglas utility function assures constant budget shares are devoted to each category. However, real government purchases and savings can also be dictated exogenously (i.e., fixed or shocked), in which case private household expenditure will adjust to satisfy the regional household's budget constraint. It is important to note that imports are traced to specific agents in the domestic economy, resulting in distinct import payments to rest of the world from private households, government households, and firms. This innovation departs from most models of global trade. It is especially important for the analysis of trade policy in regions where import intensities for the same commodity vary widely across uses.

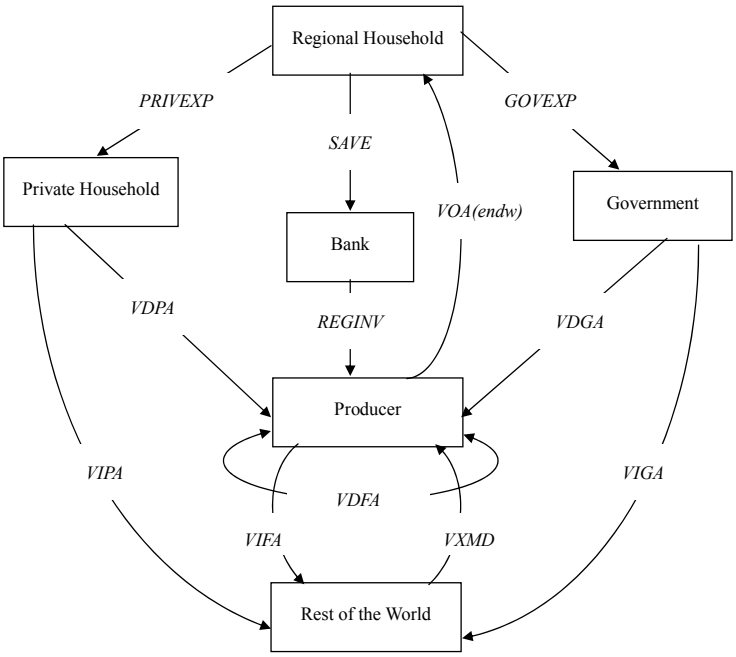
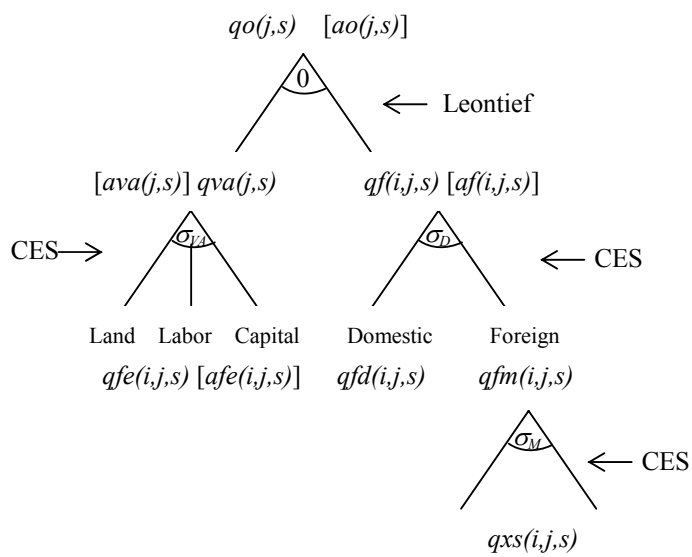


Figure 8-1.Structure of GTAP model

Regional household behavior is governed by an aggregate utility function, specified over composite private consumption, composite government purchases, and savings. The GTAP model employs a special case of the Stone-Geary utility function, whereby all subsistence shares are equal to zero. An index of current government expenditure is used to proxy the welfare derived from the government's provision of public goods and services to private households in the region. Then the aggregation of this index with private utility is adopted to make regional welfare based on the further assumption that the level of public goods provided in the initial equilibrium is optimal.

The following figure provides a visual display of the assumed technology for firms in each of the industries in the GTAP model. At the bottom of the inverted tree are the individual inputs demanded by the firm. For example, the primary factors of production are: land, labor, and capital. Firms also purchase intermediate inputs, some of which are produced domestically and some of which are imported. In the case of imports, the intermediate inputs must be "sourced" from particular exporters.



Recall
Figure 8-2. Standard GTAP Production Structure

Comparing with the GTAP model, one of the most critical variations of GTAP-E model is the incorporation of inter-fuel and fuel-factor substitutions into production function. On the production side, energy must be taken out of the intermediate input 'nest' to be incorporated into the 'value-added' nest. The incorporation of energy into the value-added nest is in two steps. Energy commodities are first separated into 'electricity' and 'non-electricity' groups. Some degree of substitution is allowed within the non-electricity group as well as between the electricity and the non-electricity groups. Next, the energy composite is then combined with capital to produce an energy-capital composite, which is in turn combined with other primary factors in a value-added-energy nest through a CES structure. In GTAP-E, the value of capital-energy substitution elasticity is assumed to be 0.5 for most industries (including electricity), and is set equal to 0.0 for coal, oil, gas, petroleum and coal products, and agriculture/forestry/fishery. This is based on the (low-to-middle) range of the values adopted by other models. The value of value added-energy substitution elasticity ranges from 0.2 to 1.45 and this seems to be slightly larger than the values adopted by other models, but these are the values currently used in the standard GTAP model.

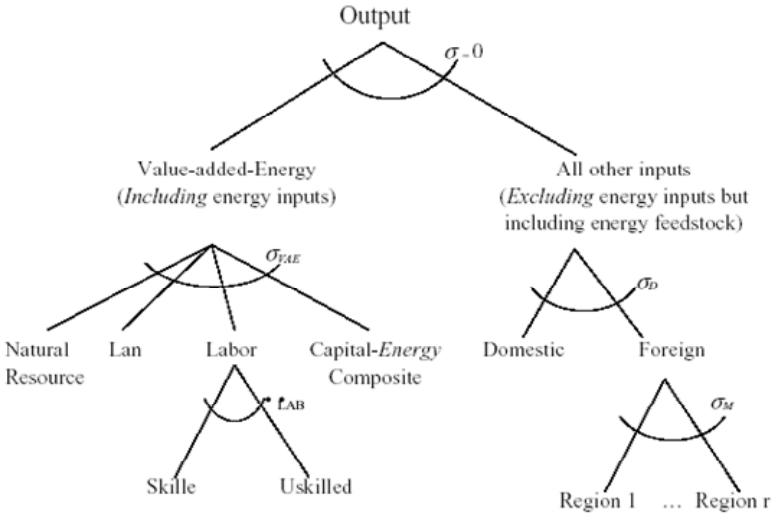


Figure 8-3. GTAP-E Production Structure

VIII.C Macro economic Impacts under different mitigation policy scenarios

Sectoral mitigation cost in cost scenario 3 is equal to that in cost scenario 2, so the mitigation effects are the same in the two scenarios. Suppose 2.5% sectoral cost from international community in the form of a direct grant is utilized for CO_2 mitigation and not industrial investment, and it will not impact China's national electricity demand and economic structure. So macro economic impacts in cost scenario 3 will be the same as that in cost scenario 1.

At present, electricity generation cost in China is about 0.0036~0.0060 US dollar/kWh, and total electricity generation cost is estimated as 4.96~8.27 billion US dollar in 2000. Global GDP is 61.03 trillion US dollar in 2000. Suppose global active capital accounts for 5% of global GDP, 2.5% increase of China's electricity generation cost is equal to $2.45\sim4.09\times10^{-6}$. This part of generation cost increase will make little impacts on global active capital. So we assume the macro economic impacts are the same in cost scenario 3 with cost scenario 1. We also can conclude that mitigation effects in measure scenario 3 are the same with measure scenario 2, and macro economic impacts in measure scenario 3 are the same with that in measure scenario 1. Consequently, we only give the results of cost scenario 1 and 2 and measure scenario 1 and 2 compared to baseline scenario without any mitigation measures.

In cost scenarios, we assume that electricity generation corporations need improve energy efficiency to pay off the increasing cost. As a result, technology upgrade and renovation is promoted indirectly. This category of scenarios is simulated through changing China's electricity generation cost directly in GTAP-E model. Based on Pigou's theory, carbon tax can optimize resources among electricity generation corporations, and corporations have to implement technologies with the same mitigation margins as tax rate at the end. Measure scenarios are simulated through imposing carbon tax on electricity sector in GTAP-E model

Using GTAP-E model we can analysis the change of hundreds economic variables under the above scenarios. But in order to simplify the analysis, we will focus on the change of GDP, CO2 mitigation, industrial products' price and output, industrial structure and commercial export value under different policy scenarios.

VIII.C.1 Changes of China's GDP

China's GDP falls 0.01%, 0.02%, 0% and 0.01% separately in four scenarios, as shown in Fig 8-4. It indicates that increasing China's electricity generation cost or implementing mitigation measures can decrease national GDP. The higher generation cost increase and the more mitigation options are implemented, the stronger GDP will get influenced.

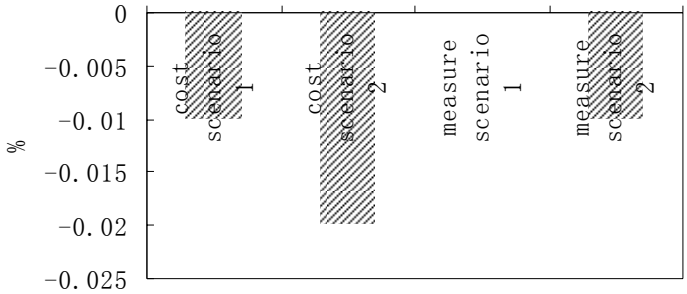


Fig 8-4. Change of China's GDP under different scenarios

VIII.C.2 Changes of China's anthropogenic CO_2 emissions

China's anthropogenic CO_2 emissions fall 0.4%, 0.73%, 0.51% and 0.9% separately under the four scenarios, as shown in Fig 8-5. It indicates that the higher sectoral producing cost increase and the more mitigation options are implemented, the greater CO_2 mitigation we will gain. Compared to the measure scenarios GDP falls more in cost scenarios, but mitigation effect is worse.

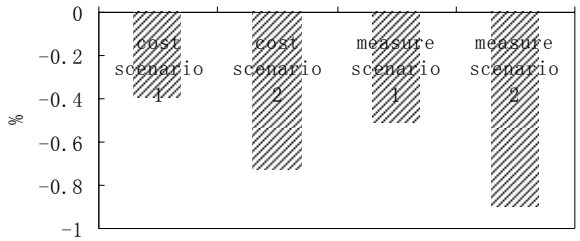


Fig 8-5. changes of China's anthropogenic CO_2 emissions under different scenarios

VIII.C.3 Changes of Chinese industrial production price and output

From Table 6-2 we can see that electricity price increases 1.64% and 3.26 when the generation cost increase 2.5% and 5%. Other industrial products' prices all fall slightly to meet the market equilibrium except pulp and paper, chemical industry, metal and metallurgy and water industry. Electricity price increases 0.83% and 1.62% when carbon tax rate is set at \$5/mt CO_2 and \$10/mt CO_2. From the results we can obviously conclude that imposing carbon tax will make less impacts on other industrial products' prices except coal industry. The most sensitive industry to electricity price changes are electricity, coal and gas under four scenarios. There is tight connection between commercial demand and supply in China's energy markets.

Table 6-2 Changes of industrial production prices under different scenarios

industry	Change rate of production market price×100			
	Cost scenario 1	Cost scenario 2	Measure scenario 1	Measure scenario 2
Agriculture	-0.01	-0.03	0	-0.01
forestry	-0.04	-0.08	-0.02	-0.05
fisheries	-0.03	-0.05	-0.01	-0.03
food	-0.01	-0.02	0	-0.01
textile	-0.01	-0.02	0	0
manufacturing	-0.01	-0.02	0	-0.01
pulp and paper	0	0	0	0
oil refining	-0.02	-0.04	0	-0.01
chemical industry	0.02	0.04	0.01	0.02
metal and metallurgy	0.01	0.03	0	0.01
construction	-0.01	-0.02	0	-0.01
trade	-0.03	-0.07	-0.01	-0.02
transport	-0.04	-0.08	-0.01	-0.03
services	-0.02	-0.04	-0.01	-0.01
other mining	-0.03	-0.06	-0.01	-0.02
water	0.12	0.24	0.07	0.13
coal	-1.25	-2.38	-1.85	-3.43
oil	-0.02	-0.05	0	0
natural gas	-0.5	-0.99	-0.31	-0.56
electricity	1.64	3.26	0.83	1.62

Table 8-3 reflects changes of China's industrial production compared to baseline scenario without any mitigation measures.

Table 8-3 impacts on industrial production under 4 scenarios

industry	Production changes (million dollar)			
	Cost scenario 1	Cost scenario 2	Measure scenario 1	Measure scenario 2
Agriculture	-2.94	-7.81	-3.47	-8.63
forestry	-7.20	-14.2	-5.94	-11.6
fisheries	-1.55	-3.46	-0.50	-1.32
food	1.98	2.23	0.30	-1.00
textile	87.0	175.6	15.9	33.3
manufacturing	114.1	230.1	55.8	110.1
pulp and paper	-7.10	-14.3	-3.63	-7.60
oil refining	-61.6	-118.4	6.21	10.6
chemical industry	-142.9	-282.0	-52.1	-105.6
metal and metallurgy	-203.5	-404.6	-70.5	-143.4
construction	-246.4	-490.4	-88.9	-178.3
trade	-2.22	-6.06	-5.06	-12.1
transport	0.73	1.14	-1.91	-4.55
services	-36.1	-80.1	-23.4	-52.7
other mining	-29.3	-58.2	-10.4	-21.1
water	-4.93	-9.82	-2.02	-4.01
coal	-73.0	-142.6	-111.5	-215.5
oil	3.98	7.34	2.76	5.37
natural gas	-35.6	-69.9	-19.4	-34.3
electricity	-678.1	-1331.3	-257.0	-500.6

Table 8-3 implies that as electricity generation cost increases and stricter mitigation measures are implemented, there will be more impacts on national industrial production outputs. Textile, manufacturing, chemical industry, metal and metallurgy, construction and coal are the most sensitive sectors towards mitigation policies implemented in electricity sector, among which outputs of textile and manufacturing will increase and the others will fall.

Fig 8-6 illustrates that coal and natural gas sectors' output change rates are the most obvious under four scenarios. Taking cost scenario 1 and measure scenario 1 as examples, electricity generation decrease 1.34% and 0.51% compared to baseline scenario without any mitigation measures, and outputs for coal and natural gas sectors fall 0.64%, 0.98% and 2.08%, 1.13%, respectively, in the two scenarios. It is concluded that there is a tight relationship among the energy products' demand and supply.

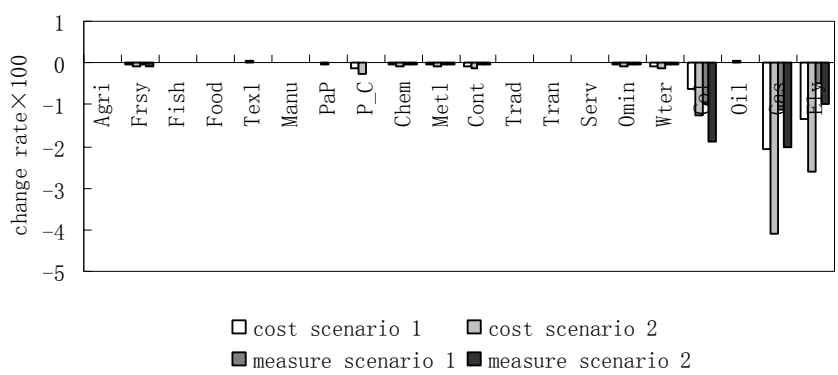


Fig 8-6 Impacts on China's industrial production outputs' change rate under 4 scenarios

VIII.C.4 Changes of industrial structure

Table 8-4, Table 8-5, Table 8-6 and Table 8-7 reveal the changes of intermediate inputs among sectors under 4 different scenarios.

Table 8-4 changes of intermediate inputs among sectors under cost scenario 1 (million dollar)

	Agri	Frsy	Fish	Food	Texl	Manu	PaP	P_C	Chem	Metl
Agri	-0.07	-0.07	-0.01	3.02	6.93	0.74	-0.17	0.00	-2.45	-0.18
Frsy	0.06	-0.48	0.00	0.01	0.01	1.21	0.02	-0.01	-2.06	-0.07
Fish	0.00	0.00	-0.08	0.08	0.00	0.01	0.00	0.00	-0.45	0.00
Food	0.21	-0.01	-0.09	1.04	1.75	0.04	0.00	0.00	-1.52	-0.06
Texl	0.01	-0.01	0.00	0.04	34.93	3.06	-0.18	-0.11	-4.33	-1.68
Manu	0.08	-0.19	0.02	0.18	1.77	51.86	-0.09	-1.59	-2.83	-11.73
PaP	0.00	-0.01	0.00	0.05	0.45	1.18	-1.57	-0.02	-1.69	-3.44
P_C	6.59	0.35	1.14	1.39	2.46	3.96	1.00	-4.45	20.69	12.15
Chem	-2.33	-0.34	-0.03	-0.37	2.05	1.64	-0.81	-0.95	-51.93	-7.60
Metl	-0.04	-0.08	-0.01	-0.11	0.34	8.92	-0.14	-0.69	-3.23	-66.16
Cont	-0.01	-0.02	0.00	0.00	0.08	0.11	-0.01	-0.06	-0.15	-0.19
Trad	-0.01	-0.14	-0.03	0.12	5.32	5.29	-0.50	-1.76	-6.64	-10.13
Tran	0.04	-0.13	0.01	0.04	1.24	1.64	-0.13	-1.22	-2.74	-6.50
Serv	-0.01	-0.31	-0.01	0.16	2.22	4.53	-0.15	-1.21	-4.52	-8.77
Omin	0.00	0.00	0.00	0.00	0.00	0.40	0.00	-0.04	-2.16	-13.84
Wter	0.00	0.00	0.00	0.00	0.06	0.07	-0.01	-0.08	-0.23	-0.28
Col	1.34	0.16	0.13	3.21	2.23	4.70	2.14	0.01	9.13	30.07
Oil	0.07	0.00	0.00	0.00	0.00	0.01	0.00	11.24	0.50	0.09
Gas	0.19	0.01	0.01	1.36	1.59	1.52	0.08	0.00	5.51	2.81
Ely	-23.40	-1.30	-3.07	-15.09	-24.44	-34.59	-11.33	0.00	-88.77	-108.12
	Cont	Trad	Tran	Serv	Omin	Wter	Col	Oil	Gas	Ely
Agri	-0.41	0.33	0.05	-0.01	-0.03	0.00	-0.52	0.00	0.00	-0.08
Frsy	-1.29	0.02	0.01	0.01	-0.02	0.00	-3.07	0.00	-0.01	-0.14
Fish	0.00	0.01	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00
Food	-0.14	0.49	0.02	-0.14	-0.01	0.00	-0.01	0.00	0.00	-0.01
Texl	-1.07	0.09	0.04	-0.17	-0.19	-0.02	-0.67	0.04	-0.26	-1.93
Manu	-18.59	2.09	1.96	2.75	-1.66	-0.24	-7.31	0.41	-3.08	-97.10
PaP	-0.19	-0.01	0.01	-0.91	-0.02	0.00	-0.10	0.01	-0.04	-0.51
P_C	1.19	2.26	1.93	13.84	0.56	0.17	0.00	0.00	-2.60	-125.92
Chem	-5.00	-0.63	-0.41	-2.14	-1.89	-0.22	-2.36	0.04	-1.06	-18.33
Metl	-91.42	-0.09	-0.06	-0.72	-0.86	-0.18	-6.57	0.10	-1.07	-5.78
Cont	-0.13	0.01	0.02	-0.74	-0.09	-0.02	-0.20	0.01	-0.10	-2.93
Trad	-12.80	0.73	0.44	-0.08	-1.13	-0.08	-2.80	0.05	-1.98	-16.89
Tran	-5.40	1.14	2.09	0.79	-1.50	-0.03	-1.51	0.03	-1.04	-10.66
Serv	-13.18	0.70	1.17	-1.36	-1.35	-0.28	-3.55	0.12	-1.21	-27.02
Omin	-6.28	0.00	0.00	-0.01	-7.13	0.00	-0.10	0.00	-0.03	-0.65
Wter	-0.25	-0.01	0.00	-0.11	-0.04	-0.35	-0.11	0.00	-0.13	-1.69
Col	0.35	0.29	0.37	2.44	0.80	0.03	-0.01	0.00	-1.05	-234.09
Oil	0.01	0.00	0.00	0.15	0.00	0.02	0.00	0.00	-0.01	-23.38
Gas	0.25	0.01	0.00	0.92	0.12	0.01	0.00	0.00	-3.23	-109.26
Ely	-7.21	-5.31	-3.28	-65.48	-6.55	-5.84	-0.02	0.00	-0.01	-216.52

Table 8-5 changes of intermediate inputs among sectors under cost scenario 2 (million dollar)

	Agri	Frsy	Fish	Food	Texl	Manu	PaP	P_C	Chem	Metl
Agri	-0.41	-0.15	-0.03	5.56	14.04	1.50	-0.33	0.00	-4.83	-0.35
Frsy	0.12	-0.94	0.01	0.02	0.01	2.41	0.04	-0.01	-4.05	-0.14
Fish	0.00	0.00	-0.19	0.10	0.00	0.02	0.00	0.00	-0.89	0.00
Food	0.31	-0.02	-0.21	1.90	3.54	0.09	0.00	0.00	-3.00	-0.12
Texl	0.02	-0.02	0.00	0.08	70.53	6.18	-0.36	-0.21	-8.52	-3.34
Manu	0.13	-0.38	0.01	0.34	3.56	104.17	-0.19	-3.04	-5.57	-23.29
PaP	0.00	-0.02	-0.01	0.07	0.91	2.38	-3.14	-0.04	-3.34	-6.84
P_C	13.07	0.70	2.27	2.75	4.86	7.82	1.97	-8.51	41.15	23.91
Chem	-4.74	-0.66	-0.06	-0.75	4.23	3.54	-1.60	-1.82	-102.41	-15.07
Metl	-0.09	-0.16	-0.02	-0.24	0.69	18.13	-0.28	-1.32	-6.38	-131.49
Cont	-0.02	-0.03	0.00	0.00	0.15	0.22	-0.02	-0.11	-0.29	-0.37
Trad	-0.06	-0.27	-0.06	0.15	10.73	10.67	-1.00	-3.37	-13.11	-20.14
Tran	0.05	-0.26	0.01	0.06	2.49	3.31	-0.26	-2.34	-5.41	-12.91
Serv	-0.08	-0.61	-0.03	0.28	4.48	9.12	-0.29	-2.32	-8.90	-17.43
Omin	0.00	0.00	0.00	0.00	0.00	0.81	0.00	-0.07	-4.27	-27.51
Wter	0.00	0.00	0.00	0.00	0.12	0.14	-0.03	-0.15	-0.45	-0.56
Col	2.61	0.31	0.25	6.26	4.36	9.20	4.16	0.01	17.62	58.31
Oil	0.14	0.00	0.00	0.01	0.01	0.02	0.00	35.66	1.06	0.18
Gas	0.38	0.02	0.02	2.65	3.10	2.97	0.16	0.01	10.70	5.47
Ely	-46.04	-2.54	-6.05	-29.65	-48.09	-68.02	-22.27	0.00	-174.38	-212.31
	Cont	Trad	Tran	Serv	Omin	Wter	Col	Oil	Gas	Ely
Agri	-0.82	0.66	0.10	-0.03	-0.06	0.00	-1.02	0.00	0.00	-0.15
Frsy	-2.56	0.03	0.01	0.02	-0.05	0.00	-5.99	0.01	-0.02	-0.27
Fish	0.00	0.00	0.00	-0.02	0.00	0.00	0.00	0.00	0.00	0.00
Food	-0.27	0.94	0.04	-0.31	-0.02	0.00	-0.03	0.00	0.00	-0.01
Texl	-2.12	0.16	0.07	-0.41	-0.37	-0.04	-1.32	0.07	-0.51	-3.83
Manu	-36.97	4.11	3.90	5.06	-3.28	-0.47	-14.27	0.77	-6.04	-193.63
PaP	-0.39	-0.05	0.01	-2.01	-0.03	-0.01	-0.20	0.01	-0.07	-1.00
P_C	2.36	4.51	3.99	27.43	1.11	0.34	-0.01	0.00	-5.09	-246.47
Chem	-9.94	-1.26	-0.82	-4.48	-3.74	-0.44	-4.62	0.06	-2.08	-36.05
Metl	-181.95	-0.18	-0.11	-1.52	-1.71	-0.35	-12.83	0.17	-2.10	-11.42
Cont	-0.25	0.00	0.04	-1.69	-0.17	-0.05	-0.38	0.01	-0.20	-5.75
Trad	-25.48	1.31	0.84	-0.48	-2.23	-0.16	-5.47	0.09	-3.89	-33.16
Tran	-10.74	2.08	4.12	1.40	-2.98	-0.05	-2.95	0.05	-2.03	-20.92
Serv	-26.22	1.23	2.32	-3.59	-2.69	-0.56	-6.93	0.23	-2.37	-53.09
Omin	-12.49	0.00	0.01	-0.03	-14.17	0.00	-0.20	0.00	-0.06	-1.28
Wter	-0.49	-0.01	-0.01	-0.24	-0.08	-0.70	-0.21	0.01	-0.26	-3.33
Col	0.68	0.55	0.71	4.75	1.57	0.05	-0.01	0.00	-2.06	-461.01
Oil	0.03	0.00	0.00	0.31	0.01	0.04	0.00	0.00	-0.01	-65.73
Gas	0.50	0.03	0.01	1.79	0.23	0.01	0.00	0.00	-6.46	-232.89
Ely	-14.18	-10.44	-6.45	-129.02	-12.88	-11.51	-0.03	0.00	-0.01	-423.62

Table 8-6 changes of intermediate inputs among sectors under measure scenario 1 (million dollar)

	Agri	Frsy	Fish	Food	Texl	Manu	PaP	P_C	Chem	Metl
Agri	-0.40	-0.06	0.00	0.98	1.48	0.36	-0.10	0.00	-0.89	-0.06
Frsy	0.03	-0.43	0.00	0.01	0.00	0.65	0.02	0.00	-0.66	-0.02
Fish	0.00	0.00	-0.03	0.02	0.00	0.00	0.00	0.00	-0.16	0.00
Food	-0.07	-0.01	-0.02	0.36	0.36	0.02	0.00	0.00	-0.55	-0.02
Texl	-0.01	-0.01	0.00	0.01	6.56	1.39	-0.11	0.01	-1.60	-0.59
Manu	0.00	-0.17	0.01	0.06	0.41	22.09	-0.09	0.21	-1.03	-4.02
PaP	0.00	-0.01	0.00	0.00	0.08	0.55	-0.88	0.00	-0.63	-1.21
P_C	3.56	0.18	0.56	1.02	1.52	2.71	0.72	0.49	11.87	9.52
Chem	-1.07	-0.25	-0.01	-0.15	-0.04	1.27	-0.36	0.05	-19.18	-2.69
Metl	-0.02	-0.07	0.00	-0.02	0.06	5.78	-0.06	0.07	-1.14	-22.13
Cont	-0.01	-0.01	0.00	0.00	0.01	0.05	-0.01	0.01	-0.05	-0.07
Trad	-0.05	-0.11	-0.01	0.02	0.99	2.57	-0.26	0.18	-2.42	-3.51
Tran	-0.01	-0.11	0.01	0.01	0.24	0.79	-0.07	0.12	-1.00	-2.25
Serv	-0.08	-0.26	0.00	0.04	0.44	2.08	-0.10	0.13	-1.66	-3.05
Omin	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	-0.79	-4.79
Wter	0.00	0.00	0.00	0.00	0.01	0.03	-0.01	0.01	-0.08	-0.10
Col	1.47	0.20	0.17	3.48	2.33	4.95	2.53	0.01	12.01	37.12
Oil	0.03	0.00	0.00	0.00	0.00	0.01	0.00	5.94	0.20	0.06
Gas	0.12	0.01	0.01	0.88	0.99	0.98	0.05	0.00	3.42	1.88
Ely	-12.21	-0.71	-1.57	-8.61	-13.28	-19.01	-6.26	0.00	-46.13	-60.96
	Cont	Trad	Tran	Serv	Omin	Wter	Col	Oil	Gas	Ely
Agri	-0.15	0.07	0.02	-0.03	-0.01	0.00	-0.79	0.00	0.00	-0.01
Frsy	-0.38	0.01	0.00	0.01	-0.01	0.00	-4.76	0.00	-0.01	-0.03
Fish	0.00	-0.03	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00
Food	-0.05	0.04	0.00	-0.10	0.00	0.00	-0.02	0.00	0.00	0.00
Texl	-0.39	-0.02	0.00	-0.16	-0.07	-0.01	-1.03	0.02	-0.14	-0.41
Manu	-6.69	0.57	0.61	0.44	-0.58	-0.10	-11.27	0.24	-1.68	-12.90
PaP	-0.07	-0.10	-0.01	-0.64	-0.01	0.00	-0.16	0.00	-0.02	-0.14
P_C	0.69	1.00	0.52	7.43	0.40	0.10	-0.01	0.00	-1.41	-34.91
Chem	-1.83	-0.30	-0.18	-1.11	-0.68	-0.09	-3.56	0.05	-0.58	-0.78
Metl	-32.52	-0.05	-0.02	-0.34	-0.30	-0.07	-9.99	0.07	-0.58	-1.57
Cont	-0.04	-0.01	-0.01	-0.52	-0.03	-0.01	-0.30	0.01	-0.06	-1.11
Trad	-4.62	-0.12	-0.08	-0.43	-0.40	-0.03	-4.28	0.03	-1.08	-6.25
Tran	-1.95	-0.08	0.48	0.08	-0.53	-0.01	-2.31	0.02	-0.56	-4.00
Serv	-4.79	-0.23	0.23	-1.82	-0.48	-0.12	-5.43	0.08	-0.66	-7.19
Omin	-2.27	0.00	0.00	-0.01	-2.53	0.00	-0.15	0.00	-0.02	-0.22
Wter	-0.09	-0.01	-0.01	-0.07	-0.01	-0.15	-0.17	0.00	-0.07	-0.37
Col	0.39	0.39	0.54	2.61	0.86	0.03	-0.01	0.00	-0.55	-343.70
Oil	0.01	0.00	0.00	0.07	0.00	0.01	0.00	0.00	0.00	-5.19
Gas	0.16	0.01	0.00	0.56	0.08	0.00	0.00	0.00	-1.62	-61.93
Ely	-3.72	-2.73	-1.67	-33.97	-3.54	-2.92	-0.03	0.00	0.00	-10.31

Table 8-7 changes of intermediate inputs among sectors under measure scenario 2 (million dollar)

	Agri	Frsy	Fish	Food	Texl	Manu	PaP	P_C	Chem	Metl
Agri	-1.06	-0.13	-0.01	1.52	3.11	0.71	-0.20	0.00	-1.80	-0.12
Frsy	0.06	-0.84	0.01	0.01	0.00	1.28	0.03	0.00	-1.35	-0.04
Fish	0.00	0.00	-0.07	-0.02	0.00	0.01	0.00	0.00	-0.33	0.00
Food	-0.24	-0.02	-0.08	0.56	0.75	0.04	0.00	0.00	-1.12	-0.04
Texl	-0.01	-0.02	0.00	0.01	13.76	2.75	-0.22	0.02	-3.25	-1.20
Manu	-0.03	-0.34	0.00	0.11	0.85	43.81	-0.21	0.38	-2.09	-8.21
PaP	-0.01	-0.01	0.00	-0.03	0.16	1.09	-1.82	0.00	-1.27	-2.46
P_C	6.94	0.35	1.09	1.96	2.94	5.23	1.39	0.84	23.07	18.25
Chem	-2.29	-0.49	-0.02	-0.34	-0.02	2.43	-0.74	0.08	-38.87	-5.46
Metl	-0.06	-0.13	-0.01	-0.07	0.13	11.20	-0.12	0.11	-2.31	-45.13
Cont	-0.02	-0.03	0.00	0.00	0.03	0.11	-0.01	0.01	-0.11	-0.13
Trad	-0.14	-0.22	-0.02	-0.03	2.06	5.07	-0.54	0.31	-4.91	-7.13
Tran	-0.04	-0.22	0.00	0.00	0.50	1.56	-0.14	0.21	-2.03	-4.57
Serv	-0.20	-0.52	-0.02	0.05	0.91	4.12	-0.20	0.22	-3.37	-6.21
Omin	0.00	0.00	0.00	0.00	0.00	0.36	0.00	0.01	-1.60	-9.75
Wter	0.00	0.00	0.00	0.00	0.02	0.07	-0.01	0.01	-0.17	-0.20
Col	2.79	0.37	0.32	6.60	4.42	9.41	4.78	0.02	22.60	70.10
Oil	0.06	0.00	0.00	0.01	0.00	0.01	0.00	11.84	0.39	0.11
Gas	0.22	0.01	0.01	1.62	1.82	1.80	0.09	0.01	6.18	3.45
Ely	-23.83	-1.37	-3.07	-16.69	-25.84	-36.94	-12.18	0.00	-89.92	-118.27
	Cont	Trad	Tran	Serv	Omin	Wter	Col	Oil	Gas	Ely
Agri	-0.30	0.14	0.04	-0.07	-0.02	0.00	-1.53	0.00	0.00	-0.01
Frsy	-0.78	0.01	0.01	0.01	-0.01	0.00	-9.20	0.00	-0.01	-0.06
Fish	0.00	-0.09	0.00	-0.02	0.00	0.00	0.00	0.00	0.00	0.00
Food	-0.10	0.02	0.01	-0.23	-0.01	0.00	-0.04	0.00	0.00	0.00
Texl	-0.78	-0.05	0.01	-0.36	-0.14	-0.02	-1.99	0.05	-0.25	-0.81
Manu	-13.42	1.05	1.17	0.53	-1.18	-0.20	-21.78	0.46	-2.96	-25.12
PaP	-0.14	-0.22	-0.02	-1.43	-0.01	0.00	-0.30	0.01	-0.04	-0.27
P_C	1.34	1.96	1.00	14.48	0.77	0.19	-0.01	0.00	-2.48	-69.00
Chem	-3.67	-0.63	-0.38	-2.41	-1.38	-0.18	-6.88	0.09	-1.02	-1.51
Metl	-65.30	-0.11	-0.05	-0.77	-0.61	-0.14	-19.30	0.14	-1.03	-3.05
Cont	-0.09	-0.03	-0.01	-1.20	-0.06	-0.02	-0.58	0.01	-0.10	-2.15
Trad	-9.26	-0.42	-0.24	-1.10	-0.81	-0.06	-8.27	0.07	-1.91	-12.17
Tran	-3.90	-0.39	0.85	0.01	-1.08	-0.02	-4.46	0.03	-1.00	-7.79
Serv	-9.59	-0.65	0.44	-4.30	-0.98	-0.23	-10.49	0.16	-1.16	-14.01
Omin	-4.54	0.00	-0.01	-0.02	-5.13	0.00	-0.30	0.00	-0.03	-0.42
Wter	-0.18	-0.02	-0.01	-0.15	-0.03	-0.29	-0.32	0.01	-0.13	-0.72
Col	0.74	0.73	1.02	4.95	1.64	0.05	-0.02	0.00	-0.98	-672.24
Oil	0.01	0.00	0.00	0.13	0.01	0.02	0.00	0.00	-0.01	-10.74
Gas	0.28	0.02	0.00	1.01	0.14	0.01	0.00	0.00	-2.87	-114.91
Ely	-7.25	-5.32	-3.26	-66.37	-6.88	-5.71	-0.05	0.00	-0.01	-20.23

Results from GTAP-E model simulation give electricity demand by other sectors, as shown in Fig 8-7. Main electricity consuming sectors are agriculture, food, textile, manufacturing, pulp and paper, chemical industry, metal and metallurgy, services and electricity itself. Fig 8-8 illustrates that implementing mitigation policies induces increase of electricity price. As a result, electricity demand for other sectors will fall down, especially for the main electricity consuming sectors, such as textile, chemical industry, metal and metallurgy, services and electricity itself. This is compatible with the data in Fig 8-7. Fig 8-8 also shows that measure scenarios have lower impacts on intermediate inputs among sectors than cost scenarios.

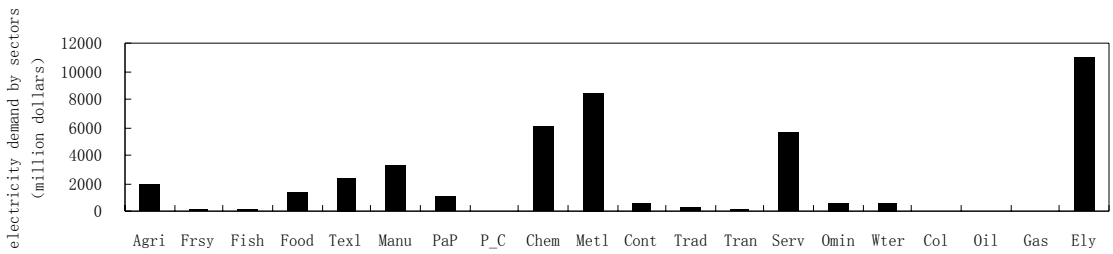


Fig 8-7 electricity demand by sectors in baseline scenario

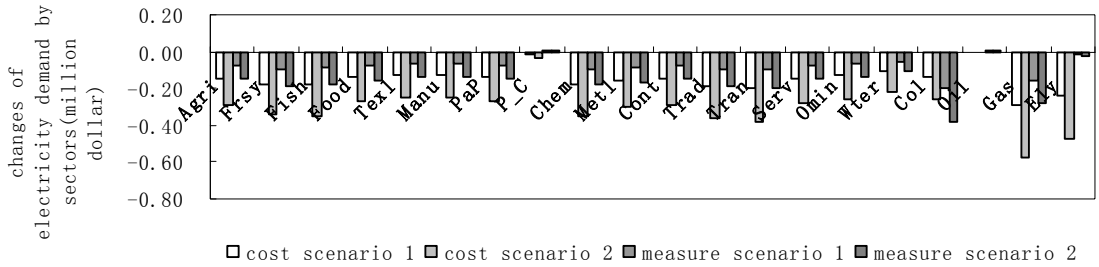


Fig 8-8 changes of electricity demand by sectors under different scenarios

To compare changes of intermediate inputs of different sectors under electricity sectoral mitigation scenarios, we choose chemical industry, metal and metallurgy, services and electricity as target sectors, the results are drawn as Fig 8-9, Fig 8-10, Fig 8-11 and Fig 8-12. Trends for changes of intermediate inputs demand are similar in chemical industry, metal and metallurgy and services industry. Either increasing electric generation cost or implementing mitigation measures can raise electricity price. Main electricity consuming sectors need to decrease electricity inputs to balance cost-effect. Intermediate inputs from oil refining, coal and natural gas grow to satisfy sectoral energy demand. Increases of intermediate inputs from oil refining and coal industry are quite obvious, for coal is the most important primary energy resource, and oil is key element for industrial production and fuel combustion of transportation. Also, we can conclude that cost scenarios have stronger impacts on intermediate inputs of sectors than measure scenarios.

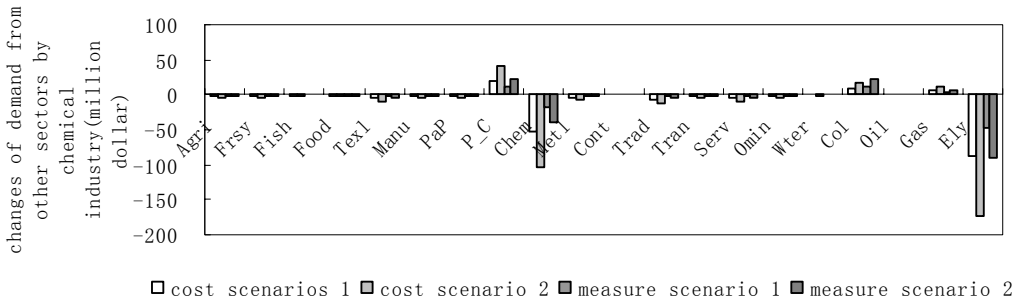


Fig 8-9 changes of demands from other sectors by chemical industry under different scenarios

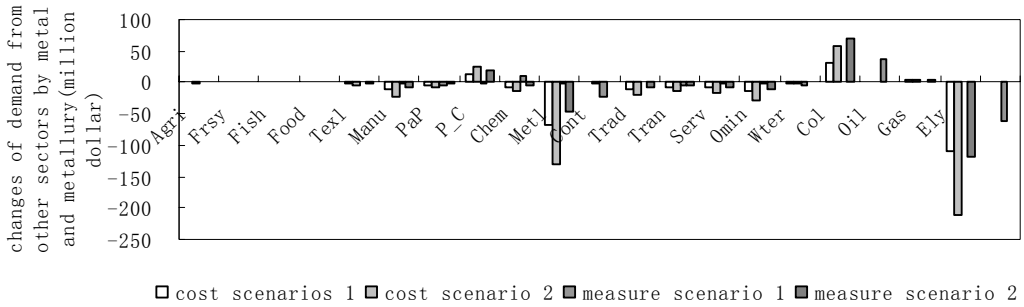


Fig 8-10 changes of demands from other sectors by metal and metallurgy under different scenarios

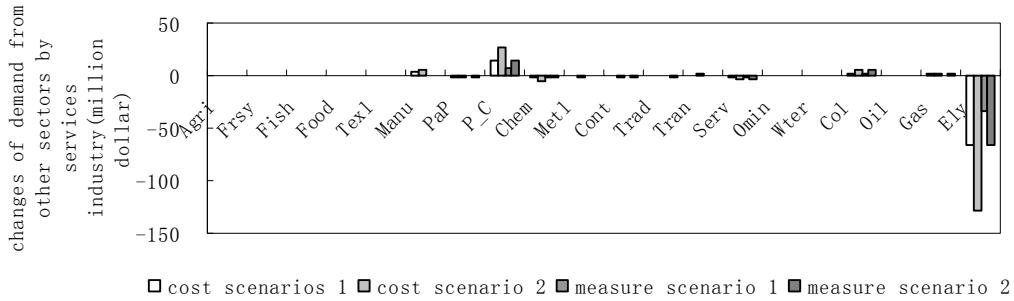


Fig 8-11 changes of demands from other sectors by services industry under different scenarios

Changes of demands from other sectors by electricity sector are quite different. Because the raise of electricity price induce the decrease of national electricity demand, Fig 8-12 shows that inputs from other sectors in electricity sector all fall down, especially from manufacturing, oil refining, natural gas and electricity itself.

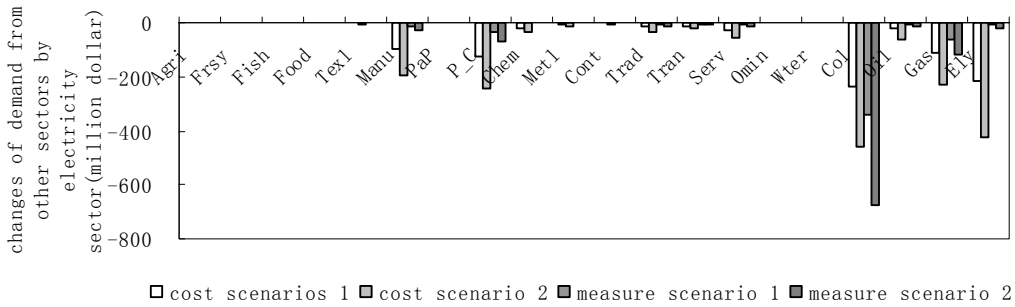


Fig 8-12 changes of demands from other sectors by electricity sector under different scenarios

VIII.C.5 Changes of commercial exports

Table 8-8, Table 8-9, Table 8-10 and Table 8-11, respectively, show changes of China's commercial exports under different scenarios compared to baseline scenario without any sectoral mitigation policy. Exports from chemical industry, metal and metallurgy, water industry and electricity sector fall down obviously after implementing sectoral mitigation policies. These four sectors are compatible with those sectors whose prices rise in Table 8-2. Price is one of the key elements of commercial export. Other sectors' exports increase, and textile, and manufacturing and coal industry are the most sensitive sectors.

Table 8-8 changes of China's commercial export under cost scenario 1 (million dollar)

	EU	US	Other developed countries	India	Other developing countries	Total
Agri	0.99	0.48	1.5	0.13	1.74	4.84
Frsy	0.04	0.01	0.14	0	0.04	0.23
Fish	0.05	0.03	0.2	0	0.11	0.39
Food	0.86	0.87	3.51	0.01	1.83	7.08
Texl	11.37	16.43	14.95	0.21	11.83	54.79
Manu	57.92	89.04	52.55	1	39.17	239.68
PaP	0.05	0.12	0.06	0	0.06	0.29
P_C	0.06	0.04	0.4	0.14	0.66	1.30
Chem	-8.67	-10.2	-8.25	-0.86	-11.3	-39.28
Metl	-5.4	-8.27	-5.86	-0.28	-6.43	-26.24
Cont	0.36	0.06	0.19	0	0.08	0.69
Trad	18.11	10.82	9.16	0.71	8.67	47.47
Tran	8.58	3.98	2.12	0.15	2.56	17.39
Serv	10.82	4.75	3.82	0.32	4.52	24.23
Omin	0.11	0.1	0.16	0.06	0.16	0.59
Wter	-0.22	-0.1	-0.08	0	-0.08	-0.48
Col	3.93	0.2	31.42	1.87	33.42	70.84
Oil	1.46	2.28	7.94	0.48	3.1	15.26
Gas	1.54	0.36	5.48	0	1.73	9.11
Ely	-3.06	-0.41	-0.69	-0.12	-2.55	-6.83

Table 8-9 changes of China's commercial export under cost scenario 2 (million dollar)

	EU	US	Other developed countries	India	Other developing countries	Total
Agri	2.05	0.99	3.09	0.27	3.59	9.99
Frsy	0.08	0.03	0.28	0	0.07	0.46
Fish	0.1	0.05	0.41	0	0.23	0.79
Food	1.75	1.78	7.14	0.03	3.73	14.43
Texl	23.04	33.33	30.29	0.42	24	111.08
Manu	115.83	178.24	105.16	2.01	78.39	479.63
PaP	0.11	0.26	0.13	0	0.13	0.63
P_C	0.14	0.08	0.84	0.31	1.41	2.78
Chem	-17.07	-20.08	-16.24	-1.69	-22.25	-77.33
Metl	-10.77	-16.46	-11.66	-0.55	-12.79	-52.23
Cont	0.71	0.11	0.38	0	0.15	1.35
Trad	36.19	21.63	18.31	1.42	17.33	94.88
Tran	17.15	7.95	4.23	0.3	5.12	34.75
Serv	21.67	9.53	7.66	0.63	9.07	48.56
Omin	0.22	0.19	0.32	0.11	0.31	1.15
Wter	-0.43	-0.2	-0.16	-0.01	-0.15	-0.95
Col	7.8	0.4	62.15	3.7	65.96	140.01
Oil	3.41	5.31	18.49	1.12	7.23	35.56
Gas	3.3	0.78	11.74	0.01	3.7	19.53
Ely	-5.79	-0.78	-1.3	-0.23	-4.84	-12.94

Table 8-10 changes of China's commercial export under measure scenario 1 (million dollar)

	EU	US	Other developed countries	India	Other developing countries	Total
Agri	0.37	0.18	0.57	0.05	0.67	1.84
Frsy	0.02	0.01	0.08	0	0.02	0.13
Fish	0.02	0.01	0.1	0	0.06	0.19
Food	0.34	0.35	1.4	0.01	0.76	2.86
Texl	2.6	3.85	3.53	0.05	2.83	12.86
Manu	21.07	32.66	19.35	0.37	14.51	87.96
PaP	-0.02	-0.04	-0.02	0	-0.02	-0.1
P_C	0.02	0.01	0.1	0.04	0.18	0.35
Chem	-3.41	-4.03	-3.25	-0.33	-4.41	-15.43
Metl	-0.86	-1.42	-1.07	-0.05	-1.22	-4.62
Cont	0.15	0.02	0.08	0	0.03	0.28
Trad	6.69	3.99	3.42	0.27	3.28	17.65
Tran	3.23	1.48	0.8	0.06	0.99	6.56
Serv	3.2	1.41	1.16	0.1	1.4	7.27
Omin	0.04	0.03	0.06	0.02	0.06	0.21
Wter	-0.12	-0.05	-0.04	0	-0.04	-0.25
Col	5.97	0.31	47.82	2.84	50.81	107.75
Oil	0.15	0.23	0.85	0.05	0.33	1.61
Gas	0.92	0.22	3.27	0	1.03	5.44
Ely	-1.58	-0.21	-0.36	-0.06	-1.33	-3.54

Table 8-11 changes of China's commercial export under measure scenario 2 (million dollar)

	EU	US	Other developed countries	India	Other developing countries	Total
Agri	0.8	0.39	1.21	0.11	1.43	3.94
Frsy	0.05	0.02	0.16	0	0.04	0.27
Fish	0.05	0.03	0.2	0	0.12	0.4
Food	0.7	0.71	2.88	0.01	1.55	5.85
Texl	5.51	8.16	7.45	0.11	5.98	27.21
Manu	41.95	65.1	38.52	0.74	28.89	175.2
PaP	-0.04	-0.07	-0.03	0	-0.03	-0.17
P_C	0.03	0.02	0.21	0.08	0.36	0.7
Chem	-6.89	-8.14	-6.57	-0.67	-8.92	-31.19
Metl	-1.98	-3.21	-2.38	-0.12	-2.7	-10.39
Cont	0.3	0.05	0.17	0	0.07	0.59
Trad	13.42	8	6.85	0.54	6.56	35.37
Tran	6.46	2.96	1.6	0.12	1.98	13.12
Serv	6.51	2.87	2.35	0.2	2.84	14.77
Omin	0.08	0.07	0.11	0.04	0.11	0.41
Wter	-0.24	-0.11	-0.09	0	-0.08	-0.52
Col	11.78	0.6	94.03	5.58	99.58	211.57
Oil	0.33	0.51	1.84	0.11	0.72	3.51
Gas	1.72	0.41	6.13	0	1.93	10.19
Ely	-3.04	-0.41	-0.68	-0.12	-2.54	-6.79

China's commercial exports under baseline scenario without any mitigation policy simulated in GTAP-E model are shown in Fig 8-13, which implies that manufacturing and textile are major export industries, followed by chemical industry, metal and metallurgy, trade, and services. We also can see that they are big electricity consuming sectors (Fig 8-8), so they will get more impacts under mitigation scenarios.

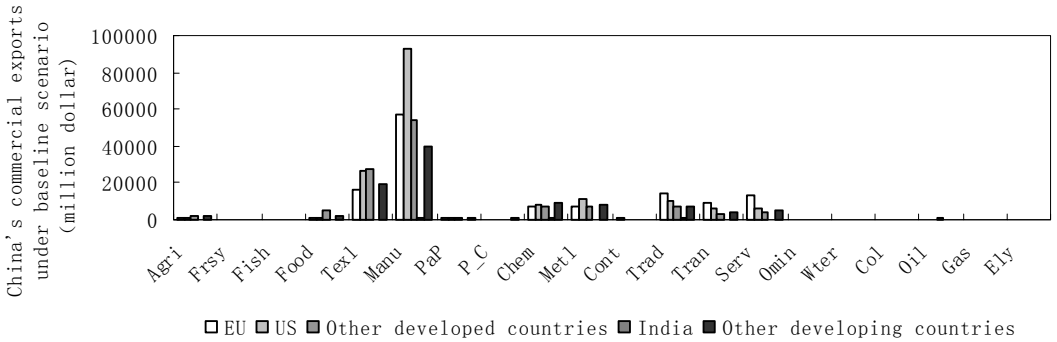


Fig 8-13 China's commercial exports under baseline scenario

The following figures take textile, manufacturing, coal, chemical industry and metal and metallurgy for examples. Research on industrial exports under electricity sectoral mitigation policy is carried on.

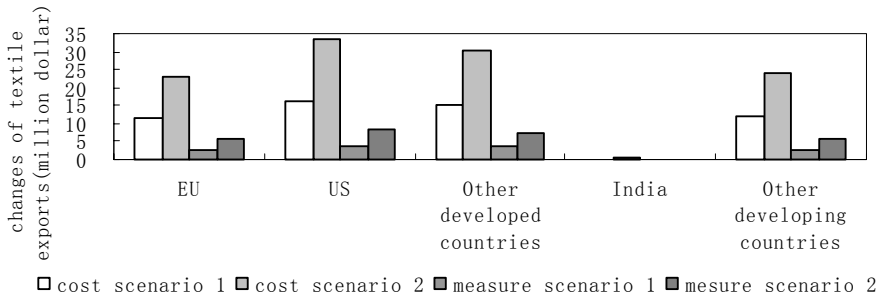


Fig 8-14 Changes of China's textile export under different scenarios

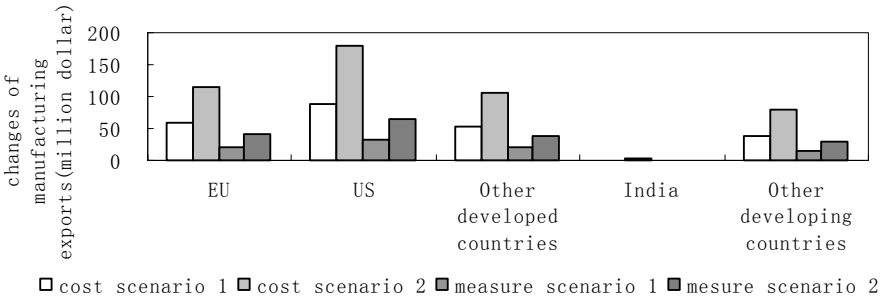


Fig 8-15 Changes of China's manufacturing export under different scenarios

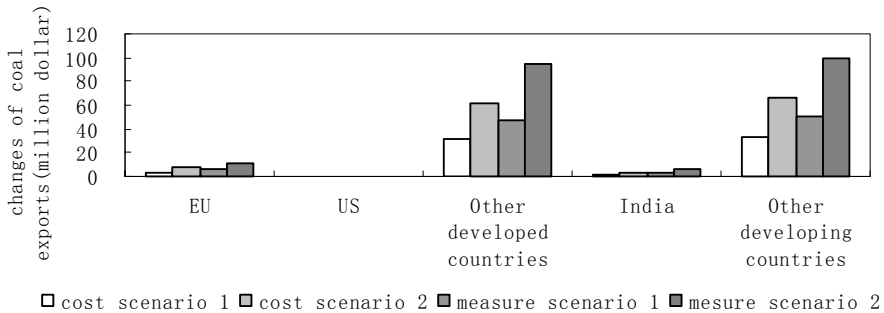


Fig 8-16 Changes of China's coal export under different scenarios

Exports from China's textile, manufacturing, coal industry to other countries and territories increase. Incremental exports from textile and manufacturing mainly focus on developed countries, and incremental exports from coal mainly focus on areas except EU and US.

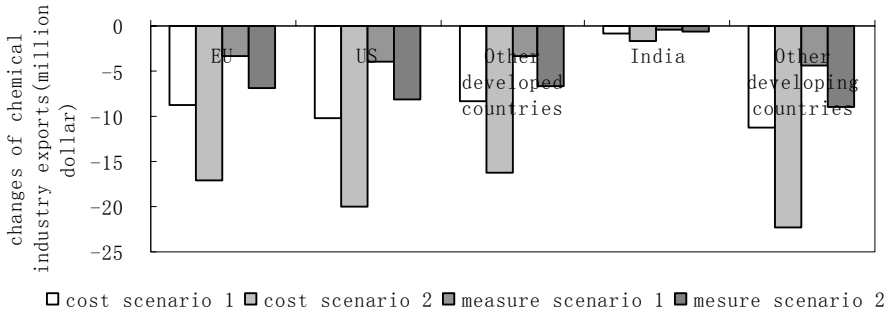


Fig 8-17 Changes of China's chemical industry export under different scenarios

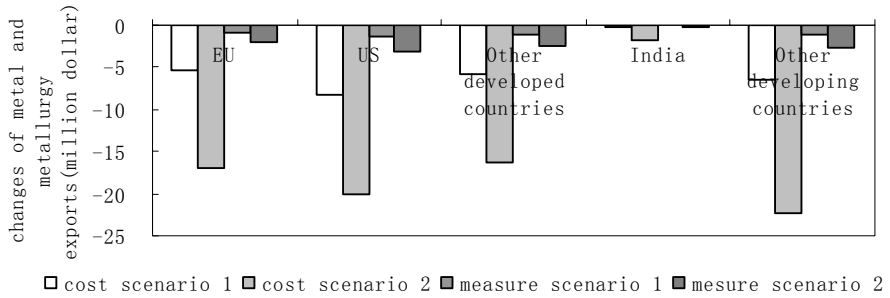
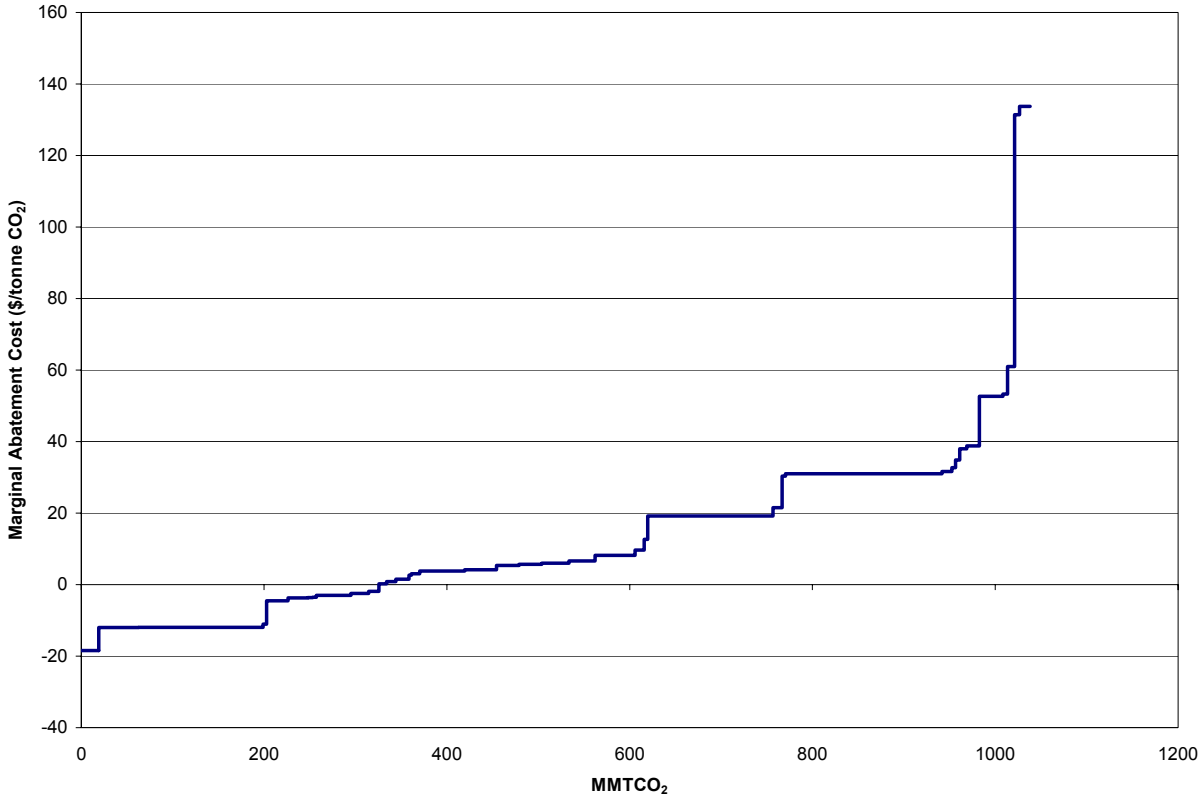


Fig 8-18 Changes of China's metal and metallurgy export under different scenarios

Correspondingly, exports from chemical, metal and metallurgy fall, mainly because of a decrease in imports in other countries except India.

From the above comparison, we can see cost scenarios have greater impacts on exports from textile, manufacturing, chemical industry, metal and metallurgy than measure scenarios. But the impacts on coal industry are the opposite. To understand this we can go back to the previous discussion on changes of industrial productions' price and outputs. Coal price rises more in measure scenarios than that in cost scenarios, so outputs of coal decrease more obviously in measure scenarios, and induce more decline on exports.

Appendix I: Integrated Marginal Abatement Cost (MAC) Curve for 2020



Marginal Abatement Costs and Annual Reductions by Measure for 2020

Marginal Abatement Cost ($/tonne CO_2e)	Total Emission Reduction ($MMTCO_2e$)	Cumulative Reduction ($MMTCO_2e$)	Mitigation Options	Sector
-18.4	19.1	19.1	Transmission Technologies	Transportation
-12.0	43.8	62.9	Vehicle Technologies	Transportation
-11.9	136.0	198.9	Engine Technologies	Transportation
-11.1	3.8	202.7	Engine-Transmission-Vehicle Technologies	Transportation
-4.5	23.5	226.2	Preventative Maintenance	Cement
-3.8	21.5	247.7	Use of Waste Derived Fuels	Cement
-3.6	5.7	253.4	CFBC (Circulating Fluidized Bed Combustion)	Electricity
-3.6	3.6	257.0	Establish energy management center	Iron and Steel
-3.0	38.0	295.0	Demand side management	Electricity
-2.4	19.5	314.5	Process management and Control	Cement
-1.9	11.3	325.8	Kiln Shell Heat Loss Reduction	Cement
0.2	8.2	334.0	High-Efficiency Motors and Drives	Cement
0.9	10.2	344.2	Active Additives	Cement
1.5	14.3	358.5	Composite Cement	Cement
2.6	2.8	361.3	BRT	Transportation
3.0	9.1	370.4	Advanced coke oven	Iron and Steel
3.8	49.1	419.5	Conversion to Multi-stage pre-heater kiln	Cement
4.1	34.8	454.3	Combustion System Improvement	Cement
5.4	24.6	478.9	Advanced blast furnace technology	Iron and Steel
5.7	25.1	504.0	Reconstruction of conventional thermal power	Electricity
6.0	29.7	533.7	Supercritical/Ultra supercritical plant	Electricity
6.6	28.6	562.3	High-efficiency roller mills	Cement
8.2	43.6	605.9	Adjust ratio of iron/steel	Iron and Steel
9.7	10.2	616.1	High-efficiency Powder Classifiers	Cement
12.7	3.7	619.7	Efficient transport systems	Cement
19.2	136.9	756.6	Nuclear power	Electricity
21.5	10.3	766.9	Fuel Switch	Transportation
30.4	3.5	770.5	Dry coke quenching	Iron and Steel
31.0	171.2	941.7	Hydropower	Electricity
31.6	10.8	952.4	Advanced sinter machine	Iron and Steel
32.7	4.2	956.6	Natural gas	Electricity
34.9	4.4	961.1	Advanced direct steel rolling machine	Iron and Steel
38.0	7.6	968.7	Wind power	Electricity
38.8	14.1	982.8	IGCC (Integrated Gasification Combined-Cycle) & PFBC (Pressurized Fluidized Bed Combustion)	Electricity
52.7	25.6	1008.4	Smelt reduction technology	Iron and Steel
53.3	5.0	1013.4	CCS (Carbon Capture and Storage)	Electricity
61.0	7.6	1021.0	Advanced converter	Iron and Steel
131.4	5.7	1026.7	Advanced EAF	Iron and Steel
133.7	11.4	1038.1	Solar thermal	Electricity

Appendix II: Oil Price Assumptions

Since the market for oil is an international market, it was decided that a single global forecast of future oil prices would be used in all sectors in all three countries. Two forecasts were considered, both from the US Energy Information Administration: the *Annual Energy Outlook 2005* (AEO 2005), and the *International Energy Outlook 2004* (IEO). The AEO 2005 is a projection of domestic energy supply and demand in the United States, but also includes a projection of world oil prices. The available AEO edition was more recent than the IEO, so it was decided to use the AEO 2005 prices.[46] The AEO 2005 includes a reference case forecast and several sensitivity scenarios; the reference case oil prices were used for the analysis. These oil prices are shown below:

Annual World Oil Price Assumptions

Year	Reference Case Price (2003 $ per barrel)
1996	23.25
1997	20.48
1998	13.2
1999	18.55
2000	29.2
2001	22.64
2002	24.1
2003	27.73
2004	35
2005	33.99
2006	30
2007	27.35
2008	26.15
2009	25.3
2010	25
2011	25.35
2012	25.69
2013	26.04
2014	26.39
2015	26.75
2016	27.1
2017	27.45
2018	27.79
2019	28.14
2020	28.5
2021	28.86
2022	29.22
2023	29.58
2024	29.94
2025	30.31

[46] At the time the analysis was conducted, oil price projections incorporating the recent increase in oil prices were not available. CCAP and the China team therefore conducted an alternative sensitivity scenario using higher oil prices from a recent projection to provide comparison. The results of this analysis can be seen in Chapter VII.

Appendix III: Workshop Summary and Participants, March 2006

Agenda

Time Slot	Speaker/Topics
9:55-10:00	Presenter: Mr. Xuedu LU **Welcome**
10:00-10:20	Presenter: Mr. Jake Schmidt, CCAP **Project Introduction**
10:20-10:40	Presenter: Mr. Can Wang, Tsinghua **Analysis of CO2 Emission Scenario and Mitigation Technology in China's Different Sectors: Background and Summary**
10:40-11:10	Presenter: Mr. Ke Wang, Tsinghua **Analysis of CO2 Emission Scenario and Mitigation Technology in China's Iron and Steel Sector**
11:10-12:00	**Comment and Discussion**
13:30-14:00	Presenter: Ms. Ying Zhang, Tsinghua **Analysis of CO2 Emission Scenario and Mitigation Technology in China's Electricity Sector**
14:00-14:40	**Comment and Discussion**
14:40-15:10	Presenter: Ms. Wenjia Cai, Tsinghua **Analysis of CO2 Emission Scenario and Mitigation Technology in China's Transport Sector**
15:10-15:50	**Comment and Discussion**
16:10-16:30	Presenter: Mr. Bin Du, Tsinghua **Technology Analysis of Industrial Water Saving and Energy Saving in China**
16:30-17:00	Presenter: Mr. Can Wang, Tsinghua **Macroeconomic Analysis of Emission Reduction in China's Different Sector and Main Results of the Project**
17:00-17:30	**Discussion**

Background and Rationale

This workshop was organized by Tsinghua University. The purpose of this workshop was to give report on the interim sector analysis results and to receive comments and suggestions from experts and governors in China.

The entire world is facing more and more serious climate change damages, which are believed to be caused by human beings using huge amount of fossil fuels and emitting vast greenhouse gases. This project, *Assisting Developing Country Climate Negotiators through Analysis and Dialogue*, intends to work with leading in-country partner organizations to analyze greenhouse gas mitigation options in four key developing countries – Brazil, China, India and Mexico. The project team will conduct in-dept micro- and macroeconomic analyses of greenhouse gas mitigation options and costs, develop a suite of potential domestic policies for the most promising options, and assess the implications of post-2012 international climate policies in these key "case study" countries.

In this workshop, project team members from Tsinghua University introduced their interim analysis results in iron/steel, electricity and transportation sector. Contents mainly include two parts: the greenhouse gas emission forecasts for those sectors through 2020, and, the emission reduction cost curves for mitigation options/technologies in each sector. Building on this bottom-up quantitative analysis,

CCAP and Tsinghua will then conduct preliminary assessments of a set of promising policies for implementation of mitigation options in selected sectors, develop preliminary evaluations of potential co-benefits in environmental, health and other areas, and analyze the macro-economic implications of the policies. The policy analysis will include both domestic options and international strategies.

Summary of Presentations and Comments

By Wenjia CAI from Tsinghua University

Mr. Xuedu LU opened the workshop, followed by **Mr. Jake Schmidt** giving a brief introduction to this project and the role of CCAP in it. Next, **Mr. Can Wang** presented the background, framework, model, scenarios of the project in China and gave out some preliminary result from sector analysis. Wang mentioned energy and environment models were added into the original GTAP model to help analyze the environmental policies in developing countries.

The first sector analysis report was given by **Mr. Ke Wang,** about the analysis of CO2 emission scenario and mitigation technology in China's Iron/Steel sector. According to his presentation, China ranks the highest in iron/steel production in the world ever since 1996. Energy intensity per ton steel production is very high in China, about 1.5 times as in Japan. Main reasons of higher energy intensity are characteristics of production process, small proportion of advanced equipment and inefficient management. Forecast for iron/steel production has been updated lately, while the whole production through 2020 can still be divided into three parts: fast increasing before 2010, slowly increasing after 2010, and a constant phase through 2020. Three scenarios had been developed to analyze the potential emission and the mitigation technology. In scenario 3, the most environmental-friendly scenario, the emission reduction potential is promising; however, it is costly at the same time. We need a lot of money to implement.

Ms. Chunxia Zhang and **Mr. Dao Huang** made comments to Wang's presentation. Comments include: 1) the trend of production should be affirmed, but some problems seemed to be with the calculation and the energy structure; 2) it is difficult to estimate the GDP and I&S production as the many uncertain factors in China so more flexible changes are needed; 3) adjustments to the mitigation options are needed, such as, adjusting iron and steel ratio option needs more discussion and proportion of emissions is too high to reach; there will be a very small potential for option "increasing coal power injection level" to develop; EAF is difficult to utilize in China given the shortage of waste steel; increased used of coke oven is useful, but not a priority; utilization of excess heat should be added as an option; 4) interactive effects between sectors are important and needed. More free comments were made concerning to the production trend, the mitigation option and the need to address ways of problem solving in high cost scenario.

The second sector analysis report was given by **Ms. Ying Zhang**, about the analysis of CO2 emission scenario and mitigation technology in China's electricity sector. According to her presentation, coal fire plants produced 81% of total electricity in China while hydro power plants took up 18% and nuclear power plants 1.2%. After the completion of three Gorges dam in 2009, the dam will be the largest hydro power plant in the world. An important regulation published by government in 1997 said that any plant below 25 MW cannot be produced. But small scale generators have continued to be build, in remote areas and small cities. Three scenarios had been developed to analyze the potential emission and the mitigation options. CCS potential is uncertain. Major contributors to emission reductions go to hydro power plants, CCS and nuclear plants. She also made conclusions that 1) CO2 emission will be very high over time; 2) in short term, it is very important to increase government management and increase publicity about this, while in long term, emission reduction will depend more on CCS, hydro power and new technologies.

Mr. Xuedu LU commented that some of the objectives in electricity sector are too ambitious. **Mr. Yong Zhao** affirmed with the general conclusion, but suggested verification on some figures due to the drastic capacity expansion and the systemic change, esp. the division of national electricity corporation. Zhao also predicted that the decreasing trend of electricity consumption by secondary industry as well as the coal intensity. Another comment is from a representative from **NDRC** who stated her preference to the methodology and trends rather than the concrete data. She also suggested that capital guarantees should be considered when making scenarios, which was why she thought scenario 2 and 3 were very hard to implement. Ms. Chen from **WWF** and **Mr. Xuedu LU** suggested not to be too optimistic about CCS, which is time- and money-consuming.

The third sector analysis report was given by **Ms. Wenjia Cai**, about the analysis of CO2 emission scenario and mitigation technology in China's transport sector. According to her presentation, transport sector takes up 1/3 of total fuel in China and half of the transport fuel consumption is from passenger vehicles. Three scenarios had been developed to analyze the potential emission and the mitigation options. Transport sector would have a very large emission reduction potential due to the implementation of vehicle technologies, BRT and fuel substitution (mainly petrol and diesel to LPG and CNG). It was concluded that 1) vehicle technologies are most effective for emission reduction; however, more work has to be done with the cost information; 2) BRT is a comparatively low investment and can be developed in short term; 3) national communications and government participation are needed to help implement those mitigation options.

Mr. Hezhong Tian, **Mr. Haiyang Gao** and **Mr. Xuedu LU** made comments to this presentation. They agreed on the situation of fuel consumption in road transport sector and the projection on vehicle population. Other comments include: 1) maybe China needs a leap-frog in developing vehicle technologies; 2) the passenger mileage and fuel economy data need to be updated; 3) more thoughts should be given to the increase usage of diesel vehicles because some of diesel emissions are carcinogenic; 4) BRT may not be applicable in all parts of the country; 5) fuel substitution from petrol and diesel to LPG and CNG is not sustainable, so it could not solve the problem; 6) cost information should be polished to be more persuasive; 7) more things need to considered, such as biodiesel, hybrid electric vehicles, road condition and urban developing, people's driving habits.

Mr. Bin DU made a presentation in Technology Analysis of Industrial Water Saving and Energy Saving in China, which was a brief introduction of his PhD dissertation. It also utilized the scenario analysis method.

Finally, **Mr. Can Wang** made a conclusion presentation on the main results of all sectors in China. It used GTAP-E model as an analysis tool, which analyzed the effects given by emission reduction to GDP, import and export, trade and employment. He also made a sum-up about the emission reduction in each sector and identified the key mitigation options and the corresponding cost. After analyzing the barriers to achieve emission reduction, he also gave out the suggestions for further research.

Mr. Wen Gang suggested that we should be more flexible about phase II, either expand or narrow scope. Other comments include: 1) there are two costs when looking at international negotiations; one is the country's ability to pay, and the other is the incremental cost; 2) more channels should be explored to get capital; 3) we need more different methodologies to reach a more appropriate estimation of energy consumption and energy saving.

Participant List

Name	Organization
From Government	
Mr. Guangsheng Gao	NDRC (National Development and Reform Commission)
Ms. Cuihua Sun	NDRC
Mr. Xuedu Lu	MOST (Ministry of Science and Technology)
Mr. Ping Fu	MOST
Mr. Gao Li	Administrative Center for China Agenda 21, MOST
Mr. Wei Su	MOFA (Ministry of Foreign Affairs)
Ms. Qingchen Chao	CMA (China Meteorological Administration)
Ms. Mengheng Zhang	SEPA (State Environmental Protection Administration of China)
From CCAP	
Mr. Jake Schmidt	CCAP
Mr. Matthew Ogonowski	CCAP
From NGOs	
Mr. Yingnan Liang	CAST (China Association of Science and Technology)
Ms. Dongmei Chen	WWF
Ms. Liming Qiao	WWF
Dr. Gang Wen	GEF-China
From Industry	
Dr. Yong Zhao	China Huaneng Group, Technical and Economics Research Institute
Ms. Chunxia Zhang	Central Iron & Steel Research Institute
Mr. Dao Huang	China Iron & Steel Association
Dr. Haiyang Gao	China Automative Technology & Research Center
From Academy	
Dr. Can Wang	Tsinghua University
Dr. Bin Du	Tsinghua University
Mr. Ke Wang	Tsinghua University
Ms. Wenjia Cai	Tsinghua University
Ms. Ying Zhang	Tsinghua University
Ms. Di Wang	Tsinghua University
Mr. Martin Resnier	Tsinghua University
Ms. Ronghua Bao	Tsinghua University
Dr. Hezhong Tian	Beijing Normal University
Translator	
Ms. Yuan Li	Beijing Foreign Studies University

Appendix IV: Phase II

I. Policy Analysis for Phase II

In Phase II, the team will conduct an-depth analysis of policies that could be used to implement key mitigation options in China. Potential implementation policies are discussed below for the following measures:

- Electricity: Energy efficiency improvement, Integrated gasification combined cycle (IGCC) plants, Renewable energy utilization; etc.
- Iron and Steel: Energy management systems, Advanced production technologies; etc.
- Transportation: Vehicle efficiency improvements, Bus rapid transit (BRT); etc.

I.A. Legal and regulatory framework for environmental policy relevant to each technical mitigation option

In China, the framework for environmental policies relevant to energy conservation and technical mitigation can be classified into three levels in terms of their scope. The highest level provides general direction and guidance. The second are those that specify the objectives and development plans. The third level consists of practical and specific incentives and managerial guidelines. In general, the first two classes are made by central government and its relevant ministries, while the third one is decided by local governments, including the provincial and municipal governments as well as county governments. Basically, policies set by local governments play more direct and practical roles.

At the beginning stage after China's establishment, environmental protection was more or less a by-product of the predominant policies for combating hunger and illness. But in 1978, environmental protection became part of the constitution of China and a year later the national environment law was enacted. The policy of government is clearly directed towards a greater emphasis on energy and environment under the framework of the National Sixth, Seventh, Eighth, Ninth, and Tenth Five-Year Plan. At the very beginning of the 1980s the central government announced that it would lay equal emphasis on development of energy suppliers and energy conservation, with the latter assuming a higher priority in the short term. Conservation policy has concurrently been refined and formalized, and the setting of energy conservation policy has gradually been coordinated with that in other areas, such as materials consumption efficiency and environmental protection. In the 1990s, some specific steps were introduced to implement the agreed environmental goals. The most current key national environment and energy policies which relate to the technical mitigation options we discussed here are: China's Agenda 21, Energy Conservation Law, 11th Five-Year Plan and Clean Product Promotion Law. For example, China determined to reduce energy consumption per unit of GDP by 20 percent and the total volume of major pollutant discharges by 10 percent between 2006 and 2010, according to the 11th Five-Year (2006-2010) Plan. It is the first time that China combines energy-efficiency with the indexes of economic growth, price, employment and balance of payments for macro-control of its economy. The China Renewable Energy Law was issued in 2005 and took into effect on January 1st of 2006. One of the primary aims of the newly established law is to promote the renewable energy reach 15% share in the energy structure in China up to 2020.

Since entering 21st century, China has looked to rely more on both market mechanisms and mandate regulation for energy efficiency improvement. The relevant policies recently set up include:

- Clean Production Promotion Law affected on January 1st 2003.
- Environmental Impact Assessment Law affected on September 1st 2003, which prohibits low energy efficiency or backward technologies in proposed construction projects.

- Updated equipment (design) energy efficiency standards, the scope of which was enlarged to cover more industrial equipment such as boilers, motors, fans, pumps and transformers.
- Pilot energy efficiency voluntary agreement for steel industry.
- Goal of decreasing energy intensity per unity GDP for 11th five-year plan period.
- China medium and long term energy conservation plan.
- Support the R&D activities on key energy efficient technologies.
- TOU (time of use) tariff and two-part tariff are used for industrial enterprises.

To achieve the goal of decreasing energy intensity by 20% in the 11th five-year plan period, multiple discussions on ensuring policies and measures have been conducted. In the industrial sector, the following measures will possibly be adopted in the near future:

- To establish a China top-1000 energy-intensive enterprises management system to monitor and cut their energy consumption;
- To enlarge energy efficiency voluntary agreement activity in the top-1000 energy-intensive enterprises based on the pilot project led in the steel industry;
- To have a preliminary idea on introducing an energy tax. But there are many uncertainties to implement it.
- To revise the Energy Conservation Law for better implementation under market conditions.

A systematic and comprehensive review of the existing legal and regulatory framework for environmental policy will be needed for each technical mitigation option that will be further analyzed in Phase II. The policy should be identified based on both the overview of the existing framework and the suggestions of the potential policies in the next sub-section.

I.B. Detailed description of the policy or policies analyzed for each individual option

Potential policies to be analyzed for Phase II for each technical mitigation option summarized above are as follows respectively:

- For energy efficiency improvement in electricity:
    - energy intensity targets set by the central government and local governments or set by specific industrial regulator;
    - capacity building efforts to increase public awareness of the advantages of energy efficiency improvements;
    - fuel pricing or fuel taxes to promote energy conservation, etc.
- For penetration of integrated gasification combined cycle (IGCC) plants:
    - subsidies or tax breaks for research and development of CCS technology
    - technology transfer from and/or technology cooperation with developed countries
- For renewable energy utilization:
    - expanded RES goal or mandate with an increase in either the total renewable share or specific share requirements for particular plant types;
    - direct incentives such as a production tax credit, price and capital investment subsidies, and tax breaks for new units;
    - fuel taxes.
- For energy management systems in iron and steel:
    - government-run voluntary assistance program, in which energy officials would work with interested plant managers to provide information and training to encourage development of such systems.
- For installation of advanced production technologies in iron and steel:

    - direct incentives for new capital investments, also for research and development of new technologies.
    - CDM
    - technology transfer from and/or technology cooperation with developed countries
- For vehicle efficiency improvements:
    - fuel pricing and fuel taxes
    - financial incentives or tax breaks
    - stricter emissions standards for criteria pollutants
    - government-run voluntary assistance program (VAP) to provide information and training to production companies, maintenance companies or individuals
    - direct subsidy (SUB) from government on investment, R&D
    - technology transfer from and/or technology cooperation with developed countries
- For bus rapid transit (BRT):
    - public sector financing and/or support from international financial institutions
    - urban planning

I.B.i Key barriers to implementation

Although China has a series of policies for environment and energy, especially regarding energy-intensive industrial sectors, most policies are shortage of implementing arrangement. Even some policies addressing very specific problems, e.g. listing encouraged and/or prohibited technologies in some industrial sectors, they are guidelines or directions rather then measures.

The goals of most existing policies are expressed in qualitative rather than quantitative terms. The costs, savings, expected efficiency gains and CO2 emissions implied by the policies are usually ambiguous. Furthermore, there are few monitoring and review mechanisms for any policy. Financial support to energy efficiency improvement is usually part of many policies, but the specific policy seldom makes sure the scale of financial support. Policy itself and the supportive funding are always separated. These institutional barriers to large extend affect the effectiveness and efficiency of the existing policies in environment and energy issue.

One of the key barriers to implement advanced technologies are various kinds of costs. High technology barriers have made it extremely hard to utilize certain kind of environmental-friendly technology to a large extent. Besides, it is also astonishing to face the expenses to construct suited factories and product lines, to train necessary labors and technicians, to maintain the right working order and to manage and operate.

Even in the case of large scale equipment and advanced technology being adopted, the performance is not as good as it could be. This is a phenomena recognized by most industrial experts in China. The low management level and shortage of well trained staff in lots of such plants are critical causes of this conflict.

Specifically, the key barrier to BRT in China is the current laggard public transport system. Although China has advocated for public transport for a long time, there has not been a very clear management system that prefers and promotes public transport. Public transport is characterized by low efficiency, congestion, and poor services. Moreover, the land planning in China is not so satisfying that creates a virtual barrier for BRT's quick expansion.

The key barrier for fuel switch in China is cost. Although LPG and CNG have lower sales price than gasoline and diesel, the comparatively weak network of gas station makes it inconvenient to refill LPG and CNG. Most drivers have not felt the obvious advantage of switching to these environmental-friendly

fuels. Besides, the higher maintenance fee for LPG and CNG engines has also withdrawn some people's willingness for fuel switch.

I.C. Key actors and players associated with policy implementation

On national level, the key actors and players associated with implementation of above mentioned policies include the following authorities and their local branches:

- the National Development and Reform Commission (NDRC)
- the Ministry of Science and Technology (MOST)
- the State Environmental Protection Administration (SEPA)
- the national association of relevant industries (e.g. the national steel association), etc.

I.C.i. Potential funding methods/programs for implementing the necessary measures i

Potential methods to help implement those mitigation options include capacity building, such as setting up the right political environment or market and training the right people, to meet the requirements of those mitigation options. The Chinese government can also use direct regulation methods, to influence the technology development trend and the transport market. More importantly, international financial and technical aids such as loans, technology transfer and joint collaboration would help China overcome financial and technical barriers in an effective and efficient way.

I.C.ii. Recommendations

To promote the technical mitigation options to be implemented in China, policy design and even pilot demonstration will be needed. Since China has no specific policy on CO2 emission control while setting ambitious goals to improve energy efficiency and diversify energy supply, it is practicable and acceptable to help design policy with effect on promoting CO2 mitigation by facilitate the implementation of energy efficiency measures. The targeted participants for the Phase II activities will thus be not only officials involved in the climate change negotiation but also those from relevant authorities in charge of environmental and energy policy issue. Based on the analysis of Phase I, some recommendations are given as following:

- The targeted technical mitigation options should be further screened out from the sectors of electricity, cement, steel, and/or transportation.
- The policies aiming to promote the identified technology should be selected through close discussion with both climate officials and industrial regulators, e.g., the Energy Bureau under NDRC, the Pollution Control Department under SEPA.
- Facilitate the dialogue and collaboration between climate change official and industrial/energy regulator through the Phase II activities will benefit the incorporation of climate policy into domestic development policy/plan in China.

Appendix V: Areas for Future Research in China

In this project, a detailed analysis of each sector was conducted given such considerations as data availability, applicability of individual mitigation options to specific national and local circumstances in China, and other issues. In the course of the analysis a number of sectors, mitigation options and areas were thus identified but not fully analyzed. Some of these areas could potentially yield promising opportunities for achieving additional mitigation opportunities, opportunities that could be assessed with further research. The key potential areas identified in the first phase of the project that might be considered for future research are detailed below.

- ***Oil refining***: This sector was not analyzed because the available baseline data is for chemicals and oil refining combined; separate data for the refining sector in China is not currently available.
- ***Electricity***: Transmission costs were not included in this analysis, because under the scope of the project the methodology used links costs with specific mitigation options, but not with electricity transmission and distribution. Cogeneration was not analyzed as a mitigation option because the share in the current electricity generation profile is very low, and its potential is projected to remain limited under different possible scenarios.
- ***Agriculture, residential, commercial:*** These sectors were not analyzed for the following reasons: 1) their respective shares in the national GHG emissions inventory are comparatively low and the mitigation potential is limited; 2) potential technical mitigation options in these sectors that would be appropriate in the Chinese context are currently quite uncertain; and 3) there is a lack of readily available and reliable data and research in these sectors. Further research to collect appropriate data and evaluate mitigation options in these sectors could therefore be useful in analyzing their potentials.
- ***Forestry***: This sector was not analyzed because the potential for afforestation and reforestation is minimal. According to China's Annual Environmental Conditions Report, deforestation has been quite minimal in the country in recent years. Illegal logging and activities likely to lead to deforestation were also prohibited under the Forest Law passed in 1998.
- ***Energy intensity target***: China's national energy intensity target under the Eleventh Five Year Plan was not included in the analysis of any of the sectors. To date there has been no specific implementation plan created to achieve the target, so the future development path is unclear. Recent media reports have also begun to doubt the feasibility and practicality of realizing the target before 2010.
- ***A2 and B2 scenarios***: For this project it was originally intended that all emission scenarios would be analyzed under two different baseline conditions based on the IPCC SRES scenarios, with one (B2) being more environmentally benign that the other (A2). Based on expert in-country judgment on likely future trends, however, it was decided that in China these two scenarios would in fact be very similar, so a separate analysis of the A2 and B2 scenarios was not conducted.

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APPLICATION OF ECONOMIC MODELING AND ANALYSIS TO CLIMATE POLICYMAKING

MAY 2, 2014

MATTHEW OGONOWSKI

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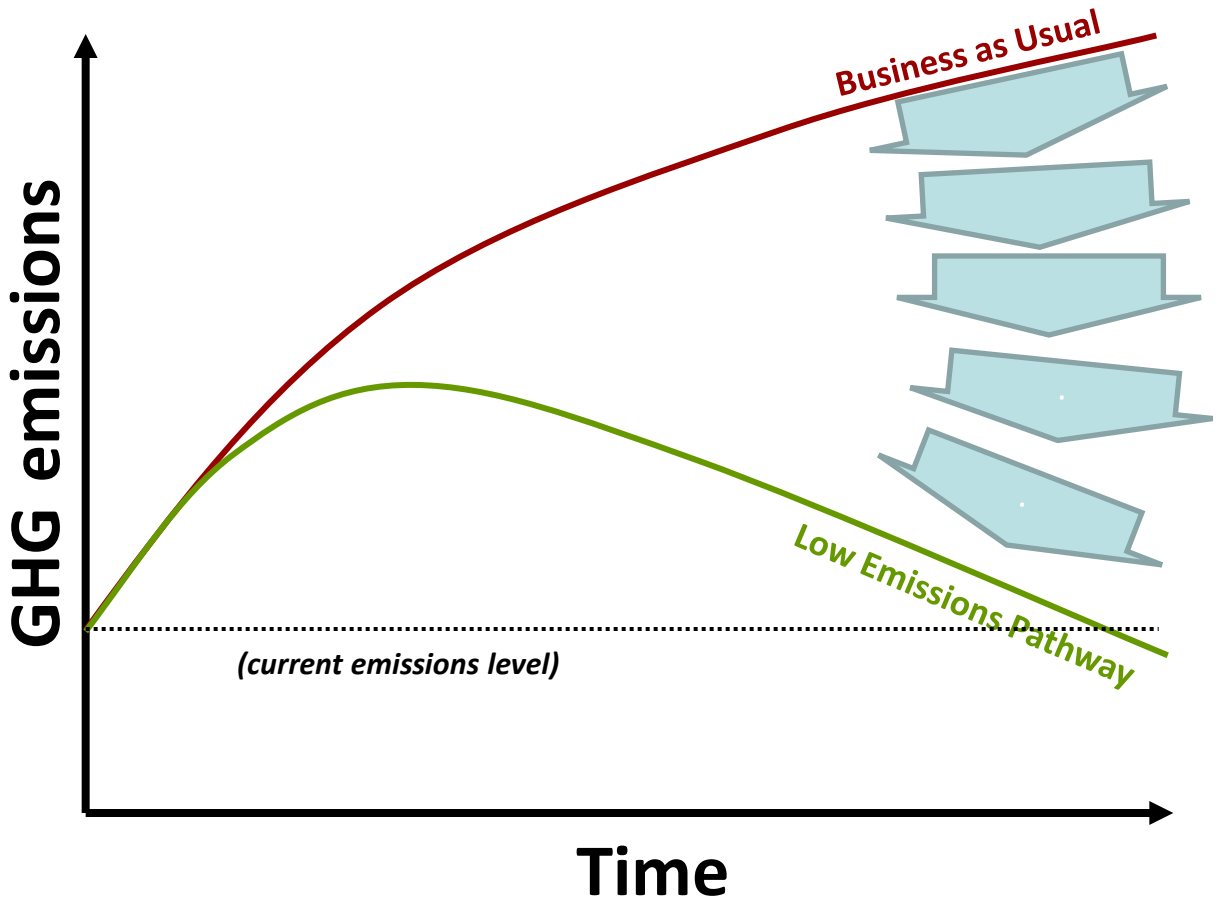
LEDS AND GHG MITIGATION: RATIONALE

- USAID-supported greenhouse gas (GHG) mitigation programs: contribute to developing economy-wide, long-term low emission development strategies (LEDS)
  - Are **not** “one-off” projects like the Clean Development Mechanism (CDM) under Kyoto Protocol
- “Successful” GHG mitigation depends on **aggregate global reductions**
  - Individual mitigation activities typically make only a small contribution to the overall goal
- Broad-scale LEDS more likely to achieve cross-sectoral synergies, be sustained over time

LOW EMISSION DEVELOPMENT



ROLE OF ECONOMIC MODELING IN LEDS

- To date, GHG mitigation policy in developing countries conducted mainly on sector-by-sector basis
  - Economic analysis focused on MACC curves, some sectoral emissions modeling

- The United Nations Framework Convention on Climate Change (UNFCCC) agreed to "nationally determined contributions" in 2015, GHG reduction goals for countries in the post-2020 period
  - Scale not specified, but major emitters anticipated to make some broader (sectoral or national-level) contributions

- As countries scale up mitigation and implement national LEDS >> role of economic modeling and analysis more important

TYPES OF ECONOMIC ANALYSIS MODELS

- Single sector models
  - ICF Consulting's Integrated Planning Model (IPM®): least-cost optimization modeling of electric power industry
- National multi-sector models
  - US Energy Information Administration (EIA)'s National Energy Modeling System (NEMS) – United States energy sector
  - Stockholm Environment Institute's Long-range Energy Alternatives Planning System (LEAP)
- National computable general equilibrium (CGE) models
- International CGE models
  - Pacific Northwest National Laboratory (PNNL)'s Phoenix, formerly Second Generation Model (SGM): 24 world regions, 26 economic sectors

MODELS IN USAID PROGRAMS

- USAID Global Climate Change (GCC)-funded projects include support for climate change modeling

- USAID focuses on building government capacity to use models, adapt to their country context
  - RDMA: Training countries through the Low Emissions Asian Development (LEAD) program on use and application of the LEAP model
  - Eastern Europe: Using the multi-sector TIMES model to support LEDS planning and clean energy development

APPLICATIONS: NATIONAL POLICYMAKING

- Estimate GHG reductions from sectoral, regional, national economic policies (e.g., carbon taxes)
- CGE: Estimate net impacts of GHG mitigation on the economy and society
  - Production, prices, employment, trade
- Impacts of sector-specific mitigation policies on other sectors, regions, national economy
- Prioritize and time sectors for implementation
- Impact of regional/sub-national GHG mitigation programs

APPLICATIONS: NATIONAL POLICYMAKING (2)

- Cross-sectoral synergies
  - Impacts from mitigation actions that have benefits across sectors
- Cross-sectoral leakage
  - Supply leakage: GHG mitigation policies >> companies and individuals move into higher-emission activities
  - Demand leakage: Changes in prices >> product substitution among consumers (e.g., cement, steel, aluminum and wood -- energy- and emission-intensive substitutes)
- Long-term LEDS planning: Assist with development of transition from fossil fuels to renewable energy (RE)
  - Increasing shares of RE investment coordinated with government actions (e.g., electricity grid integration, transportation infrastructure development) and tied to demand growth

APPLICATIONS: NATIONAL POLICYMAKING (3)

- Identify sectors for/types of technology development or transfer
- Estimate impacts of mitigation actions on external trade patterns and emissions
  - Can be particularly useful for USAID regional programs
- Determine which sectors/ministries are needed for LEDS coordination
- Build institutional and public support for LEDS by demonstrating economic and social benefits of mitigation

APPLICATIONS: INTERNATIONAL CLIMATE POLICY

- International modeling: help funding institutions estimate costs, identify potential types and amounts of assistance

- Can help the Green Climate Fund (an operating entity of the financial mechanism of the UNFCCC providing support to mitigation and adaptation efforts), other institutions with leveraging, identify areas where private sector can play

- Analyze emissions trading programs
  - Future carbon permit prices
  - Economic/emissions impacts of specific carbon prices
  - Identify which countries/regions may be buyers/sellers

- Identify potential international emissions leakage (e.g., with internationally traded substitute commodities)

LIMITATIONS: CAPACITY AND DATA

- Models can be expensive and data-intensive to apply
  - Major emitter countries larger, more economically advanced – may require more complex models covering multiple sectors
  - Limited in-country experience with models, climate change analysis requires capacity building

- Data limitations
  - Countries often have only limited emissions/other data
  - Data collection often incomplete/inconsistent
  - Availability limited by confidentiality concerns

LIMITATIONS

- Rapid growth rates and volatility in many emission-intensive sectors – make long-term projections difficult

- Net negative cost measures
  - Difficult to account for risk aversion
  - Preferences related to time patterns of benefits/costs may reduce willingness to invest
  - May be difficult to incorporate into some models

MODEL REFERENCES

Integrated Planning Model (IPM®):

http://www.icfi.com/insights/products-and-tools/ipm

National Energy Modeling System (NEMS):

http://www.eia.gov/oiaf/aeo/overview

Long-range Energy Alternatives Planning System (LEAP):

http://www.energycommunity.org/default.asp?action=47

Phoenix:

http://www.globalchange.umd.edu/models/phoenix

TIMES:

http://www.iea-etsap.org/web/Times.asp

GCC Economics
&
Harberger's 3 CBA Buckets

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30 April 2014

Harberger's 3 CBA Buckets

Bucket 1. CBA is ***Trivial***

Bucket 2. CBA can be ***Fruitful***

Bucket 3. CBA is ***Impossible***

Bucket 2 – When CBA is Fruitful

Worthwhile:

- Major policy distortions – i.e., Policy Failures, and/or
- Major market failures

Possible:

- Physical inputs-outputs are known or determinable
- Values are (indirectly) determinable

Bucket 1 – When CBA is trivial

(Not) Worthwhile:

- Policy distortions are relatively minor, and
- No major market failures (or the project does not deal with them)

Possible – indeed, simple:

- Simply re-align financial analysis
- Easily calculate consumers' and producers' surpluses using known elasticities and prices (***feeds back to 'worthwhile' for projects with non-marginal changes in market quantities***)

Bucket 3 – When CBA is impossible

Unknown/unknowable variables:

- Physical inputs & outputs unknowable, and/or
- Values for quantities are unknowable

Pure uncertainty instead of risk:

- **Risk**: We can assign probabilities to variables
- **Uncertainty**: We do not know enough to be able to assign probabilities

At Interface Between Buckets 2 &3…

- Cost-effectiveness analysis (CEA)
- Least-cost analysis (LCA)
- Heavy use of alternative analytical methods – including
  - Sensitivity, switching value analysis
  - Monte Carlo simulations
  - Robust Decision Making

Possibilities & forms of CBA

Project Appraisal Process	Forms of CBA Possible
Identify	(Only) **Identify** output while valuing costs: ***LCA***
↓	
Quantify	**Quantify** output while valuing costs: ***CEA***
↓	
Value	**Value** outputs & costs: ***Full CBA***

Which bucket(s) for GCC economics?

- GCC applications are at ***border of Bucket 2 & Bucket 3***
- ***Mitigation analysis*** stays in ***Bucket 2*** by calling upon CEA rather than trying to use CBA
- ***Adaptation*** is currently in ***Bucket 3*** because it involves so much uncertainty

Global Climate Change (GCC) and The Discount Rate (DR)

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Today's Topics

1. **GCC & discount rate in practice**
   a) GCC & energy efficiency generally more capital-intensive than BAU
   b) Lower DR → Lower PV cost of EE & GCC mitigation
   c) Discounting practice in MACC versus global modeling
2. **The discount rate in theory**
   a) OCC versus STP approaches
   b) Stern (2006) vs Nordhaus (2007) & GCC Strategy
   c) Defining & dealing with Risk *versus* Uncertainty
      - » the discount rate
      - » In CBA & CEA
      - » EOA vs MPO Analysis – theory & practice

Why the DR matters

In MACC:

- Mitigation options (EE in particular) typically involve capital/recurrent cost tradeoffs
- Efficient option commonly has higher investment costs coupled with lower operating costs

In Global GCC Strategy:

- Costs are mostly incurred now
- Benefits mostly occur in (distant) future
- Act now? Wait & act later?

Capital/Recurrent Cost Tradeoffs in EE

- Energy efficiency (EE) is major part of mitigation strategy in many countries
- Discount rate affects purchase decisions on EE/GHG related options

EE Options & the BIG/EARLY problem

EXAMPLES:

- Hydro power is dominantly up-front cost – caricature comparison is with diesel or gas turbine generation
- Diesel generation is not only low-investment/high-operating cost but GHG difference also accompanied by localized and global pollutant differences
- Hybrid cars cost more up-front than petrol or diesel cars
- Etc., etc., etc.

Hybrid vs. Gasoline Vehicle Life-Cycle Costs (2008)

Car	Cost	Difference	City L/100km	HW L /100km	AVG L/100km	L / year	Gas $/yr	yrs to payback
Civic LX	$25,170	–	8.2	5.7	6.95	1390	$1,807	–
Civic Hybrid	$29,200	$4,030	4.7	4.3	4.5	900	$1,170	6.33
Corolla LE	$24,665	–	7.4	5.6	6.5	1300	$1,690	–
Prius	$32,866	$8,201	4	4.2	4.1	820	$1,066	13.14
Ford Escape (fwd)	$30,226	–	10.3	7.7	9	1800	$2,340	–
Escape Hybrid	$35,119	$4,893	5.7	6.7	6.2	1240	$1,612	6.72
Camry LE	$30798	–	9.5	6.2	7.85	1570	2041	–
Camry Hybrid	$36191	$5,393	5.7	5.7	5.7	1140	1482	9.65

http://www.milliondollarjourney.com/hybrid-vs-gasoline-vehicle-comparison-are-hybrids-worth-it.htm#31KG557WtuKQH3jI.99

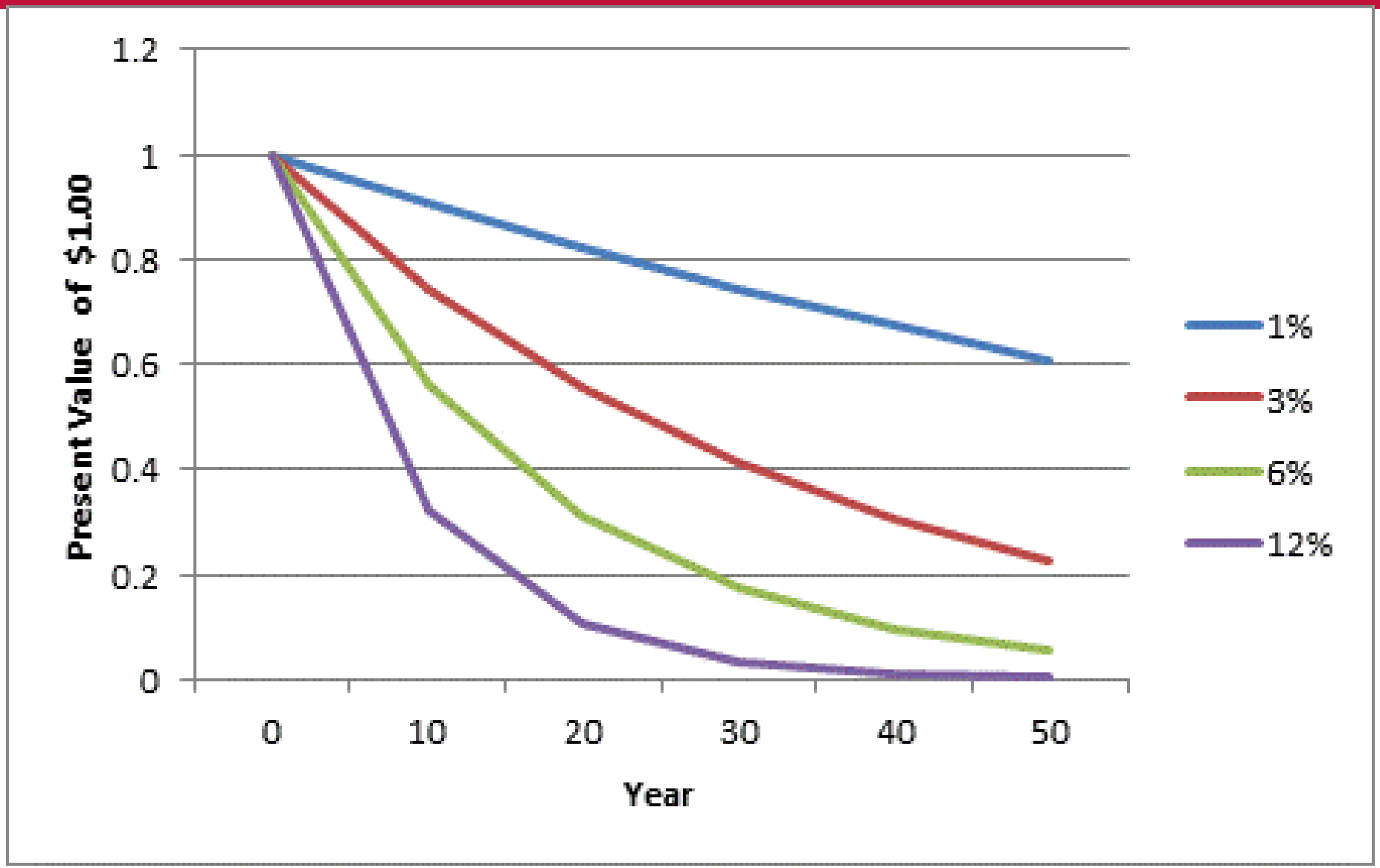
Major Life-Cycle Cost Differences

	----- Diesel Costs ------				----- Minihydro Costs -----		
Year	**Investment**	**Operating**	**Total**		**Investment**	**Operating**	**Total**
1	210	0	210		500	0	500
2		69	69		1000	0	1000
3		69	69		500	0	500
4-20		69	69			20	20
21	-20	69	49			20	20
22-32		0	0			20	20
33		0	0		-100	20	-80

Factors that determine Present Value (PV)

- The size of the Undiscounted Value (UDV)
- The size of the Discount Factor (DF, made up of two parts):
  - How far into the future the UDV occurs (“n”, for ‘number of years’): The farther out, the lower the PV
  - The Discount Rate (DR – a.k.a. interest rate) – the higher the DR, the lower the PV

PV of $1 in a Future Year at Discount Rates of 1% to 12%



PV analysis of Gasoline vs Hybrid Engine – Not good if DR is high, e.g. 10%

DR	10%			
Year	Costs Gas Car	Costs Hybrid Car	Costs Gas Car Minus Costs Hybrid Car	PV of Gas Minus Hybrid Car
0	$ 25,170	$ 29,200	$ (4,030)	(4,030)
1	$ 1,807	$ 1,170	$ 637	579
2	$ 1,807	$ 1,170	$ 637	526
3	$ 1,807	$ 1,170	$ 637	479
4	$ 1,807	$ 1,170	$ 637	435
5	$ 1,807	$ 1,170	$ 637	396
6	$ 1,807	$ 1,170	$ 637	360
7	$ 1,807	$ 1,170	$ 637	327
8	$ 1,807	$ 1,170	$ 637	297
9	$ 1,807	$ 1,170	$ 637	270
10	$ 1,807	$ 1,170	$ 637	246
		SUM	$ 2,340	$ (116)

At low DR of 2% – Hybrid looks much better

DR	2%			
Year	Costs Gas Engine	Costs Hybrid Engine	Costs Gas Car Minus Costs Hybrid Car	PV of Gas Car Minus Hybrid Car
0	$ 25,170	$ 29,200	$ (4,030)	(4,030)
1	$ 1,807	$ 1,170	$ 637	625
2	$ 1,807	$ 1,170	$ 637	612
3	$ 1,807	$ 1,170	$ 637	600
4	$ 1,807	$ 1,170	$ 637	588
5	$ 1,807	$ 1,170	$ 637	577
6	$ 1,807	$ 1,170	$ 637	566
7	$ 1,807	$ 1,170	$ 637	555
8	$ 1,807	$ 1,170	$ 637	544
9	$ 1,807	$ 1,170	$ 637	533
10	$ 1,807	$ 1,170	$ 637	523
		SUM	$ 2,340	$ 1,692

CROSS-OVER DISCOUNT RATE

- Good to know at what DR the **choice** would **switch** between the two options

- **Crossover DR”** – the DR above which the low-capital cost option (with high running costs) becomes cheaper than the high-capital-cost option with the lower running costs (a.k.a. the more ‘energy-efficient’ option)

- Crossover DR = IRR on a third cash flow set up by subtracting (cell-by-cell) the respective UDVs from each of the two options (next slide)

Crossover DR = DR at which the choice of option switches

Year	Costs Gas Car	Costs Hybrid Car	Costs Gas Car Minus Costs Hybrid Car
0	$ 25,170	$ 29,200	$ (4,030)
1	$ 1,807	$ 1,170	$ 637
2	$ 1,807	$ 1,170	$ 637
3	$ 1,807	$ 1,170	$ 637
4	$ 1,807	$ 1,170	$ 637
5	$ 1,807	$ 1,170	$ 637
6	$ 1,807	$ 1,170	$ 637
7	$ 1,807	$ 1,170	$ 637
8	$ 1,807	$ 1,170	$ 637
9	$ 1,807	$ 1,170	$ 637
10	$ 1,807	$ 1,170	$ 637
		IRR = Crossover DR:	9.33%

TAKE-AWAYS ON COST STRUCTURE & DISCOUNT RATE

- The more energy (GHG) efficient option typically has higher capital (up-front) costs than the less energy-efficient option
- This makes DR important variable in comparing EE options
- Important issue, since ≈75% of global GHG emissions are from energy development and use
- High DRs (and/or lots of uncertainty) discourage people from using technologies that tie up a lot of resources now in order to save money in the future

Risk vs Uncertainty

Since Frank Knight's (1921) book *Risk, Uncertainty and Profit* – economists make the following distinction:

- **RISK** refers to PREDICTABLE VARIATION
- **UNCERTAINTY** refers to UNPREDICTABLE VARIATION

GCC & Knight's Risk & Uncertainty

Planning and analysis models in economics are traditionally based on **Knightian Risk** – e.g., in CBA we have

- Expected Outcome Analysis (EOA)
- Most Probable Outcome Analysis' (MPOA)

Both of which EXPLICITLY deal with RISK

Does the CBA (DCF) account for RISK?

- **Capital Markets Approach** to discounting (a.k.a. MPOA) –
  - *The risk is loaded into the DR (coupled with UDVs that are **MPO**)*
- **Expected Cash Flows Approach** (a.k.a. EOA) –
  - *The probabilities are imbedded in the expected values of the UDVs**

** Approach in Dr. Nandakumar's decision tree example*

TAKE-AWAYS ON RISK & UNCERTAINTY

Risk (a.k.a. probabilities) is included in traditional CBA/ planning models whether it is in the DR or in the UDV estimates

But…**uncertainty** is NOT handled in either the DR or in the UDVs

How does Economic Analysis handle Knightian Uncertainty?

Uncertainty is handled outside the usual discounting framework

- In the Risk & Sensitivity Analysis
- Using Robust Decision Making (RDM) instead of probability weighting
- Using Monte Carlo Simulations, etc.

Risk vs Uncertainty in Adaptation vs Mitigation Analysis

- **GCC Adaptation** options – Need newer models for handling ***uncertainty*** (working on them)
- **GCC Mitigation** options – Use the usual ***risk***-based models

The GCC Broad Strategy Debate

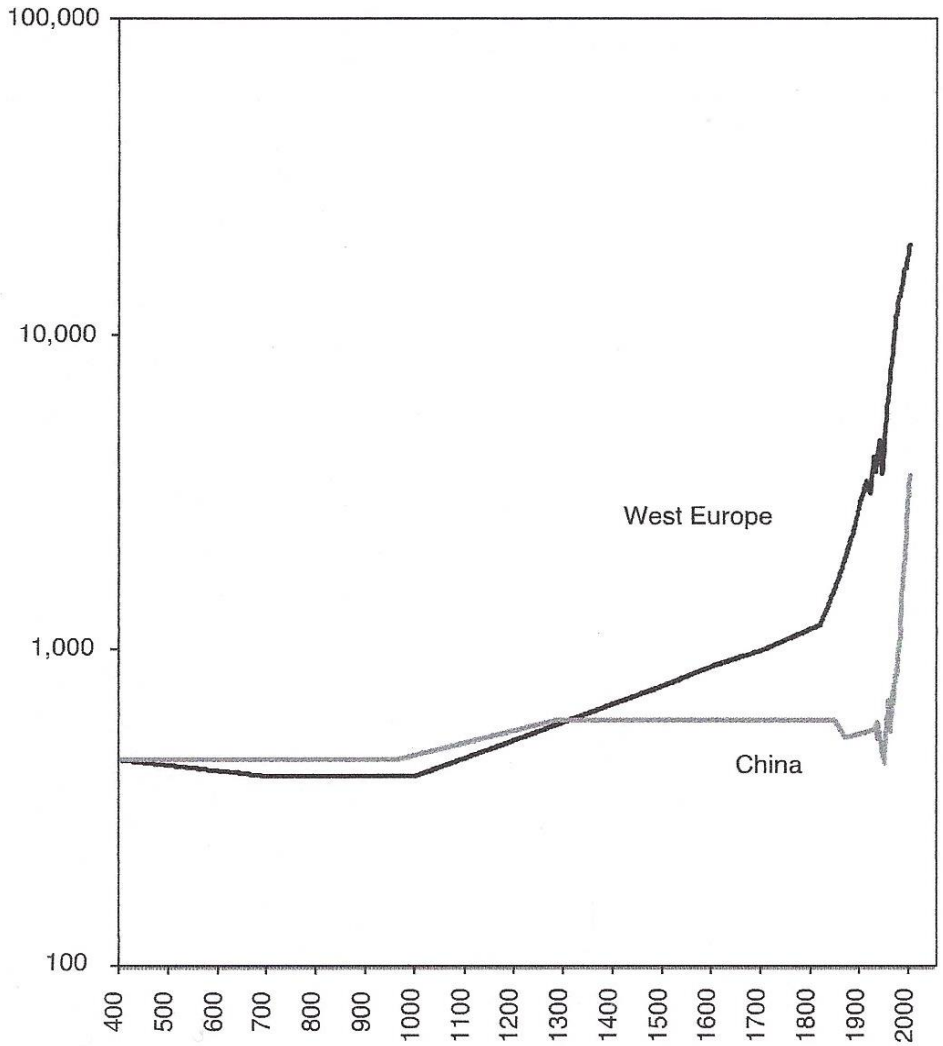
- **React Strongly & Now (Stern)**
  - Long delay in impacts, so act now to affect year 2064
  - Lower DR yields bigger PV of future damages

- **React Gradually & Later (Nordhaus)**
  - We will be richer later (can better afford it)
  - We will have better technology later (see also Hallegatte)
  - We will have better information later (Uncertainty converts to Risk – we don't really know the damage functions yet)
  - Using the right DR gives a low PV cost for waiting ….

Central Factors in the Stern/ Nordhaus debate

1. **Rate of LT economic growth**—faster the growth the better to ‘wait’ & fix when richer
2. **Rate of technological progress**—faster the rate of progress, better technology we will have next year, and the next, and the next (so wait)
3. **Climate sensitivity** to GHGs (damage function responsiveness)—less the sensitivity the less we need to do about it today
4. **The DR**—declining rate at which we value consumption over time

LT Growth (400 AD to 2000 AD) – GDP/Cap in 1990 US$



← 2nd Industrial Revolution (1860s -1920s)

←1st Industrial Revolution (1720-1820)

↖1978 China 'Opening'

Will we grow fast or slow?
See Economic Growth in Each Era

- **Ancient Era** – (after Ag c 12000 BC before 1000 or so) Growth by conquest

- **Middle Era** – After Age of Conquest, before 1st Industrial Rev of 17-1800s – Growth by Mercantilist Expansion

- **Modern Era** – (after 1st Ind & Ag Revolutions, before 'New Economy post ≈1985) Productivity growth by accumulating/ investing in physical capital

- '**New Economy**' (New Growth Theory/Non-Convergent Growth) – Growth by investing in Knowledge/Ideas – Paul Romer (1983, 1985, 1990) shows there is no foreseeable limit on ideas

Nordhaus-Stern Debate Take-Aways

- Major debates exist among ***recognized GCC scholars*** – not just political opposites
- Central issue: How DR is modeled
- The leading strategy debate (Stern vs Nordhaus) comes down to 4 model variables:
  - Rate of GDP growth
  - Rate of Tech Progress
  - Damage functions
  - Citizen time preferences (Discount Rate)

Approaches to Modeling DR

TRADITIONAL:

- **Economic Opportunity Cost of Capital (EOCC)** – Harberger CBA (1972) + Nordhaus (2007)
- **Social Time Preference (STP)** – Ramsey (1928) + Stern (2006)

BEHAVIORAL ECONOMICS:

- **Hyperbolic Discount Rate (HDR)** – arising from behavioral economics studies showing most people have high DR for early years and lower DR for later years

Supply-side versus Demand-side Bias

- **The EOCC** derives from **supply-side** costs in meeting society's multitude of consumption demands

- **The STP** derives from **demand-side** valuations of present versus future ***consumption***

The EOCC

The rate of return on the alternative use of those same resources somewhere else. Can be high when

- Investment yields are high in private sector and taxing away those alternatives to build public project is costly
- Rates of return on alternative public projects are high

Social Time Preference Rate

- The **Social Time Preference (STP)** approach – Society's valuation of present consumption versus future consumption – i.e., like a *willingness to wait* index

- Generally much lower than EOCC rate

The Social Time Preference Rate

Made up of:

1. The value of additional consumption as income changes, and
2. A “pure rate of time preference” that weighs utility in one period directly against utility in a later period

Big debate in pure theory literature on role of inter-generational equity in determining STP

In Practice…

- EOCC calculations
  - Favored for public investment by CBA legend Al Harberger
  - Usually range from 5% to 15%
  - New Zealand Treasury at low end (5.6%)
  - World Bank and USAID typically use 12% for regular CBA

- STP rates usually range between zero percent and 5%
  - Pigou and Ramsey favored very low rates→zero
  - Major support in GCC practice for using 1.5%

- MACC Calculations of C/E Ratios
  - Put two separate blanks for DR in Excel table (to be filled in later)
  - Discount costs at EOCC
  - Discount CO2e at zero

Behavioral Economics/ Hyperbolic Discounting

- Research reveals that individual discount rates tend to be high for early years
- Individuals tend not to extend discounting far into the future – i.e., they value year 21, 22, 23 pretty much the same as year 20
- Unlike commonly-applied math of finance, individuals do NOT apply a single discount rate to all future years

FINAL TAKE-AWAYS

- Generally, 3 ways to estimate discount rate
  - STP
  - EOCC
  - Hyperbolic Rate
- A lot of normative* analysis goes into selecting and calibrating a DR estimation model
- Uncertainty (i.e., beyond ‘risk’) dominates
  - Physical outcomes
  - Human values

* Often subjective, personal values masquerading as positivist research.

Financial and Economic Analysis of Climate Change Programs on Mitigation and Adaptation

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Juan A. B. Belt

USAID

Introduction

- **Purpose**
  - Show how these courses are components of wider initiatives
- **Outline**
  - Why CBA?
  - Progress in reintroducing CBA at AID: early efforts concentrated in Feed the Future
  - Main priorities going forward:
    - GCC
    - Power, water, roads, education

Why CBA?

CBA can help answer critical questions

- **Is this project beneficial for the economy/society?**
  - Is it financially sustainable? **Sustainability analysis is mandatory as part of project design**
  - Who are the winners and who are the losers?
  - What are the risk factors?
  - Are the benefits to society higher than the costs?
- **CBA is closely linked with Project Design & M&E**
  - CBA can help guide design process alongside LOGFRAME
  - Performance monitoring: CBA defines a without project situation, generates targets & identifies critical variables to monitor
  - Impact evaluation: CBA compares with and without the project scenarios. Ex-post economic rate of return a good summary statistic

Project Design, M&E and CBA in USAID Mid 1990s to 2010

Reintroducing CBA at USAID 2010-13

- 2010: Mary Ott & Gary Linden initiative
  - Arnold (Al) Harberger USAID Chief Economic Advisor
  - 25 USAID officers trained at Duke
  - Supply of USAID CBA analysts exceeded demand: **no CBAs were carried out**
- 2011: June BFS management mandates CBA of Feed the Future programs
- 2012: Getting ready for CBA in other sectors including power, roads, water, GCC
- 2013: Working in other sectors & greater emphasis on CPCs

CBA Training 2010 to 2013

	# of courses	# of participants
Four-week intensive course in CBA	4	90
Online course in CBA	2	130
Feed the Future Workshops	10	200
Project Design & CBA	2	30
GCC Mitigation	1	20
GCC Adaptation	1	30
RDMA: energy, agriculture, GCC	1	25
Pakistan CBA power and agriculture	1	25
Afghanistan CBA for power and agriculture	1	25
CBA for agricultural project design	1	25
Advanced Topics in CBA power, education, & health	1	25
South Africa CBA for government counterparts	1	40
Kenya CBA course for government counterparts	1	40
TOTAL	**27**	**705**

CBA of Feed the Future Programs

- **First Round**: Haiti, Uganda, Ghana, Tanzania, Rwanda, & Bangladesh
- Teams: E3/EP, BFS DLIs, & mission staff
- **E3/EP predominant role with help from G. Jenkins (CRI)**
- **Second Round**: Additional 13 countries
- Teams E3, BFS, & mission staff
- Trainings on CBA of agricultural projects
  - Regional workshops East Africa, West Africa, South Africa (2), Asia, Europe & Central America
  - Country workshops in Haiti and Kosovo
  - 200 USAID officers trained (mostly AG officers)
- **Reduced role for E3/EP in CBAs**

Findings from 14 *Feed the Future* Focus Countries: Radelet Model Validated

	Average	Median	Range
ERR* (%)	30%	22%	14%-64%

- Useful for new and on-going projects – but ***most useful at design stage***
- Important for ensuring sustainability of investments
- Most useful if model "installed" in the mission
- FSN participation critical
- Multidisciplinary effort necessary
- Field visits useful/necessary

* Modified IRR

** Excluding farmer costs

CBA/CEA into the Future

- Continue to support BFS
- New directions:
  1. Carry out CBA early in the project cycle
  2. Strive for impact on resource allocation
  3. Use CBA throughout the project cycle: design, monitoring, and final evaluation
  4. Train partner country officials
  5. Encourage greater use of CBA by partner countries
  6. Work in sectors other than agriculture such as power, water, education, transport, **GCC discussed next slide**

Should CBA be mandatory?

GCC Activities

- **PAST**
  - Eric Postel AA/E3 requested EP include GCC in CBA/CEA plans
  - Courses on Mitigation & Adaptation March 2013 Abt Associates
  - Hiring Bill Ward May 2013
- **PRESENT** Courses on Mitigation & Adaptation 2014
- **FUTURE TRAINING**
  - Mozambique
  - RDMA
  - El Salvador

- Courses based on actual projects
- Include partner government officials

Questions?

Points of Contact for Cost Benefit Analysis

- Juan Belt (jbelt@usaid.gov) (juan.a.b.belt@gmail.com)
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- Jerrod Mason (jemason@usaid.gov)
- Kristen Schubert (krschubert@usaid.gov)
- Bill Ward (wward@usaid.gov)

More information on CBA @ AID

http://245elmp01.blackmesh.com/Strengthening_CBA_USAID_Juan_Belt/story_content/external_files/USAID-CBA-STRENGTHENING_CBA-FINAL.pdf

The Social Cost of Carbon: A Primer and Overview of the U.S. Government's SCC Estimates

Elizabeth Kopits
National Center for Environmental Economics, U.S. EPA

Presentation at the 1st Session of the OECD/ITF Working Group on Assessment of Policies for Long-Term Transition to Sustainable Transport
December 12, 2013

The views expressed in this presentation are those of the presenter and do not necessarily represent those of the U.S. EPA.

NCEE

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The Social Cost of Carbon: A Primer and Overview of the U.S. Government's SCC

Estimates

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The views expressed in this presentation are those of the presenter and do not necessarily represent those of the U.S. EPA.

Outline

- What the Social Cost of Carbon Is and Is Not
- Overview of U.S Government's (USG) SCC Estimates
  - 2009-2010 Process
  - 2013 Update
- Discussion

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- What the Social Cost of Carbon Is and Is Not
- Overview of U.S Government's (USG) SCC Estimates

– 20092010 Process – 2013 Update

- Discussion

What is the Social Cost of Carbon?

- The SCC provides a measure of the marginal damage from CO_2 emissions – and thus the *marginal benefit of abatement*
  - The SCC is the theoretically consistent value to compare with the marginal cost of abatement in benefit cost analysis
- Specifically, the SCC is the monetized value of future worldwide economic damages associated with a one-ton increase in CO_2 emissions in a particular year discounted to the present.
  - This is identical to the avoided damages associated with a one-ton decrease.
- It is intended to be a comprehensive measure of climate change damages, including (but not limited to):
  - changes in net agricultural productivity
  - net energy demand
  - human health
  - property damages from increased flood risk
  - the value of ecosystem services

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What the Social Cost of Carbon is Not

- The SCC is not the carbon shadow price derived from various policies (e.g., cap-and-trade program, performance standards)
- The carbon price associated with a policy that specifies an environmental target provides a measure of the *marginal cost of abatement.*
  - This is useful in evaluating policy cost-effectiveness
  - It is NOT an alternative way to value damages from CO_2 emissions
  - It does implicitly require a valuation of damages when setting the constraint
    - E.g., a target set to keep temperature increases to a certain amount to avoid "far too risky" outcomes implies a valuation of damages.
- The marginal cost of abatement and the marginal benefit of abatement (i.e., the true value of the SCC) are equal only when the emissions target is set at the economically efficient level

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Overview of USG SCC Estimates

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Overview of USG SCC Estimates

How is the SCC Used to Evaluate the Effects of U.S. Regulation?

- Executive Order 12866 directs federal agencies "to assess both the costs and benefits of the intended regulation…."
  - The SCC is an estimate of the benefits of reducing emissions of CO_2, which allows those benefits to be considered in benefit-cost analysis.
  - Without a SCC, the benefit to society of reducing CO_2 emissions would be treated as zero – effectively ignoring climate change damages
- In 2009, the Obama Administration launched an interagency process to promote consistency in the SCC values used by agencies
  - Prior to 2008, reductions CO_2 emissions impacts were not valued
  - From 2008 to 2009, SCC estimates varied substantially among agencies
  - In 2009, "interim" USG SCC estimates were issued based on literature review
  - The 2010 USG SCC estimates have been used in 30+ regulations to date (EPA, DOT, DOE)

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Overview of USG SCC Analytic Process

- Used 3 "integrated assessment models" (IAMs) that combine climate processes, economic growth, and feedbacks between the two in a single modeling framework
  - PAGE, DICE, and FUND models, each given equal weight
  - IAMs are highly simplified representations of the potential economic damages from climate change and limited by the current state of research
  - Despite their inherent uncertainties and limitations, they are the best tools currently available for estimating the SCC
- Applied a common set of assumptions in each model for: reference socioeconomic and emissions trajectories, climate sensitivity, and discount rates
- All other features of the IAMs were left unchanged
- It was decided that the value should reflect global damages from CO_2 emissions, not just those that would occur in the U.S.

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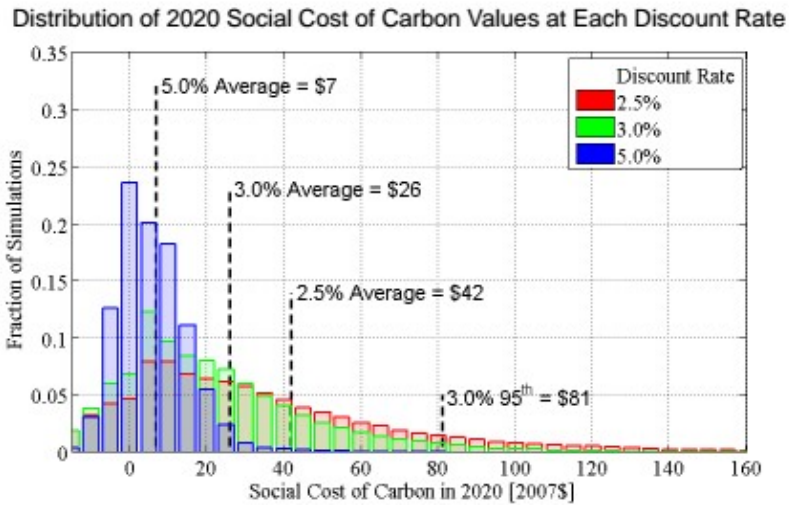
USG SCC Estimates (Feb 2010)

- The model runs produced 45 separate SCC distributions for a given year
  (3 models) x (5 socioeconomic scenarios) x (1 climate sensitivity distribution) x (3 discount rates)
- The distributions from each model and scenario were equally weighted and combined to produce three separate probability distributions for SCC in a given emissions year, one for each of the three discount rates
- Four final values chosen:
  - Average SCC at each discount rate: 2.5%, 3%, 5%
  - 95th percentile at a 3% discount rate, representing higher than expected economic impacts further out in the tails of the distribution.



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Distribution of 2020 Social Cost of Carbon Values at Each Discount Rate

2013 Update

- While acknowledging the continued limitations of the approach taken in 2010, the USG recently updated the SCC estimates based on new versions of each IAM.
- Improvements in the way damages are modeled are confined to those incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature.
  - USG model input decisions were not revisited
- Revisions vary by model and include: improvements to calculation of sea level rise damages, updated adaptation assumptions, changes to how temperature responds to buildup of GHG concentrations.
- Some model revisions increase the SCC, others decrease it. The new estimates reflect the net effect of all of changes.

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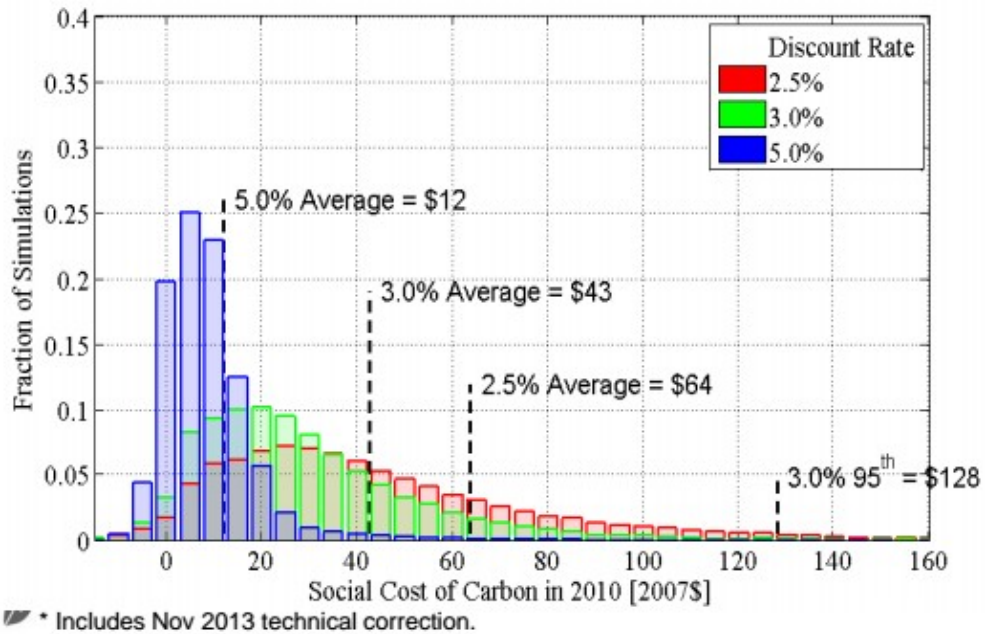
Updated USG SCC Estimates

- For 2020, the revised SCC values are: $12, $43, $64, & $128 (2007$).

Distribution of SCC Estimates for 2020 (2007$/ton CO_2)*



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Distribution of SCC Estimates for 2020 (2007$/ton CO

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* Includes Nov 2013 technical correction.

United States Department of State

Office of Global Partnerships

TROPICAL FOREST ALLIANCE 2020
(TFA 2020)

The Challenge

Tropical forests are critical to life, livelihoods, and well-being. They provide shelter, food, jobs, water, medicine and security to more than 1 billion people, and are essential to maintaining clean water and clean air. Yet, rising global demand for food and consumer products is accelerating deforestation, particularly in tropical areas. Governments, the private sector, and civil society together face the daunting challenge of meeting humanity's needs for food and other agricultural commodities without further loss of the world's tropical forests.

The Alliance

The **Tropical Forest Alliance 2020 (TFA 2020)** is a public-private partnership in which members will take voluntary actions—individually and in combination—aimed at reducing tropical deforestation associated with the sourcing of commodities like palm oil, soy, beef, paper and pulp. TFA 2020 was born in 2012 out of discussions between the United States Government and the Consumer Goods Forum (CGF). TFA 2020 supports the Obama Administration's broader development and climate objectives, and seeks to deliver solutions that spur economic growth and enhance food security. U.S. participation in TFA 2020 is a whole-of-government effort. The State Department's Office of Global Partnerships and Bureau of Oceans, Environment and Science provide critical guidance, in close partnership with the U.S. Agency for International Development, which leads implementation for the U.S. CGF represents over 400 companies globally that manufacture and sell consumer goods.

Cross-Cutting Objectives

TFA 2020 will coordinate and mobilize actions by governments, the private sector, and civil society to reduce the tropical deforestation associated with key commodity supply chains. The United States and other partner countries, companies, and civil society organizations will work together to focus on the following areas:

1. **LAND AND FOREST MANAGEMENT** ▸ Improve planning and management related to tropical forest conservation and agricultural land use and land tenure.

2. **AGRICULTURE AND CONSERVATION PRACTICES** ▸ Share best practices for tropical forest and ecosystem conservation and commodity production, including working with smallholder farmers and other producers on sustainable agricultural intensification, and promoting the use of degraded lands and reforestation.

3. **MARKET CAPACITY** ▸ Provide expertise and knowledge to assist in the development of commodity markets that promote the conservation of tropical forests.

4. **MONITORING** ▸ Improve monitoring of tropical deforestation and forest degradation to measure progress.

15 million
Hectares of tropical forest lost annually.

Up to 17%
Percent of global greenhouse gas emissions attributable to deforestation.

50%
Percent of all terrestrial plant and animal species found in forests, mostly tropical forests.

50%
Estimated percentage of annual tropical deforestation attributable to expansion of oil palm, soy, beef, and wood products.

70%
Increase in global food production by 2050 that will be required to meet human demand.

Initiatives

TFA 2020 will help align the efforts of diverse partners in complementary ways and find synergies between ongoing efforts. For example, TFA 2020 seeks to combine resources and expertise to improve the yields of smallholder farmers; develop incentives for growers to plant on degraded lands rather than in areas of high conservation value tropical forest; and apply objective and scientifically robust systems for measuring tropical deforestation, and forest degradation.

Partnering with TFA 2020

We invite new partners, including producer and consumer countries, private sector companies, and civil society organizations to join TFA 2020 in addressing tropical deforestation. We welcome participation of additional partners who are ready to endorse the goals of TFA 2020, and agree to undertake specific actions to address commodity-drive tropical deforestation.

Partners

The Consumer Goods FORUM

Government of the Netherlands
Government of Norway
Government of the United Kingdom

*The Tropical Forest Alliance 2020 (TFA 2020) is a public-private partnership that was founded by the U.S. Government and the Consumer Goods Forum with the goal of reducing the tropical deforestation associated with key global commodities. The Alliance is open to new members,including producer and consumer countries, private sector companies and civil society organizations that agree to undertake specific actions to address commodity-driven tropical deforestation.

For more information about the Tropical Forest Alliance please visit www.usaid.gov/climate/tfa2020 or contact partnerships@state.gov.

www.usaid.gov/climate/tfa2020

Climate Change 2013: The Physical Science Basis

http://www.ipcc.ch/report/ar5/wg1/

Climate Change 2014: Impacts, Adaptation, and Vulnerability

http://www.ipcc.ch/report/ar5/wg2/

Climate Change 2014: Mitigation of Climate Change

http://www.ipcc.ch/report/ar5/wg3/

INTERNATIONAL MONETARY FUND

ENERGY SUBSIDY REFORM: LESSONS AND IMPLICATIONS

January 28, 2013

EXECUTIVE SUMMARY

Energy subsidies have wide-ranging economic consequences. While aimed at protecting consumers, subsidies aggravate fiscal imbalances, crowd-out priority public spending, and depress private investment, including in the energy sector. Subsidies also distort resource allocation by encouraging excessive energy consumption, artificially promoting capital-intensive industries, reducing incentives for investment in renewable energy, and accelerating the depletion of natural resources. Most subsidy benefits are captured by higher-income households, reinforcing inequality. Even future generations are affected through the damaging effects of increased energy consumption on global warming. This paper provides: (i) the most comprehensive estimates of energy subsidies currently available for 176 countries; and (ii) an analysis of "how to do" energy subsidy reform, drawing on insights from 22 country case studies undertaken by IMF staff and analyses carried out by other institutions.

Energy subsidies are pervasive and impose substantial fiscal and economic costs in most regions. On a "pre-tax" basis, subsidies for petroleum products, electricity, natural gas, and coal reached $480 billion in 2011 (0.7 percent of global GDP or 2 percent of total government revenues). The cost of subsidies is especially acute in oil exporters, which account for about two-thirds of the total. On a "post-tax" basis—which also factors in the negative externalities from energy consumption—subsidies are much higher at $1.9 trillion (2½ percent of global GDP or 8 percent of total government revenues). The advanced economies account for about 40 percent of the global post-tax total, while oil exporters account for about one-third. Removing these subsidies could lead to a 13 percent decline in CO_2 emissions and generate positive spillover effects by reducing global energy demand.

Country experiences suggest there are six key elements for subsidy reform. These are: (i) a comprehensive energy sector reform plan entailing clear long-term objectives, analysis of the impact of reforms, and consultation with stakeholders; (ii) an extensive communications strategy, supported by improvements in transparency, such as the dissemination of information on the magnitude of subsidies and the recording of subsidies in the budget; (iii) appropriately phased price increases, which can be sequenced differently across energy products; (iv) improving the efficiency of state-owned enterprises to reduce producer subsidies; (v) targeted measures to protect the poor; and (vi) institutional reforms that depoliticize energy pricing, such as the introduction of automatic pricing mechanisms.

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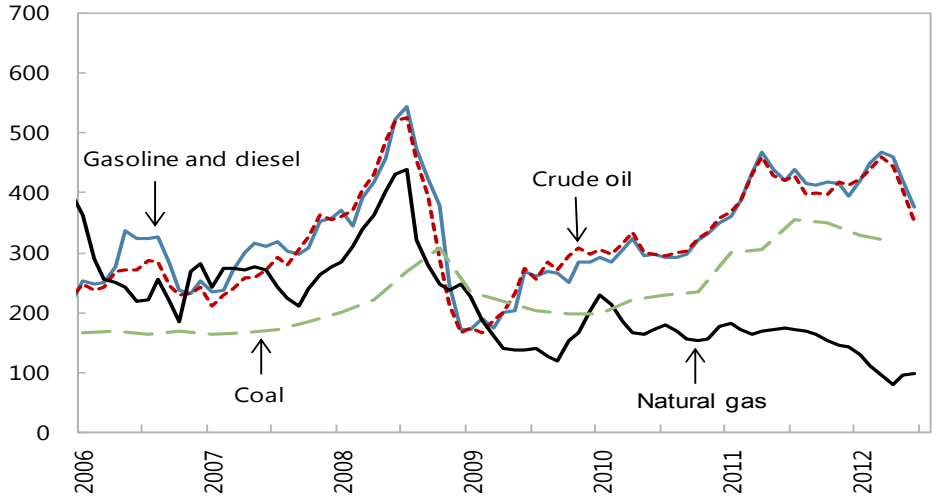
BACKGROUND

1. The recent surge in international energy prices, combined with incomplete pass-through to domestic prices, has prompted calls to phase out energy subsidies.[1] International energy prices have increased sharply over the past three years, with the exception of natural gas (Figure 1). Yet many low- and middle-income economies have been reluctant to adjust their domestic energy prices to reflect these increases. The resulting fiscal costs have been substantial and pose even greater fiscal risks for these countries if international prices continue to increase. In advanced economies, pass-through has been higher, but prices remain below the levels needed to fully capture the negative externalities of energy consumption on the environment, public health, and traffic congestion.

Figure 1. International Prices of Oil, Coal, and Natural Gas, 2006–2012

(Indexed January 2000=100)

International energy prices, other than for natural gas, have rebounded since the 2008–09 global crisis.



Sources: IMF *World Economic Outlook* (WEO), U.S. Energy Information Administration (EIA), and the Organisation for Economic Co-operation and Development (OECD).

Note: Coal price is average of quarterly U.S. import prices (EIA) and quarterly OECD import price (IEA/OECD). Natural gas price is average of the monthly U.S. import and export prices (EIA); these prices are weighted averages for LNG and pipeline natural gas. Crude oil price is average of Brent, Dubai, and WTI monthly prices (WEO/Primary Commodities Price System). Gasoline price is monthly New York Harbor conventional gasoline spot price (EIA). Diesel price is monthly Los Angeles ultra-low sulfur CARB diesel spot price (EIA). Gasoline and diesel prices are then averaged.

[1]The G-20 Pittsburgh Communiqué in September 2009 called for a phase out of inefficient fossil fuel subsidies in all countries. This commitment was reaffirmed at the 2012 Los Cabos meeting of the G-20.

2. Energy subsidies have wide-ranging economic consequences. Subsidy expenditures aggravate fiscal imbalances, and crowd out priority public spending and private investment, including in the energy sector. Underpriced energy distorts resource allocation by encouraging excessive energy consumption, artificially promoting capital-intensive industries (thus discouraging employment creation), reducing incentives for investment in renewable energy, and accelerating the depletion of natural resources. Subsidies lead to higher energy consumption, exerting pressure on the balance of payments of net energy importers, while also promoting smuggling to neighbors with higher domestic prices. As most subsidy benefits are captured by higher-income households, energy subsidies have important distributive consequences that are often not fully understood. Even future generations are affected through the reduced availability of key inputs for growth and the damaging effects of increased energy consumption on greenhouse gas emissions and global warming.

3. Yet energy subsidies have been difficult to reform. Subsidy reform has been a frequent topic of discussion between IMF staff and member countries—in some cases over decades. The adjustment of prices for subsidized energy has often led to widespread public protests by those who benefit from subsidies and to either a complete or partial reversal of price increases.[2] The absence of public support for subsidy reform partly reflects a lack of confidence in the ability of governments to reallocate the resulting budgetary savings to benefit the broader population, as well as concerns that vulnerable groups will not be protected. This is particularly challenging in oil-exporting countries, where subsidies are seen as a mechanism to distribute the benefits of natural resource endowments to their populations; in addition, these countries typically lack capacity to administer targeted social programs. Governments are also often concerned about the inflationary effects of higher domestic energy prices and their adverse impact on the international competitiveness of domestic producers. Furthermore, subsidy reform can be complex when it involves efforts to reduce inefficiencies and production costs, as is often the case for the electricity sector.

4. This paper focuses on "how to do" energy subsidy reform in light of country experiences. The second section reviews the challenges arising from energy subsidies, emphasizing their fiscal costs, adverse macroeconomic and environmental impacts, and the regressive distribution of subsidy benefits. A novel feature of the paper is that it presents the most comprehensive estimates of energy subsidies available covering petroleum products, electricity, natural gas, and coal. A central objective of the paper is to learn from past subsidy reform experiences, both successful and otherwise, to identify key design features that can facilitate reform. In this regard, the third section draws on lessons from international reform experiences from 22 country case studies (covering 28 reform episodes) undertaken by IMF staff, which are provided in a supplement to this paper. These are combined with insights from past IMF analyses (including Gupta and others, 2000; Coady and others, 2006; IMF, 2008a; Coady and others, 2010; and Arze del Granado, Coady, and Gillingham, 2012) as well as from analyses carried out by other institutions (including Global Subsidies Initiative, 2010; UNEP, 2002 and 2008; World Bank, 2010; Vagliasindi, 2012).

[2]Examples of reform reversals where price increase had to be quickly reversed—either partially or fully due to public demonstrations—include Bolivia (2010), Cameroon (2008), Nigeria (2012), Venezuela (1989), and Yemen (2005).

ENERGY SUBSIDIES

A. Definition and Measurement

5. Energy subsidies comprise both consumer and producer subsidies. Consumer subsidies arise when the prices paid by consumers, including both firms (intermediate consumption) and households (final consumption), are below a benchmark price, while producer subsidies arise when prices received by suppliers are above this benchmark.[3] Where an energy product is internationally traded, the benchmark price for calculating subsidies is based on the international price.[4] Where the product is mostly non-traded (such as electricity), the appropriate benchmark price is the cost-recovery price for the domestic producer, including a normal return to capital and distribution costs. This approach to measuring subsidies is often referred to as the "price-gap approach" (Koplow, 2009), and is used widely in analyses by other international agencies. In most economies, there are elements of both producer and consumer subsidies, although in practice it may be difficult to separate the two.[5] The advantage of the price gap approach is that it also helps capture consumer subsidies that are implicit, such as those provided by oil-exporting countries that supply petroleum products to their populations at prices below those prevailing in international markets. The price gap approach does not capture producer subsidies that arise when energy suppliers are inefficient and make losses at benchmark prices.[6]

6. Consumer subsidies include two components: a pre-tax subsidy (if the price paid by firms and households is below supply and distribution costs) and a tax subsidy (if taxes are below their efficient level). Box 1 describes the calculation of these two components. Most economies impose consumption taxes to raise revenue to help finance public expenditures. Efficient taxation requires that all consumption, including that of energy products, be subject to this taxation. The efficient taxation of energy further requires corrective taxes to capture negative environmental and other externalities due to energy use (such as global warming and local pollution).[7] The discussion below focuses on both "pre-tax subsidies" and "post-tax subsidies," where the latter includes an allowance for efficient taxation.

[3]The calculation of producer subsidies should incorporate any subsidies received on inputs.

[4]The benchmark price is the international price adjusted for distribution and transportation costs. The estimates in this paper assume similar distribution and transportation margins across countries.

[5]Producer and consumer subsidies have different economic consequences. Unlike consumer subsidies, producer subsidies do not lead to excessive consumption of energy.

[6]In many developing countries, cost-recovery prices are abnormally high because of inefficiencies in state-owned enterprises in the energy sector.

[7]These taxes are often referred to as "Pigouvian" or "corrective" taxes. In this paper, only broad estimates of these tax subsidies will be reported. A subsequent study by the Fiscal Affairs Department will provide more refined, country-specific estimates.

Box 1. Pre-tax and Post-tax Consumer Subsidies

A consumer subsidy is defined as the difference between a benchmark price and the price paid by energy consumers (including both households for final consumption and enterprises for intermediate consumption). There are two concepts of consumer subsidies: pre-tax subsidies and post-tax subsidies.

For the calculation of pre-tax subsidies for internationally traded goods (such as the refined petroleum products considered in this paper), the benchmark price is the international price appropriately adjusted for transport and distribution costs [1] (Pw) so that:

$$\text{Pre-tax subsidy} = Pw - Pc,$$

where Pc is the price paid by consumers. When the good or service is not traded internationally, as is the case for electricity in most countries, then the benchmark price is taken as the cost-recovery price (e.g., the costs of generation, transmission, and distribution of electricity). The pre-tax subsidy is then calculated as above, but Pw is the cost-recovery price. Pre-tax subsidies only exist in countries where the price paid by consumers is below the international or cost-recovery price ($Pc<Pw$).

For the calculation of post-tax subsidies, the benchmark price includes an adjustment for efficient taxation ($t^*>0$) to reflect both revenue needs and a correction for negative consumption externalities:

$$\text{Post-tax subsidy} = (Pw + t^*) - Pc,$$

where Pw and Pc are defined as above. Therefore, when there is a pre-tax subsidy the post-tax subsidy is equal to the efficient tax plus the pre-tax subsidy. When there is no pre-tax subsidy, the post-tax subsidy is equal to the difference between efficient and actual taxation.

[1] When the refined petroleum product is imported, the benchmark price is taken as the international fob price plus the cost of transporting the product to the country's border plus the cost of internal distribution. When the product is exported, the benchmark price is the international fob price minus the cost of transporting the product abroad (since this cost is saved when the product is consumed domestically rather than exported) plus the cost of internal distribution.

7. Although energy subsidies do not always appear on the budget, they must ultimately be paid by someone. Whether and how subsidies are reflected in the budget will depend on who incurs them and how they are financed. For example, the cost of pre-tax consumer subsidies may be incurred by state-owned enterprises (SOEs) that sell electricity or petroleum products at a price below supply costs. If the government fully finances these losses with a transfer, the consumer subsidy will be reflected in the budget as expenditure and financed through higher taxes, increased debt, or higher inflation if the debt is monetized. In many instances, however, the subsidy may be financed by the SOE and reflected in its operating losses or lower profits, lower tax payments to the government, the accumulation of payment arrears to its suppliers, or a combination of all three. Alternatively, the cost of consumer subsidies could be offset by subsidized access to energy inputs, the cost of which would again fall on the government. In practice, the ways in which subsidies are financed and recorded in the budget vary across countries and can change over time. For example, whereas Indonesia, Jordan and Malaysia fully record fuel subsidies in the budget, Sudan and Yemen only partially record subsidies, and all subsidies are off-budget in Angola. In India, the extent to

which fuel subsidies are recorded on budget has varied (Box 2). In sum, in one way or another, someone always pays the cost of subsidies.

Box 2. Financing Fuel Subsidies in India

Domestic fuel prices in India have not kept pace with rising international fuel costs, resulting in consumer price subsidies. Reflecting sharp increases in fuel import prices over 2007 and 2008, subsidies peaked at over 2 percent of GDP in FY 2008/09. As international prices collapsed over the second half of 2008, subsidies also fell sharply to just under 0.9 of a percent of GDP in FY2009/10. However, with the rebound in international prices over the last three years, subsidies again started to escalate, reaching nearly 2 percent of GDP in FY 2011/12.

Fuel subsidies have been financed through a number of channels, including off-budget sources. Subsidies are incurred in the first instance by the predominantly state-owned oil marketing companies (OMCs) who sell fuel products to consumers at subsidized prices. These losses incurred by OMCs have been financed in a variety of ways. In FY 2007/08, just less than one-half of the financing was recorded on budget, with the remaining half financed off budget. On-budget transfers mainly took the form of so-called government "oil bonds" issued to OMCs, while direct budget transfers to OMCs were negligible. Off-budget financing was split between transfers from state-owned enterprises involved in the upstream production of crude oil and OMCs' self-financing. In effect, OMCs used part of the profits from the sale of other unregulated fuel products to offset these subsidy losses. By FY 2011/12, all on-budget financing took the form of direct budget transfers to OMCs, which accounted for around three-fifths of subsidies, with the remainder financed by upstream transfers.

Pre-tax subsidies

8. Subsidies for petroleum products are calculated for 176 countries using the price gap approach drawing on data compiled by IMF staff, the OECD, and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) for 2000–2011. Consumer subsidies are estimated for gasoline, diesel, and kerosene. Producer subsidies to refineries to cover inefficient operations are not estimated due to the lack of data. Therefore, our estimated petroleum product subsidies capture only consumer subsidies and should be seen as a lower bound. See Appendix I for details.

9. Natural gas and coal subsidies are estimated for 56 countries and are largely based on the price gap approach. These data are mostly drawn from the IEA for 2007–2011. Producer subsidies are also included for coal for 16 OECD countries.

10. A number of different methods are used to estimate electricity subsidies for 77 countries. For some countries in Africa, the Middle East, and emerging Europe, estimates of combined producer and consumer subsidies are compiled from various World Bank and IMF reports. For these countries, subsidy estimates are based on average domestic prices, and cost-recovery prices that cover production and investment costs as well as distributional losses and the non-payment of electricity bills. For other countries, consumer price subsidies are taken from IEA which are derived on the basis of the price gap approach.

Post-tax subsidies

11. The benchmark price was also adjusted for corrective taxes and revenue considerations to estimate post-tax subsidies. Rough estimates of corrective taxes, drawing on other studies, were made to account for the effects of energy consumption on global warming; on public health through the adverse effects on local pollution; on traffic congestion and accidents; and on road damage. Estimates of the global warming damages from CO_2 emissions vary widely (see Appendix I). Our estimates assume damages from global warming of $25 per ton of CO_2 emissions, following the United States Interagency Working Group on Social Cost of Carbon (2010), an extensive and widely reviewed study. For final consumption, this price also assumes that energy products are subject to the economy's standard consumption tax rate (an ad valorem tax) on top of the corrective tax. The estimates are based on VAT rates for 150 countries in 2011. For countries without a VAT, the average VAT rate of countries in the region with a similar level of income is assumed.

Caveats

12. These estimates are likely to underestimate energy subsidies and should be interpreted with caution. First, data on producer subsidies are not available for all countries and all products.[8] Second, consumer subsidies for liquefied petroleum gas (LPG) are not included due to lack of data. Third, fuel subsidy estimates are based on a snapshot of prices paid by firms and households at a point in time (end-of-year) or average of end-of-quarter prices when such data are available. Fourth, for electricity, natural gas, and coal, they lack full comparability across countries, since they are drawn from different sources and use different approaches. Fifth, they rely on the assumption of similar transportation and distribution margins across countries. Sixth, in light of these factors, our subsidy estimates may differ from those found in country budget documents (including those reported in the case studies supplement). Seventh, the estimates of corrective taxes are made on the basis of studies for just a few countries and a common assumption regarding how these would vary with country income levels. However, these weaknesses are outweighed by the merits of constructing a broad picture of the magnitude of energy subsidies across as many countries and products as possible.

Magnitude of energy subsidies

13. Global pre-tax energy subsidies are significant. The subsidy estimates capture both those that are explicitly recorded in the budget and those that are implicit and off-budget. The evolution of energy subsidies closely mimics that of international energy prices (Figure 2). Although subsidies declined with the collapse of international energy prices, they have started to escalate since 2009. In 2011, global pre-tax subsidies reached $480 billion (0.7 percent of global GDP or 2 percent of total government revenues). Petroleum and electricity subsidies accounted for about 44 percent and

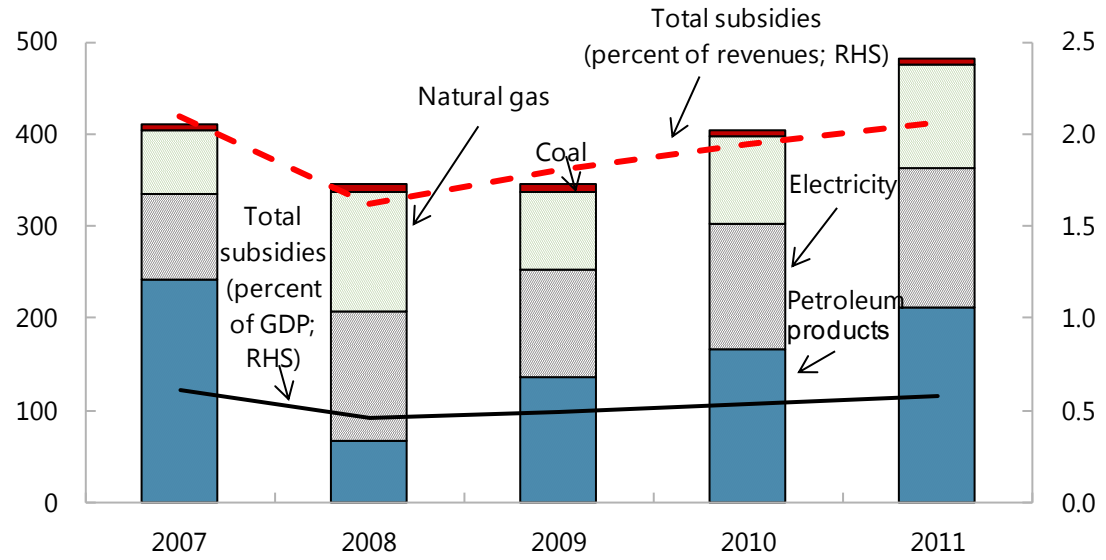
[8]In practice, identifying producer subsidies can be especially difficult since these often take the form of differential tax treatment and tax exemptions for specific sectors.

31 percent of the total respectively, with most of the remainder coming from natural gas. Coal subsidies are relatively small at $6½ billion.

Figure 2. Pre-tax Energy Subsidies, 2007–2011[1]

(Billions of U.S. dollars)

Energy subsidies have surged since the 2008–09 crisis and closely mimic changes in international prices.



Sources: Staff estimates, Organisation for Economic Co-operation and Development, International Energy Agency, Deutsche Gesellschaft für Internationale Zusammenarbeit, IMF *World Economic Outlook*, and World Bank.

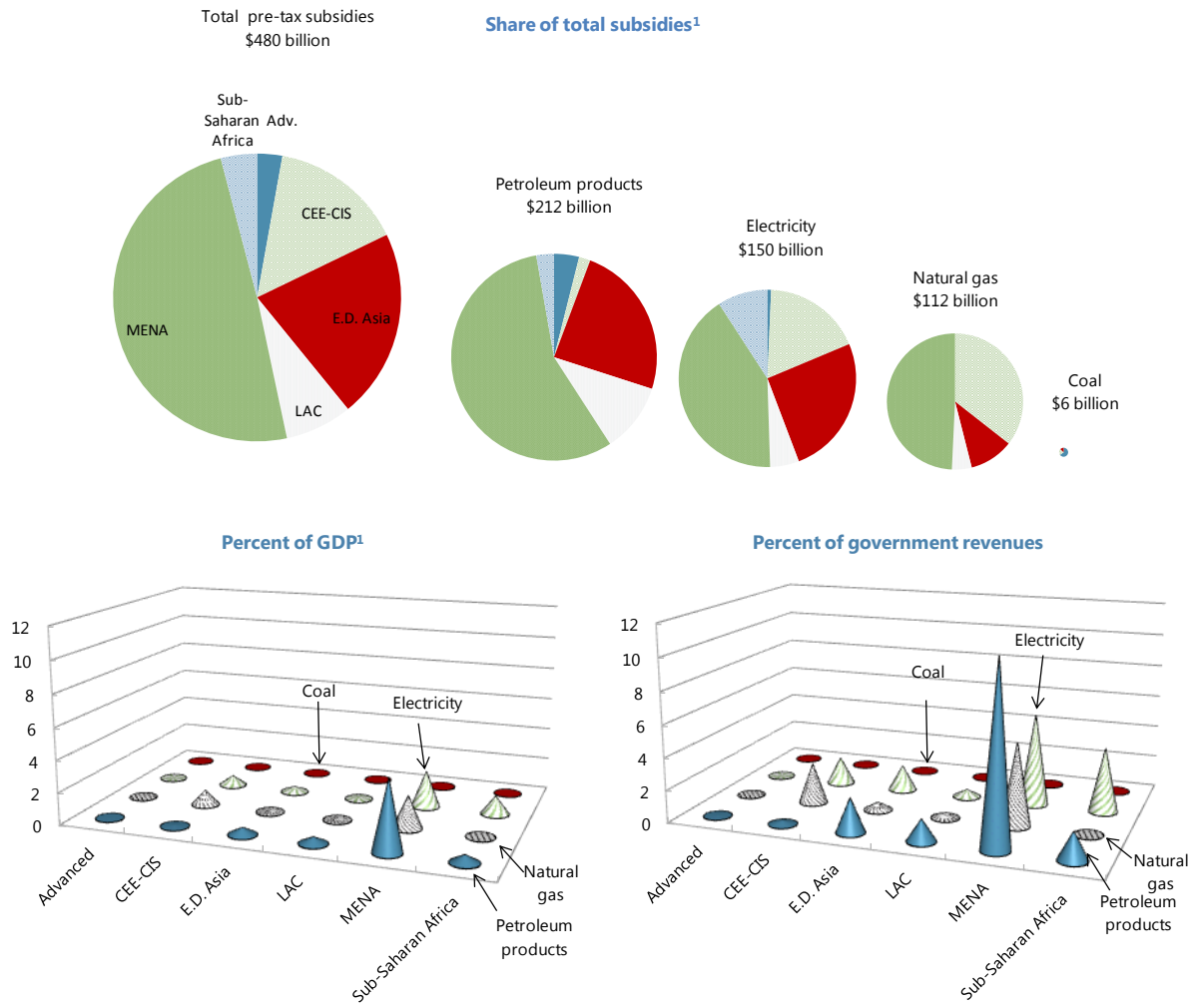
[1]Data are based on most recent year available. Total subsidies in percent of GDP and revenues are calculated as total identified subsidies divided by global GDP and revenues, respectively.

14. Pre-tax subsidies are concentrated in developing and emerging economies. Oil exporters—most of which are developing or emerging economies—tend to have the largest subsidies. This finding holds not only when measuring subsidies in absolute terms, but also as a share of GDP and on a per capita basis.

- The **Middle East and North Africa** region accounted for about 50 percent of global energy subsidies (Figure 3, Appendix Table 2). Energy subsidies totaled over 8½ percent of regional GDP or 22 percent of total government revenues, with one-half reflecting petroleum product subsidies. The regional average masks significant variation across countries. Of the 20 countries in the region, 12 have energy subsidies of 5 percent of GDP or more. Subsidies are high in this region for both oil- exporters and importers (Figure 4).

Figure 3. Pre-tax Energy Subsidies by Region, 2011

Energy subsidies are concentrated mostly in Middle East/North Africa, Central/Eastern Europe, and Emerging and Developing Asia.



Sources: Staff estimates, Organisation for Economic Co-operation and Development, International Energy Agency, Deutsche Gesellschaft für Internationale Zusammenarbeit, IMF *World Economic Outlook*, and World Bank.

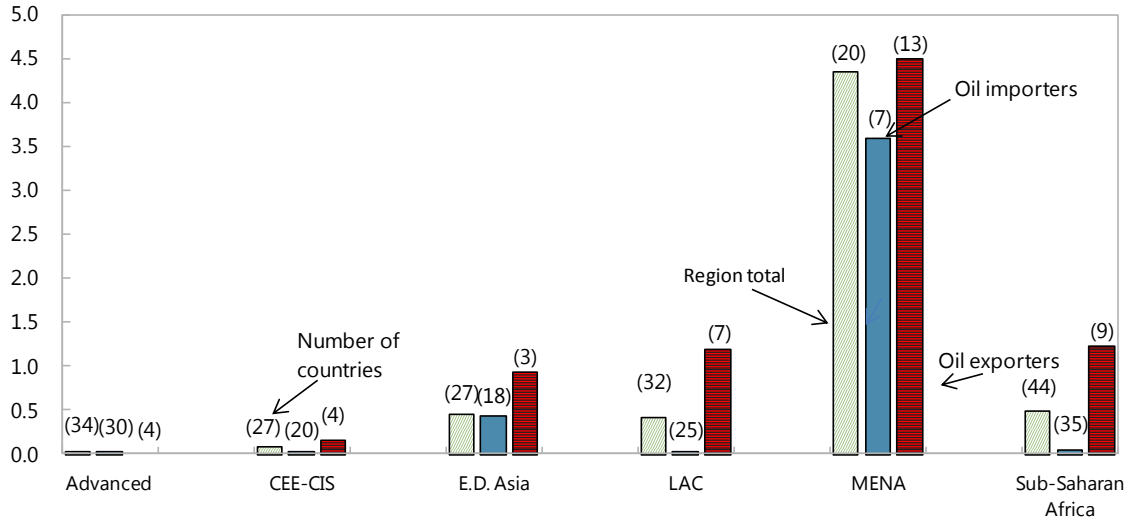
Note: Adv.=Advanced, CEE-CIS=Central and Eastern Europe and Commonwealth of Independent States, LAC=Latin America and Caribbean, S.S. Africa=Sub-Saharan Africa, MENA=Middle East and North Africa, and E.D. Asia=Emerging and Developing Asia.

[1]Data for electricity are for the most recent year available. Subsides in percent of GDP and revenues are calculated as identified subsidies divided by regional GDP and revenues, respectively.

Figure 4. Pre-tax Petroleum Subsidies Among Petroleum Importing and Exporting Countries, 2011

(Percent of GDP)

Petroleum product subsidies are systematically higher for oil exporters.



Sources: Staff estimates, Organisation for Economic Co-operation and Development, International Energy Agency, Deutsche Gesellschaft für Internationale Zusammenarbeit, IMF *World Economic Outlook*, and World Bank.

Note: CEE-CIS=Central and Eastern Europe and Commonwealth of Independent States, LAC=Latin America and Caribbean, MENA=Middle East and North Africa, and E.D. Asia=Emerging and Developing Asia.

Subsidies in percent of GDP are calculated as identified subsidies divided by regional GDP.

Number of countries in each category indicated in parentheses.

- Countries in **Emerging and Developing Asia** were responsible for over 20 percent of global energy subsidies. They amounted to nearly 1 percent of regional GDP or 4 percent of total government revenues, with petroleum products and electricity accounting for nearly 90 percent of subsidies. Energy subsidies exceeded 3 percent of GDP in four countries (Bangladesh, Brunei, Indonesia, and Pakistan).

- The **Central and Eastern Europe and CIS** accounted for about 15 percent of global energy subsidies, including the highest share (at nearly 36 percent) of global natural gas subsidies. Energy subsidies amounted to over 1½ percent of regional GDP or 4½ percent of total government revenues, with natural gas and electricity accounting for about 95 percent. They exceeded 5 percent of GDP in four countries (Kyrgyz Republic, Turkmenistan, Ukraine, and Uzbekistan).

- The **Latin America and Caribbean** made up over 7½ percent of global energy subsidies (approximately ½ percent of regional GDP or 2 percent of total government revenues), with petroleum subsidies accounting for nearly 65 percent. Energy subsidies exceeded 5 percent of GDP in two countries (Ecuador and Venezuela).

- **Sub-Saharan Africa** accounted for about 4 percent of global energy subsidies. Energy subsidies amounted to 1½ percent of regional GDP or 5½ percent of total government revenues, with electricity subsidies accounting for over 70 percent. Total subsidies exceeded 4 percent of GDP in three countries (Mozambique, Zambia, and Zimbabwe).

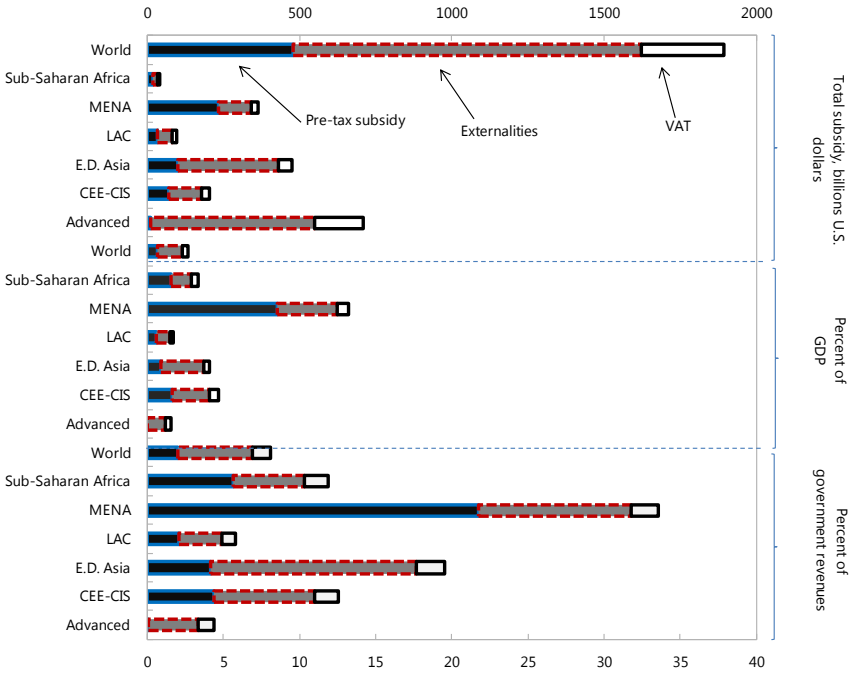
- The only **advanced economy** where energy subsidies were a non-negligible share of GDP was Taiwan Province of China at 0.3 percent of GDP (electricity).

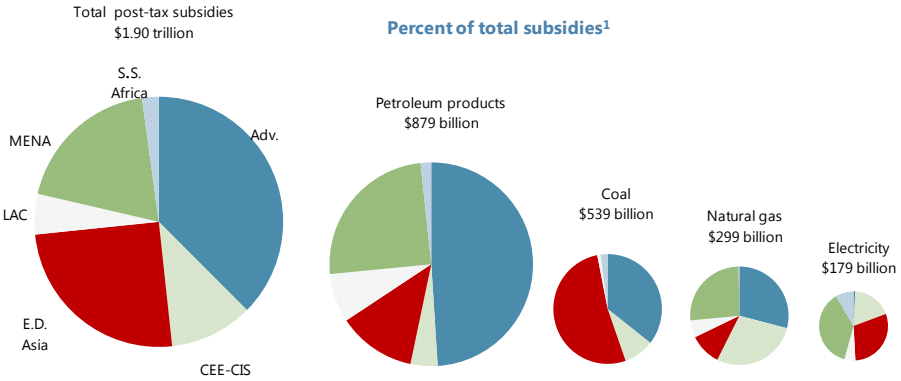
15. In summary, pre-tax subsidies are pervasive and impose significant fiscal costs in most developing and emerging regions. They are most prominent in Middle East and North Africa, especially among oil exporters. Given that energy consumption can be expected to rise as incomes grow, the size of subsidies could climb in regions where they currently account for a small share of the global total, such as sub-Saharan Africa.

16. Post-tax energy subsidies are much larger than pre-tax subsidies, amounting to $1.9 trillion in 2011—about 2½ percent of global GDP or 8 percent of total government revenue. Virtually all of the world's economies provide energy subsidies of some kind when measured on a tax-inclusive basis, including 34 advanced economies. For some products, such as coal, post-tax subsidies are substantial because prices are far below the levels needed to address negative environmental and health externalities. The fact that energy products are taxed much less than other products also contributes to the high level of post-tax subsidies. In MENA, for example, applying the same rate of VAT or sales taxes to energy products as other goods and services would generate ¾ percent of GDP. Of the global total, pre-tax subsidies account for about one-quarter, and tax subsidies account for about three-quarters (Figure 5). The advanced economies account for about 40 percent of the global total. The top three subsidizers across the world, in absolute terms, are the United States ($502 billion), China ($279 billion), and Russia ($116 billion).

Figure 5. Adjustment of Energy Subsidies for Taxes and Externalities, 2011

Energy subsidies increase substantially when externalities and tax considerations are taken on board.





Sources: Staff estimates, Organisation for Economic Co-operation and Development, International Energy Agency, Deutsche Gesellschaft für Internationale Zusammenarbeit, IMF *World Economic Outlook*, and World Bank.

Note: VAT refers to the tax subsidy provided when energy products are taxed by less than the economy's standard VAT rate (see Appendix I).

Note: Adv.=Advanced, CEE-CIS=Central and Eastern Europe and Commonwealth of Independent States, LAC=Latin America and Caribbean, S.S. Africa=Sub-Saharan Africa, MENA=Middle East and North Africa, and E.D. Asia=Emerging and Developing Asia.

[1]Estimates for electricity are for the most recent year available. Subsidies in percent of GDP and revenues are calculated as identified subsidies divided by global or regional GDP and revenues, respectively.

B. Macroeconomic, Environmental, and Social Implications

17. Energy subsidies depress growth through a number of channels. The effects of subsidies on growth goes beyond their adverse impact on fiscal balances and public debt (Rogoff and Reinhart, 2010; Kumar and Woo, 2010):

- *Subsidies can discourage investment in the energy sector.* Low and subsidized prices for energy can result in lower profits or outright losses for producers, making it difficult for SOEs to expand energy production and unattractive for the private sector to invest both in the short and long run (Box 3). The result is severe energy shortages that hamper economic activity.[9]

Box 3. Electricity Subsidies and Growth in Sub-Saharan Africa

Electricity subsidies in sub-Saharan Africa (SSA) are substantial and primarily reflect high costs of production. The average cost of subsidized electricity prices in a sample of 30 countries was 1.7 percent of GDP, and in 12 countries it exceeded 2 percent of GDP. On average, the effective tariff in SSA was only about 70 percent of the cost-recovery price during 2005–09. The primary driver of high subsidies has been high costs, rather than low retail prices—residential tariffs in SSA countries are much higher than in other regions of the world. High costs stem from operational inefficiencies, extensive use of back-up electricity generation, low economies of scale in generation, and limited regional integration. Therefore, in addition to increasing tariffs, reducing subsidies will require improving operational efficiency and modernizing electricity operations.

The losses incurred by electricity suppliers due to subsidized prices have severely constrained their ability to invest in new electricity capacity and improve service quality. As a result, installed per capita generation capacity in SSA (excluding South Africa) is about one-third of that of South Asia and one-tenth of that in Latin America. Similarly, per capita consumption of electricity in SSA (excluding South Africa) is only 10 kWh per month, compared with roughly 100 kWh in developing countries and 1,000 kWh in high-income countries.

Deficient electricity infrastructure and shortages dampen economic growth and weaken competitiveness. Weaknesses in electricity infrastructure are correlated with low levels of productivity (Escribano, Guasch, and Pena, 2008). For example, potential efficiency gains in electricity generation and distribution could reduce costs in the sector by more than 1 percentage point of GDP for at least 18 SSA countries. Simulations based on panel data in Calderón (2008) suggest that if the quantity and quality of electricity infrastructure in all SSA countries were improved to that of a better performer (such as Mauritius), long-term per capita growth rates would be 2 percentage points higher.

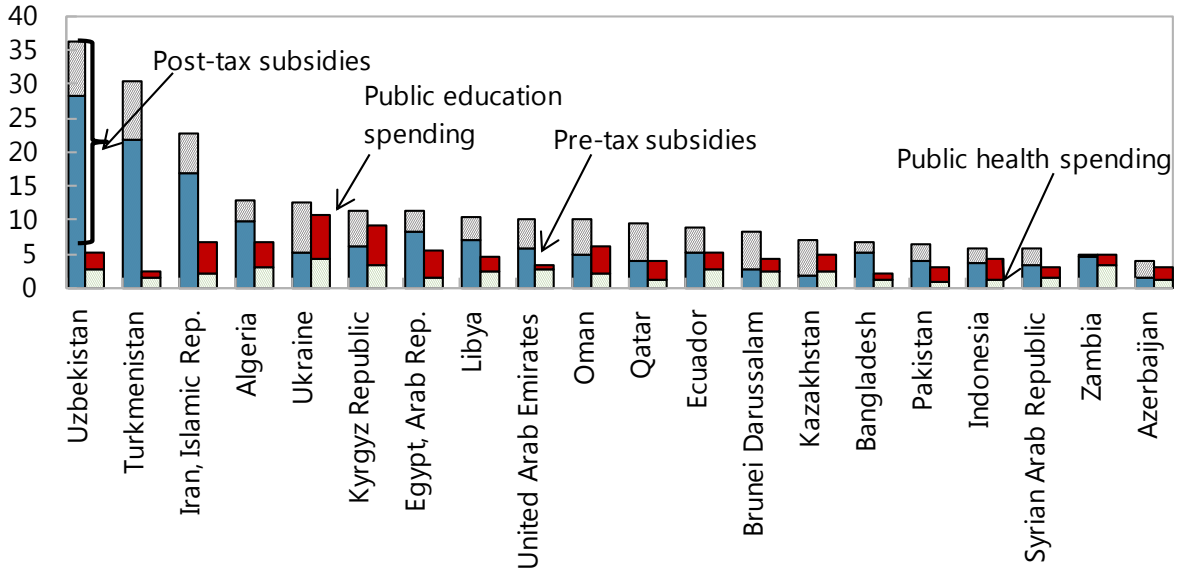
[9]Both households and firms spend considerable amounts to address electricity shortages, including through the purchase of generators. For example, in the Republic of Congo private household and enterprise generator capacity is nearly double the public generation capacity. The cost of own generation by firms is estimated in the range of $0.3–$0.7 per kWh—about three to four times as high as the price of electricity from the public grid (Foster and Steinbuks, 2008). These costs are even higher for households because of the smaller generators they use.

- *Subsidies can crowd out growth-enhancing public spending*. Some countries spend more on energy subsidies than on public health and education (Figure 6). Reallocating some of the resources freed by subsidy reform to more productive public spending could help boost growth over the long run.

Figure 6. Post-tax Subsidies and Social Spending, 2010

(Percent of GDP)

Subsidies are substantially higher than critical social spending in many countries.



Sources: International Energy Agency; World Bank; Clements, Gupta, and Nozaki (2012); IMF staff estimates; and Organisation for Economic Co-operation and Development.

Note: Health and education spending are for 2010 or latest available.

- *Subsidies diminish the competitiveness of the private sector over the longer term.* Although in the short-run subsidy reform will raise energy prices and increase production costs, over the longer term there will be a reallocation of resources to activities that are less energy and capital intensive and more efficient (Box 4), helping spur the growth of employment. Removing energy subsidies helps prolong the availability of non-renewable energy resources over the long term and strengthens incentives for research and development in energy-saving and alternative technologies. Subsidy reform will crowd-in private investment, including in the energy sector, and benefit growth over the longer term.

- *Subsidies create incentives for smuggling.* If domestic prices are substantially lower than those in neighboring countries, there are strong incentives to smuggle products to higher-priced destinations. Illegal trade increases the budgetary cost for the subsidizing country while limiting the ability of the country receiving smuggled items to tax domestic consumption of energy. Fuel smuggling is a widespread problem in many regions around the world including in North America, North Africa, and the Middle East, parts of Asia, and Africa. For example, Canadians buy

cheap fuel in the United States; Algerian fuel is smuggled into Tunisia; Yemeni oil is smuggled into Djibouti; and Nigerian fuel is smuggled into many West African countries (Heggie and Vickers, 1998).[10]

Box 4. Energy Subsidy Reform and Competitiveness

The short-run effects of higher energy prices on competitiveness depend on the energy intensity of traded sectors and developments in energy prices in competing countries. Increases in energy prices to reduce subsidies—or avoid the emergence of subsidies in periods of rising international prices—increase production costs. The effects on costs will vary by sector, depending on both their direct use of energy (e.g., fuel products) and indirect use (e.g., the higher costs of intermediate inputs that use fuel) (Gupta, 1983; Dick and others, 1984). Higher fuel prices, for example, can lead to higher electricity prices, which in turn will affect costs and output in manufacturing (e.g., Clements, Jung, and Gupta, 2007). The use of input-output tables can often be helpful to trace the direct and indirect effects of higher energy prices on costs and competitiveness and to quantify which sectors will be most affected. The effect of higher energy prices on competitiveness depends on developments in energy prices in countries competing for the same markets. If all countries pass on the increase in international prices to domestic prices, for example, the effects on production costs may be similar across countries.

The adverse effects on competitiveness, at the aggregate level, can be reduced if appropriate macroeconomic policies are in place. The extent to which higher energy costs result in a persistently higher price level and an adverse effect on competitiveness will depend on the strength of "second round" effects on wages and the prices of other inputs (Fofana, Chitiga, and Mabugu, 2009). If prices rise relative to those in trading partners, the real exchange rate will appreciate, reducing competitiveness. These second-round effects can be contained with appropriate monetary and fiscal policies that help anchor inflationary expectations (IMF, 2012a). Subsidy reform helps support an appropriate fiscal policy response by reducing budget deficits and helping contain demand pressures on prices. Flexible exchange rate regimes also mitigate the impact of volatile international prices on economic growth (IMF, 2008b).

The resources freed from subsidy reform can boost competitiveness over the longer term. Subsidy reform can contribute to lower budget deficits and interest rates, thus stimulating private investment (Fofana, Chitiga, and Mabugu, 2009; Clements, Jung, and Gupta, 2007). Furthermore, if part of the freed resources is invested in productivity-enhancing public spending, growth dividends can be high (Breisinger, Engelke, and Ecker, 2011; Lofgren, 1995). By removing distortions in price signals, subsidy reform can help reallocate resources toward their best use and improve incentives to adopt energy-saving technologies. Not all sectors will benefit from subsidy reform over the longer term, because those that cannot adapt to higher energy prices will suffer a loss of competitiveness. Yet in the aggregate, the effects on competitiveness are positive. Empirical estimates suggest that higher investment in more efficient and energy-saving technologies could boost growth by up to 1 percent over the long term (Burniaux and others, 2009; Ellis, 2010; UNEP, 2008; and von Moltke, McKee, and Morgan, 2004).

[10] In 2011, it was estimated that more than 80 percent of gasoline consumed in Benin was smuggled from Nigeria (IMF, 2012c).

18. Energy subsidies exacerbate the difficulties of both oil importers and exporters in dealing with the volatility of international energy prices. The balance of payments of many energy-importing countries is vulnerable to international price increases (IMF, 2008b).[11] The adverse impact can be mitigated by passing through international price increases and by providing greater incentives for improving energy efficiency and lowering energy consumption (Dudine and others, 2006).[12] The volatility of subsidies also complicates budget management. For oil exporters, energy subsidies accentuate macroeconomic volatility by increasing subsidies during periods of international price increases (Gelb and others, 1988). Allowing domestic prices to rise with international prices can help cool off domestic demand during commodity booms and build up fiscal buffers for use during periods of declining prices. To offset concerns about the transmission of high international price volatility to domestic prices, some smoothing of price increases can be considered (see paragraph 45).

19. The negative externalities from energy subsidies are substantial. Subsidies cause over-consumption of petroleum products, coal, and natural gas, and reduce incentives for investment in energy efficiency and renewable energy. This over-consumption in turn aggravates global warming and worsens local pollution. The high levels of vehicle traffic that are encouraged by subsidized fuels also have negative externalities in the form of traffic congestion and higher rates of accidents and road damage. The subsidization of electricity can also have indirect effects on global warming and pollution, but this will depend on the composition of energy sources for electricity generation. The subsidization of diesel promotes the overuse of irrigation pumps, resulting in excessive cultivation of water-intensive crops and depletion of groundwater.

20. Eliminating energy subsidies would generate substantial environmental and health benefits. To illustrate the impact of subsidies on global warming and local pollution, the effects of raising energy prices to levels that would eliminate tax-inclusive subsidies for petroleum products, natural gas, and coal were estimated (see Appendix II).[13] The results suggest that this reform would reduce CO_2 emissions by 4½ billion tons, representing a 13 percent decrease in global energy-related CO_2 emissions. Eliminating subsidies would also generate significant health benefits by reducing local pollution from fossil fuels in the form of SO_2 and other pollutants. In particular, this reform would result in a reduction of 10 million tons in SO_2 emissions and a 13 percent reduction in other local pollutants.

[11]IMF (2008b) estimated that a 20 percent increase in international oil prices would reduce international reserves in developing economies by more than half a month of imports.

[12]Based on a review of 124 developed and developing countries, Dahl (2012) estimates a range of values for the demand price elasticity between -0.11 and -0.33 for gasoline, and between -0.13 and -0.38 for diesel. Long-run price elasticities are estimated to be larger than those found for the short-term. For developed countries, Goodwin and others (2004) found a mean price elasticity for fuel consumption ranging from -0.25 (short run) to -0.64 (long run).

[13]The impact of electricity subsidy removal is not assessed due to data limitations.

21. The over-consumption of energy products due to subsidies can also have effects on global energy demand and prices. The multilateral removal of pre-tax fuel subsidies in non-OECD countries, under a gradual phasing-out, would reduce world prices for crude oil, natural gas, and coal by 8 percent, 13 percent, and 1 percent respectively in 2050 relative to the no-change baseline (OECD, 2009; IEA, 2011c). The reduction would be substantially larger if prices were raised to levels that eliminated subsidies on a post-tax basis. These spillover effects suggest that non-subsidizers would share the gains from subsidy reform, as well as extending the availability of scarce natural resources.

C. Equity Implications

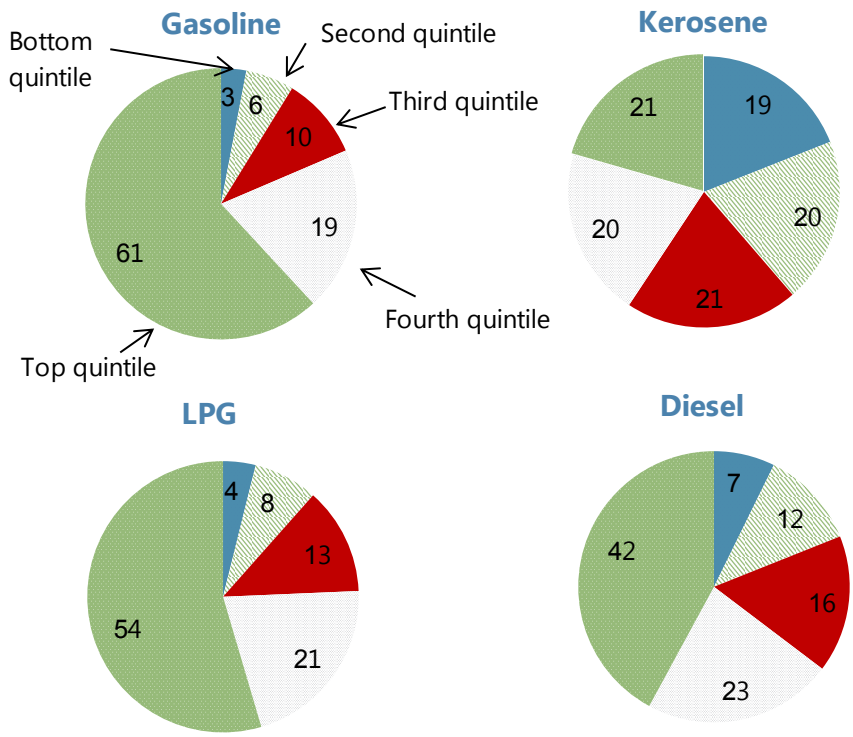
22. Energy subsidies are highly inequitable because they mostly benefit upper-income groups. Energy subsidies benefit households both through lower prices for energy used for cooking, heating, lighting and personal transport, but also through lower prices for other goods and services that use energy as an input. On average, the richest 20 percent of households in low- and middle-income countries capture six times more in total fuel product subsidies (43 percent) than the poorest 20 percent of households (7 percent) (Figure 7). The distributional effects of subsidies vary markedly by product, with gasoline being the most regressive (i.e., subsidy benefits increase as income increases) and kerosene being progressive. Subsidies to natural gas and electricity have also been found to be badly targeted, with the poorest 20 percent of households receiving 10 percent of natural gas subsidies and 9 percent of electricity subsidies (IEA, 2011a). While subsidies primarily benefit upper-income groups, a sharp increase in energy prices can nevertheless have a significant impact on the budgets of poor households, both directly through the removal of the subsidies and indirectly through the reduction in real income because of higher consumer prices. For example, a $0.25 per liter increase in fuel prices can reduce real consumption of the poorest 20 percent of households by about 5½ percent (Arze del Granado, Coady, and Gillingham, 2012). This underscores the need for mitigating measures to ensure that fuel subsidy reform does not result in increased poverty (Sterner, 2012). In the case of electricity, the ability to differentiate tariff levels according to consumption levels (e.g., a lifeline tariff) can help protect low-income groups during electricity subsidy reforms. Nevertheless, such subsidies do not reach poor households who have no access to electricity, which limits their progressivity. Only 30 percent of households, for example, are connected to the grid in sub-Saharan Africa (IFC, 2012).

23. Energy subsidies divert public resources away from spending that is more pro-poor. In many subsidizing countries, equity could be improved by reallocating outlays toward better-targeted programs in health, education, and social protection. Over the longer term, the removal of subsidies, accompanied by a well designed safety net and an increase in pro-poor spending, could yield significant improvements in the well-being of low-income groups. In oil-exporting countries, subsidies are often used as a tool for sharing oil wealth with its citizens. But given the high share of benefits that accrues to upper-income groups, the inefficiencies that subsidies create in resource allocation, and in some countries the large share of the expatriate population, energy subsidies are a much less effective policy instrument for distributing wealth than other public spending programs.

Figure 7. Distribution of Petroleum Product Subsidies by Income Groups

(Percent of total product subsidies)

The distribution of subsidies varies across products, with gasoline being the most regressive and kerosene progressive.



Source: Arze del Granado and others, 2012.

REFORMING ENERGY SUBSIDIES: LESSONS FROM EXPERIENCE

A. Overview

24. This section provides insights from country case studies to identify ingredients for successful subsidy reform. The country case studies include both successful and unsuccessful subsidy reform episodes over the past two decades across a broad range of countries and different energy products. A total of 22 country case studies were undertaken covering 28 major reform episodes (Table 1 and supplement). These involve episodes in which governments attempted to reduce the fiscal burden of subsidies by raising energy prices to households and firms or improving the efficiency of state-owned enterprises in the energy sector. They contain cases where governments attempted to reduce pre-tax subsidies but also where governments sought to restore energy taxation to levels that had prevailed prior to increases in international energy prices and to levels needed to eliminate post-tax subsidies.[14] The studies include cases where countries successfully implemented reforms that led to a permanent and sustained reduction of subsidies (success); those which achieved a reduction of subsidies for at least a year, but where subsidies have reemerged or remain a policy issue (partial success); and subsidy reforms that failed, with price increases or efforts to improve efficiency in the energy sector being rolled back soon after the reform began (unsuccessful). Out of the 28 reform episodes, 12 were classified as a success, 11 as a partial success—often because of reversals or incomplete implementation—and five as unsuccessful. Out of the 22 case studies, 14 address fuel subsidy reform, seven electricity sector reform, and one involves coal sector reform. The studies cover seven countries from sub-Saharan Africa, two countries in emerging and developing Asia, three countries in the Middle East and North Africa, four countries in Latin America and the Caribbean, and three countries in Central and Eastern Europe and the CIS. In 14 of the 28 episodes, an IMF-supported program was in place, and in all but two the program contained conditionality on energy subsidy reform.

25. The selection of countries for the case studies reflects the availability of data and of previously documented evidence on country-specific reforms. The larger number of studies on fuel subsidies reflects the wider availability of data and past studies of these reforms. The countries were chosen to ensure coverage of different regions of the world and a mix of reform outcomes.

[14]For instance, as a result of subsidy reforms over the late 1980s and the 1990s, Turkey has eliminated subsidies on a post-tax basis.

Table 1. Summary of Country Energy Subsidy Reform Episodes

Region/Country	Energy product	Reform episode	Reform outcome	Reform impact	IMF-supported program during the reform episode	Conditionality on energy subsidy reform
CEE-CIS						
Turkey	Fuel	1998	Successful	SOEs turned from net loss to net profitability	Yes	Yes
Armenia	Electricity	Mid-1990s	Successful	Electricity sector financial deficit declined from 22 percent of GDP in 1994 to zero after 2004	Yes	Yes
Turkey	Electricity	1980s	Successful	Generated additional revenues for maintenance	Yes	Yes
Poland	Coal	1990–1998	Unsuccessful	n.a.	Yes	Yes
	Coal	1998	Successful	The industry became financially viable and achieved substantial reduction in government transfer	No	
Emerging and Developing Asia						
Indonesia	Fuel	1997	Unsuccessful	n.a.	Yes	Yes
	Fuel	2003	Unsuccessful	n.a.	No	
	Fuel	2005	Partially successful	Subsidies declined from 3.5 percent of GDP in 2005 to 1.9 percent in 2006	No	
	Fuel	2008	Partially successful	Subsidies declined from 2.8 percent of GDP in 2008 to 0.8 percent in 2009	No	
Philippines	Fuel	1996	Successful	0.1+ percent of GDP	Yes	Yes
Philippines	Electricity	2001	Successful	Subsidies declined from 1.5 percent of GDP in 2004 to zero in 2006	No	
LAC						
Brazil	Fuel	Early 1990s–2001	Successful	From 0.8 percent of GDP in subsidies in mid-1990s to revenue generating since 2002	Yes	Yes
Chile	Fuel	Early 1990s	Successful	n.a.	No	
Peru	Fuel	2010	Partially successful	0.1 percent of GDP	No	
Brazil	Electricity	1993–2003	Successful	0.7 percent of GDP	Yes	Yes
Mexico	Electricity	1999/2001/2002	Unsuccessful	n.a.	Yes	No
MENA						
Iran	Fuel	2010	Partially successful	Growth in the consumption of petroleum products initially stabilized	No	
Mauritania	Fuel	2008	Unsuccessful	n.a.	Yes	No
	Fuel	2011	Partially successful	Subsidies declined from 2 percent of GDP in 2011 to close to zero in 2012	Yes	Yes
Yemen	Fuel	2005	Partially successful	Subsidies declined from 8.7 percent of GDP in 2005 to 8.1 percent in 2006	No	
	Fuel	2010	Partially successful	Subsidies declined from 8.2 percent of GDP in 2010 to 7.4 percent in 2011	Yes	Yes
Sub-Saharan Africa						
Ghana	Fuel	2005	Partially successful	50 percent price increase on average	No	
Namibia	Fuel	1997	Partially successful	0.1+ percent of GDP	No	
Niger	Fuel	2011	Partially successful	0.9 percent of GDP	No	
Nigeria	Fuel	2011–12	Partially successful	Subsidies declined from 4.7 percent of GDP in 2011 to 3.6 percent in 2012	No	
South Africa	Fuel	1950s	Successful	Successfully avoided subsidies and secured supply	No	
Kenya	Electricity	Mid-1990s	Successful	Subsidies declined from 1.5 percent of GDP in 2001 to zero in 2008	Yes	Yes
Uganda	Electricity	1999	Successful	2.1 percent of GDP	Yes	Yes

Source: IMF staff.

Note: n.a.=not applicable.

Note: CEE-CIS=Central and Eastern Europe and Commonwealth of Independent States, LAC=Latin America and Caribbean, S.S. Africa=Sub-Saharan Africa, and MENA=Middle East and North Africa.

The findings from the country studies identified in Table 1 are complemented with the insights from additional country studies conducted previously by the IMF and others, including Gupta and others (2000); Coady and others (2006); IMF (2008b); Coady and others (2010); Global Subsidies Initiative (2010); the UNEP (2002 and 2008); World Bank (2010); Vagliasindi (2012); and Arze del Granado, Coady, and Gillingham (2012).[15] They also draw on lessons from technical assistance reports on energy subsidies undertaken by the Fiscal Affairs Department.[16]

B. Barriers to Reform

26. Country reform experiences suggest a number of barriers to successful subsidy reform. While there is no single recipe for success, addressing these barriers, which vary from country to country, can increase the likelihood of reforms achieving their objectives and help avoid policy reversals.

- ***Lack of information regarding the magnitude and shortcomings of subsidies.*** The full fiscal cost of energy subsidies—including both producer and consumer subsidies—are rarely reflected in the budget. This is especially the case for oil exporters, since the subsidies provided by low energy prices are often implicit, i.e., not explicitly recorded in the budget.[17] Populations are also often unaware of how domestic energy prices compare with international market prices, the consequences of low energy prices for both the budget and economic efficiency, and the benefit distribution of energy subsidies. As a result, the public is unable to make a connection between subsidies, constraints on expanding high-priority public spending, and the adverse effects of subsidies on economic growth and poverty reduction. This is especially important for oil exporters, where subsidies are very large. Out of the 28 reform episodes, 17 indicate that the lack of information was a barrier to reform, including fuel subsidy reforms in Ghana, Mexico, Nigeria, the Philippines, Uganda, and Yemen, and electricity subsidy reforms in Mexico and Uganda. Most countries that successfully reformed energy subsidies undertook an evaluation of the magnitude of energy subsidies prior to implementing subsidy reforms. Public discussions based on such studies were an important component of the information campaigns in fuel subsidy reforms in Ghana, Namibia, and the Philippines.

- ***Lack of government credibility and administrative capacity.*** Even where the public recognizes the magnitude and shortcomings of energy subsidies, it often has little confidence that the government will use savings from subsidy reform wisely. This is especially true in countries with a history of widespread corruption, lack of transparency in the conduct of public policy, and perceived inefficiencies in public spending. The middle class may fiercely resist the

[15]The case studies do not disentangle the effects of subsidy reform on macroeconomic variables such as inflation and the real exchange rate. This would require isolating these effects over the period in which subsidy reforms were implemented, which on average was five years.

[16]Over the past five years, there were 19 technical assistance missions to member countries addressing the issue of energy subsidy reform. About one third of these missions were to sub-Saharan Africa and another third to the MENA region.

[17]Gupta and others (2004) estimate implicit subsidies in oil exporters at 3½ percent of GDP, on average, in 1999.

removal of these subsidies because they are viewed as one of the few concrete benefits they receive from the state. This is especially the case for oil exporters that have ample fiscal resources yet lack the administrative capacity to implement cash transfer programs. Lack of credibility was seen as an important factor behind the less successful fuel subsidy reforms in Indonesia in 2003 and Nigeria in 2011.

- ***Concerns regarding the adverse impact on the poor.*** Although most of the benefits from energy subsidies are captured by higher-income groups, as noted earlier, energy price increases can still have a substantial adverse impact on the real incomes of the poor, both through higher energy costs of cooking, heating, lighting, and personal transport, as well as higher prices for other goods and services, including food. This is an important consideration for countries that do not have a well-functioning social safety net that is capable of effectively protecting the poor from the adverse impact of higher energy prices. In 20 episodes, subsidy reform was accompanied by specific measures to mitigate the impact of price increases on the poor. In seven episodes, price increases were initially concentrated on products that were less important for poor household budgets.

- ***Concerns regarding the adverse impact on inflation, international competitiveness, and volatility of domestic energy prices.*** Increases in energy prices will have short-term effects on inflation, which may give rise to expectations of further increases in prices and wages unless appropriate macroeconomic policies are in place (Box 4). This may especially be a concern for countries that have difficulty in anchoring inflation expectations. Higher energy prices may also lead to concerns about the international competitiveness of energy-intensive sectors. In addition, countries are hesitant to liberalize energy prices in order to avoid high volatility in domestic prices arising from international price developments. In Armenia, the impact of electricity price increases on inflation was mitigated by the implementation of macroeconomic stabilization measures. In Iran and Nigeria, fuel subsidy reform was accompanied by specific measures intended to mitigate the impact of price increases on energy-intensive sectors.

- ***Opposition from specific interest groups benefiting from the status quo.*** Politically vocal groups that benefit from subsidies can be powerful and well organized and can block reforms. For example, in some countries the urban middle class and industrial sector (which also benefits from subsidies) can be an obstacle to reform. On the other hand, those benefitting from reform are often dispersed and less organized. Reform strategies therefore need to address the concerns of the losers. In Poland, initial mining sector reforms were unsuccessful because they did not provide adequate support for miners. In Mexico, strong opposition from labor unions contributed to the failure of the electricity sector reform. An important stumbling block to reform in many countries is often SOEs in the energy sector, which can resist efforts to strengthen governance and performance.

- ***Weak macroeconomic conditions.*** Public resistance to subsidy reform is lower when economic growth is relatively high and inflation is low—although subsidy reform cannot always be postponed and is often required as part of efforts to constrain inflation and stimulate growth. Rising household incomes can help households better afford the increases in energy prices

entailed by subsidy reform. In Peru, the implementation of subsidy reforms in early 2010 during a period of stable prices and strong economic growth helped make the reform politically more palatable. In Turkey, reforms of the electricity sector coincided with a period of economic growth and improving standards of living, which assured the public that reforms were moving the country in the right direction. High inflation is also an obstacle to reform. When inflation is high, frequent large changes in controlled prices are needed to avoid the emergence of fuel subsidies (as in Brazil).

C. Designing a Subsidy Reform Strategy

27. Many countries have incorporated specific measures into their subsidy reform strategies to overcome the above barriers. Staff's review of country reform experiences suggests the following key elements can increase the likelihood of successful subsidy reform:
(i) a comprehensive reform plan; (ii) a far-reaching communications strategy, aided by improvements in transparency; (iii) appropriately phased energy price increases, which can be sequenced differently across energy products; (iv) improving the efficiency of SOEs to reduce producer subsidies; (v) targeted mitigating measures to protect the poor; and (vi) depoliticizing energy pricing to avoid the recurrence of subsidies. Each of these elements is discussed in turn below in more detail.

(i) Comprehensive reform plan

28. Most of the successful reforms were well planned with a clear reform strategy. In Iran, the 2010 fuel subsidy reform incorporated clear objectives, compensating measures, and a timetable for reform, preceded by an extensive public relations campaign. The public information campaign emphasized that the main objective of the reform was to replace price subsidies with cash transfers to reduce incentives for excessive energy consumption and smuggling. Bank accounts were opened for most citizens prior to the reform and compensating cash transfers deposited into these accounts preceding the implementation of price increases. In Namibia, the authorities undertook comprehensive planning, with broad consultation with civil society and a well-crafted plan that included the introduction of a fuel price adjustment mechanism and a targeted subsidy for those living in remote areas. A clear medium-term reform strategy backed by careful planning was also a major factor behind the successful electricity price liberalization reforms in the Philippines and Turkey. By contrast, the lack of effective planning contributed to less successful outcomes in some countries (fuel subsidy reform in Indonesia in 1998 and only partial success in Nigeria in 2011). A good reform plan often requires extensive time to prepare, as in Iran.

29. A comprehensive reform plan requires establishing clear long-term objectives, assessing the impact of reforms, and consulting with stakeholders.

***Clear long-term objectives*.** Subsidy reforms are more likely to be successful and durable if they are embedded within a broader reform agenda. In particular, reforms should incorporate both a sustainable approach to energy pricing and a plan to improve the efficiency of energy consumption and supply.

- In the Philippines and Turkey, full price liberalization and structural reform of the energy sector, for both fuel and electricity, were articulated as the ultimate goals of reform. This contributed to the eventual success of reform as the public and governments were able to focus on and adhere to long-term goals, without being distracted by setbacks at intermediate stages.

- This comprehensive strategy is especially important for electricity reforms. There is a strong inverse correlation between the size of electricity subsidies and the quality of service, reflecting the dampening effect of subsidies on investment. Yet the public is often unwilling to pay higher prices in the absence of quality improvements. Reforms in this sector should not only seek to improve access and service quality but also tackle operational inefficiencies (such as high distribution losses and inadequate bill collection and metering). The need to accompany tariff increases with service improvements can constrain the speed of reform, since improving services often requires up-front investment. Electricity subsidy reforms in Armenia, Brazil, and Kenya were successful because they were part of a broader package intended to address supply problems.

Assessing the impact of reforms. Designing a comprehensive subsidy reform strategy requires information on the likely impact of reforms on various stakeholders and the identification of measures to mitigate adverse impacts. This involves assessing the fiscal and macroeconomic effects of subsidies and identifying the winners and losers from reform. In Ghana, in 2005, the government commissioned an independent poverty and social impact analysis to assess the winners and losers from fuel subsidies and subsidy removal. This was an important foundation for persuasively communicating the necessity for reform and for designing policies to reduce the impact of higher fuel prices on the poor. In Nigeria, in contrast, the National Assembly did not support the removal of the gasoline subsidy in 2011, claiming a lack of firm data underpinning the size and incidence of subsidies.

Consultation with stakeholders. Stakeholders should be invited to participate in the formulation of the subsidy reform strategy. This "stakeholder approach" has proven successful in a number of countries (Graham, 1998; Gupta and others, 2000).

- In Kenya, electricity tariff increases faced significant difficulties early in the reform process. These were overcome after intense negotiations with stakeholders, particularly with large consumers, and efforts to communicate the objectives and benefits of the reform.

- In Namibia, the National Energy Council, chaired by the Minister of Mines and Energy, established the National Deregulation Task Force to examine fuel price deregulation through a consultative process.

- In Niger, the authorities established the Comité du Différé to discuss the best way to approach the fuel subsidy reforms and their subsequent consultation with all relevant stakeholders.

- In Indonesia, on the other hand, consultation with stakeholders was inadequate. The opposition to the 2003 fuel subsidy reform was partially motivated by the belief that the reform had been undertaken in favor of powerful interest groups.

(ii) Communications strategy

30. A far-reaching communications campaign can help generate broad political and public support and should be undertaken throughout the reform process. A review of subsidy reform experiences found that the likelihood of success almost tripled with strong public support and proactive public communications (IMF, 2011). The information campaign should explain the magnitude of energy subsidies and their implications for other parts of the budget. The benefits of removing subsidies, including on a post-tax basis, should be underscored, in particular the scope for using part of the budgetary savings or additional revenues to finance high-priority spending on education, health, infrastructure, and social protection. Information campaigns have underpinned the success of a number of countries, including fuel subsidy reforms in Ghana, Iran, Namibia, and the Philippines, and electricity subsidy reforms in Armenia and Uganda.

- In Namibia, a White Paper on Energy Policy was produced, which formed the basis of an effective public communications campaign.

- In the Philippines, a public communication campaign began at an early stage and included a nationwide road-show to inform the public of the problems of petroleum price subsidies.

- In Uganda, the government effectively communicated the cost of the electricity subsidy and its incidence to the public. As a consequence, a large portion of the media considered the raising of tariffs to be a pro-poor measure.

31. Ensuring transparency is a key component of a successful communications strategy. Useful information to be disseminated includes: (i) the magnitude of subsidies and how they are funded, including in oil-exporting countries where subsidies are provided implicitly and not shown in the budget or recorded as tax expenditures. To the extent that subsidies are off-budget, they could be reported as a memorandum item in budget documents. Data on subsidies should also cover producer subsidies, which may necessitate better reporting of the accounts of SOEs in the energy sector and reporting on SOEs in budget documents (see paragraph 35); (ii) the distribution of subsidy benefits across income groups; (iii) changes in subsidy spending over time; and (iv) the potential environmental and health benefits from subsidy reform. Prior to its successful subsidy reform, Niger started to record fuel subsidies explicitly in the budget. Making such information public allows for an independent assessment of the costs and benefits of subsidy policies. It is particularly important for determining whether subsidies are the most effective way to achieve desired outcomes, such as social protection for the poor. Subsidy expenditures should be compared to spending on priority areas and planned increases in these outlays as a consequence of the enlarged fiscal space from subsidy reform. Governments should also disclose as much information as possible about how prices are formulated and the factors behind planned price increases. Both

Ghana and South Africa regularly publish such details for petroleum products on their government websites and in the national media.

(iii) Appropriately phased and sequenced price increases

32. Phasing-in price increases and sequencing them differently across energy products may be desirable. The appropriate phasing-in and sequencing of price increases will depend on a range of factors, including the magnitude of the price increases required to eliminate subsidies, the fiscal position, the political and social context in which reforms are being undertaken, and the time needed to develop an effective communications strategy and social safety nets. In the case studies, successful and partially successful subsidy reforms required, on average, about five years.

- ***Pace and timing of energy price increases.*** Too sharp an increase in energy prices can generate intense opposition to reforms, as happened with fuel subsidy reforms in Mauritania in 2008 and Nigeria in 2012. A phased approach to reforms permits both households and enterprises time to adjust, and permits the country time to build credibility by showing that subsidy savings are being put to good use. As noted earlier, it also helps reduce the impact of subsidy reform on inflation and creates room for governments to establish supporting social safety nets. The case studies show that 17 out of the 23 reform episodes that were successful or partially successful involved a phased reduction of subsidies. In Namibia, subsidies were removed steadily according to a three-year reform plan. In Brazil, the government pursued a step by step approach to reforming petroleum subsidies during the 1990s in order to minimize opposition from key interest groups. Despite initial sharp increases in prices, gradual adjustment of fuel prices was a key design feature of the reforms introduced in Iran, where the plan was to eliminate petroleum subsidies over a five-year period. A gradual approach was also adopted by Kenya (electricity), where the authorities were able to progressively gain support for broader reform by delivering improved services. The timing of energy price increases should also be considered carefully. For example, coordinating increases in electricity with the expansion of capacity could help win broad acceptance of tariff increases, as in Uganda. Tariff increases that coincide with price increases for other socially sensitive products, such as food and fuels, may meet strong resistance.

- ***Sequencing of reform.*** Price increases can also be sequenced differently across energy products. For example, petroleum price increases can initially be larger for products that are consumed more by higher-income groups and by industry, such as gasoline and jet kerosene. As the safety net is strengthened, subsequent rounds of reform can include larger increases in prices for fuel products that are more important in the budgets of poor households and part of the budgetary savings can be used to finance targeted transfers to poor households. For electricity, tariff increases can initially focus on large residential users and commercial users. Out of the 28 reform episodes, seven reforms sequenced price increases in this way. In Brazil, for instance, petroleum product reforms started by liberalizing prices for petroleum products used primarily by industry, followed by a more extensive liberalization of gasoline prices and finally diesel prices. Reforms in Peru initially focused on raising high-octane gasoline prices.

33. However, gradual reform can create additional reform challenges. First, a slower pace of reform reduces budgetary savings in the short term. There is thus a trade-off between the objectives of achieving budgetary savings and softening the impact of reforms on households. Second, sequencing of reforms can severely distort consumption patterns. For example, there is a limit to how low kerosene prices can be maintained without serious disruption of energy markets when other petroleum product prices are raised. These problems include the redirection of kerosene and LPG from households to the transport sector and cross-border smuggling. Turkey had to curtail LPG subsidies more rapidly than planned because of a sharp increase in LPG consumption due to the conversion of vehicles to LPG. Third, a gradual reform runs the risk that opposition may build up over time. To address this concern, gradual reforms must be accompanied by the government's long-term commitment to follow-through on planned price increases, possibly over several successive administrations. This challenge can be overcome by building up a broad support base for reforms. For example, Turkey started toward a more liberalized regime for energy pricing, including fuel and electricity, in the late 1980s and early 1990s, and continued implementing the plan under subsequent administrations. Effective planning and communication promoted broad consensus on the need for petroleum and electricity sector reforms in the Philippines and enabled the government to successfully implement its reform strategy gradually.

(iv) Improving the efficiency of SOEs to reduce producer subsidies

34. Improving the efficiency of SOEs can reduce the fiscal burden of the energy sector. Energy producers often receive substantial budgetary resources—both in terms of current and capital transfers—to compensate for inefficiencies in production and revenue collection. Improvements in efficiency can strengthen the financial position of these enterprises and reduce the need for such transfers.

35. Country experiences suggest the importance of strengthening SOE governance, improving demand management and revenue collection, and better exploitation of scale economies to improve enterprise efficiency:

- Governance of SOEs can be strengthened by improving the reporting of information on operations and costs. This can help identify system inefficiencies (e.g., overstaffing) and vulnerabilities (e.g., major loss points and bottlenecks in energy flows). Countries that have adopted information systems include Kenya, Uganda, and Zambia. Consistent with the Code of Good Practices on Fiscal Transparency, all extrabudgetary activity of the central government, including that undertaken by SOEs, should be reported in budget documents (see also IMF, 2012b). A second step is to set performance targets and incentives on the basis of this information. In Cape Verde, the electricity company is allowed to keep resources from over-performance on their targets, which can then be used for investment. Introducing competition, including from the private sector, can strengthen performance. This option will be more viable for countries with larger markets, where there is scope to "unbundle" activities in both the petroleum and electricity sectors. Notwithstanding these limitations, the private sector's role in the electricity sector is growing in many emerging and low-income countries. Many of these

countries have permitted competition among private generation companies and some of them have invited the private sector to manage electricity distribution, primarily to address operational inefficiencies.

- Improved demand management (by charging higher prices during peak periods) has proven effective in shifting demand to periods where marginal costs of provision are lower (Antmann, 2009). Utilities in sub-Saharan Africa have had programs to provide free compact fluorescent bulbs, which have helped reduce demand and costs in Cape Verde, Ethiopia, Malawi, Uganda, and Rwanda. Revenue-enhancing measures include improved collection and metering. These efforts can start with large customers and then gradually extend to medium and smaller ones.

- Efficiency can be improved by exploiting regional trade in electricity (Foster and Briceño-Garmendia, 2010). For instance, Mali and Burkina Faso have been able to expand domestic supply and household access through integration into the regional market.

(v) Targeted mitigating measures

36. Well-targeted measures to mitigate the impact of energy price increases on the poor are critical for building public support for subsidy reforms. The first step in this regard is to assess the capacity to expand existing (or implement new) social programs in the short term. Implementing or expanding targeted programs immediately prior to price reforms can help demonstrate the government's commitment to protecting the poor. Untargeted cash transfers to compensate the population following a subsidy reform could be limited to the amount consumed by the poorest. This can generate fiscal savings, since poor households typically consume substantially lower quantities of energy than the rich. Further fiscal savings would be generated by targeted cash transfers to compensate only lower income groups. In some oil-exporting countries, where subsidies are often seen as a form of wealth sharing, uniform per capita transfers can be both more efficient and more equitable than untargeted energy subsidies. However, wealth sharing may be better achieved through targeted and productive public spending aimed at building physical and human capital. The degree to which compensation should be targeted is a strategic decision that involves trade-offs between fiscal savings, capacity to target, and the need to achieve broad acceptance of the reform. Out of the 28 reform episodes, 18 relied on targeted mitigating measures, including expansion of public works, education, and health programs in poor areas.

37. Targeted cash transfers or near-cash transfers (vouchers) are the preferred approach to compensation. Cash transfers give beneficiaries the flexibility to purchase the level and type of energy that best suits their needs, and at a time and place of their choosing. They also remove the need for governments to be directly involved in the distribution of subsidized energy to households, which is often extremely costly and prone to abuse (Grosh and others, 2008). Targeted cash transfers were used to protect poor households in nine out of the 28 reform episodes. Indonesia's unconditional cash transfer program, which covered 35 percent of the population, was an important component of its successful strategy in overcoming social and political opposition to fuel subsidy reforms. Its experience also suggests that such programs need good preparation and monitoring in order to effectively assist the poor. Armenia successfully introduced a targeted cash transfer

program during its electricity reform and was able to gradually reduce the coverage of households from 25 percent in 1999 to 18 percent in 2010. The recent expansion of conditional cash transfer programs throughout emerging and low-income economies, with eligibility for benefits linked to household investments in the education and health status of family members, has greatly increased the capacity of these economies to protect poor households from price and other shocks while simultaneously addressing the root causes of persistent poverty (Fiszbein and Schady, 2009; Garcia and Moore, 2012).

38. When cash transfers are not feasible, other programs can be expanded while administrative capacity is developed. This should focus on existing programs that can be expanded quickly, possibly with some improvements in targeting effectiveness (for instance, school meals, public works, reductions in education and health user fees, subsidized mass urban transport, subsidies for consumption of water and electricity below a specified threshold). This approach was used in 15 of the reform episodes, sometimes in conjunction with targeted cash transfers.

- Gabon, Ghana, Niger, Nigeria, and Mozambique expanded targeted social spending programs to protect lower-income households from fuel price increases.
- In the context of electricity reforms, Armenia, Brazil, Kenya, and Uganda kept their lower electricity lifeline tariffs fixed and concentrated tariff increases on households with higher electricity consumption levels.
- The Philippines maintained electricity subsidies for indigent families, college scholarships for low-income students, and subsidized loans to convert engines used in public transportation to less costly LPG (World Bank, 2008).
- Kenya subsidized connection costs in place of electricity price subsidies, which helped expand coverage to poor households and those in remote and rural areas. The rural electrification program helped to increase the number of connections from 650,000 in 2003 to 2 million at present, with a fund for connection fee payments financed by donors.

39. Providing an affordable alternative energy source can mitigate the impact of subsidy reform on low-income groups. A key objective of subsidies in many countries is to provide an affordable source of energy to low-income households. Subsidy reform can therefore often be more acceptable if it is accompanied by complementary measures that support this objective. Such measures were included in five reform episodes. In Indonesia and Yemen, subsidy reform was facilitated by the government's efforts to help households convert from the use of kerosene for cooking to low-cost LPG.

40. Subsidy reform involving SOE restructuring requires temporary sector-specific social measures to support employees and enterprises. In the short term, SOE restructuring may involve laying-off part of the workforce or require increased investment in energy-saving technologies. Policies that mitigate the impact on workers and promote restructuring can increase support for subsidy reform. In the case of coal sector reform in Poland, unemployed miners had access to social

assistance and job training. In the context of fuel subsidy reform, the Iranian government undertook extensive consultation with enterprises to understand the challenges they faced if energy prices increased substantially. This led to a program targeted to agriculture and energy-intensive sectors hard hit by price increases, which included direct assistance and access to subsidized fuel. Such measures should be temporary, with a clearly specified lifespan and communicated to the public to demonstrate the government's commitment to reforms.

(vi) Depoliticize energy pricing

41. Successful and durable reforms require a depoliticized mechanism for setting energy prices. Many countries have successfully implemented reforms only to see subsidies reappear when international oil prices increase. Out of 28 reform episodes, 11 were classified as partially successful because subsidies later re-emerged. In Ghana, the 2005 reform eliminated fuel subsidies but when oil prices soared in 2007 and 2008, the government abandoned its policy of linking domestic to international prices and automatic adjustment was temporarily suspended. In Indonesia, in spite of increasing international prices, subsidy reform reduced fuel subsidies from 3½ percent of GDP in 2005 to 2 percent of GDP in 2006. However, unwillingness to fully pass-through continued increases in international prices resulted in fuel subsidies escalating again to 2.8 percent of GDP in 2008.

42. Automatic pricing mechanisms can help reduce the chances of reform reversal. Establishing an automatic pricing formula for fuel products can help distance the government from pricing of energy and make it clearer that domestic price changes reflect changes in international prices which are outside the control of the government. Reliance on a formula can reassure the public that price increases would not lead to windfall profits for suppliers. South Africa has successfully implemented an automatic pricing mechanism for fuel products for over five decades. Both the Philippines and Turkey successfully implemented such a mechanism during their transition to liberalized fuel pricing. In all three countries, detailed information on the mechanism and its implementation was disseminated to the public on government websites and through other media.

43. However, adoption of such a mechanism is not a panacea for achieving a sustained reform of energy subsidies. A number of countries have abandoned such mechanisms shortly after adopting them, partly due to an unwillingness to pass through sharp international price increase to consumers. Gabon suspended its mechanism in August 2002 as international oil prices started to increase. Ghana adopted an automatic mechanism in February 2001 but suspended it before the end of the year. It reintroduced the mechanism in January 2003, only to suspend it again in June 2003. More recently, newly adopted pricing mechanisms have been suspended in other sub-Saharan African countries, including the Gambia, Sierra Leone, and Togo. The sustainability of these mechanisms can be enhanced if they are packaged and communicated as part of broader structural reforms, including expansion of targeted social safety net and social spending programs. Using price smoothing rules can also help to avoid large price increases (see paragraph 45 below).

44. Responsibility for implementing the automatic mechanism can be given to an independent body. Technical decisions on pricing can be delegated to an independent institution to ensure that subsidy reform proceeds as planned. The institution can also have the responsibility

for implementing the automatic mechanism once subsidies are eliminated. A number of countries that successfully reformed subsidies for petroleum products (including South African and Turkey) and electricity (including Armenia, Kenya, the Philippines and Turkey) gave responsibility for reforming and regulating energy prices to an independent agency.

45. A smoothing rule can be incorporated into the automatic pricing mechanism to avoid sharp increases in domestic prices (Coady and others, 2012). Countries often abandon automatic pricing mechanisms when international prices increase sharply. In China, for example, a key barrier to the adoption of an automatic pricing mechanism has been concern about the political and social consequences of fully passing through such sharp price increases. Some countries (including Chile, Colombia, Malawi, Nigeria, Peru, Thailand, and Vietnam) have used smoothing rules to address this problem. Smoothing mechanisms can also help contain inflationary expectations if supported by appropriate macroeconomic policies. They can help dampen the effects of international price and exchange rate volatility. Several sub-Saharan countries, including the Gambia, Sierra Leone, and Togo, are considering the use of smoothing rules. With a smoothing mechanism, periods of sharp increases in international prices would only gradually be transmitted to domestic prices. For instance, energy prices changes could be limited to a maximum of, say, 5 percent of the current consumer price in any given month.

46. To protect the budget over the medium term, smoothing must be applied both to price increases (when subsidies increase or taxes fall) and to price decreases (when subsidies decrease or taxes increase). How much smoothing the government chooses to implement will depend on its preference between lower price and higher fiscal volatility. Peru adopted a smoothing rule in 2004 whereby international price changes were fully passed through to domestic prices as long as the latter fell within a fixed price band. When prices fell outside this price band, the cost (if above) or benefit (if below) was absorbed by the budget. Since 2010, the band price limits are updated to reflect trends in international prices, with adjustments limited to 5 percent. While stabilization funds have also been used to smooth price increases, experience with such funds has been mixed, with funds exhausting their reserves during periods of sharp increases in international prices or incurring large contingent liabilities for the budget (Chile, Namibia, Peru, the Philippines, and Thailand).

47. Over the longer term, subsidy reforms for petroleum products should aim to fully liberalize pricing. More liberalized regimes—where prices are determined by private sector suppliers and move freely with international prices—tend to be more robust to the reintroduction of subsidies than automatic pricing mechanisms (Baig and others, 2007). Under a liberalized regime, the role of the government is to ensure that fuel markets are competitive and there is free entry and exit from the sector. A well functioning social safety net should be in place before countries liberalize to ensure that low-income groups can be protected from future price increases and thus avoid public pressure to reintroduce subsidies. Successful implementation of an automatic pricing mechanism can facilitate the transition to a liberalized pricing regime by getting the public used to frequent changes in domestic energy prices. It can also build up the confidence of private suppliers that the government will not return to subsidized pricing. This approach was used in the Philippines,

which adopted an automatic pricing mechanism in 1996 as part of its transition to a liberalized supply and pricing regime in 1998.

48. In the electricity sector, the small size of the market in some countries limits the scope for competition and price liberalization. In many emerging and low-income economies, the electricity market is small. Under these circumstances, the market may not support many firms of a size sufficient to reap economies of scale and produce at the lowest possible cost. In such cases, price regulation will be needed, and competition alone will not be the best approach to reforming the sector (Besant-Jones, 2006). Prices should be determined by an autonomous agency and set at a level that is sufficient to avoid subsidies and ensure an adequate return to investment under efficient operations. Enhancing the progressivity of tariff structures by imposing higher tariff rates for larger consumers can also reduce subsidy expenditures while protecting the poor. For instance, there is scope to make tariff structures more progressive in many African countries. Greater emphasis could also be given to subsidizing connections, rather than consumption of electricity.

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Appendix I. Estimating Pre-tax and Post-tax Global Energy Subsidies

This appendix describes the data sources and methodologies used for the estimation of subsidies for petroleum products, coal, natural gas, and electricity.

A. Pre-tax Subsidies

Petroleum products

Pre-tax consumer subsidies for gasoline, diesel, and kerosene are estimated as the difference between international prices adjusted for transport margins and domestic consumer prices for 176 countries between 2000 and 2011.[18] International prices are taken as the monthly average of spot prices from IEA. For importers, margins are calculated as $0.10 per liter to cover international transport costs and another $0.10 per liter to cover domestic distribution and retailing costs. For net oil exporters, no adjustment is made as the two costs are assumed to cancel out each other. Domestic consumer prices for petroleum products (for both firms and households) are taken from publicly available sources for Organization of Economic Cooperation and Development (OECD) countries. For other countries, domestic prices were provided by country authorities to IMF staff, supplemented by survey data from the Deutsche Gesellschaft für Internationale Zusammenarbeit (Ebert and others, 2009). For gasoline, the price is for regular unleaded or other grades, based on availability. Where consumer prices were unavailable, they were imputed based on observed pass through behavior. This was done for approximately 54 countries in 2009 and one country (Venezuela) in 2011. End-of-year prices are used to estimate subsidies except for 30 countries, mostly in the MENA region, where quarterly price data are available.

Fuel product consumption levels used to calculate total subsidies are based on OECD and International Energy Agency (IEA) data, and include consumption by both households and enterprises.

Coal and natural gas

Consumer subsidy estimates are based on IEA data for coal in 39 countries and for natural gas in 37 countries between 2007 and 2011. IMF staff estimates on natural gas subsidies are available for additional four countries in the MENA region. In addition, producer coal subsidies for 16 countries between 2007 and 2011 are based on OECD data. This calculation measures subsidies as the difference between the reference price and the domestic price paid by households and firms. The IEA reference prices for natural gas and coal, both traded goods, are defined differently for net importers and net exporters. For net importers, the reference price was defined as the price at the nearest international market, adjusted for quality differences, the cost of freight and insurance, distribution and marketing costs, and any value added tax (VAT). The price does not include excise

[18]Subsidies for oil-based heating fuels and non-road transportation vehicles, which are substantial in some countries, are not included due to data limitations.

duties. For net exporters, the reference price was calculated as the price at the nearest international market, adjusted for quality differences, less the costs of freight and insurance, plus distribution, marketing, and VAT. It should be noted that the quantities of coal and natural gas used in this calculation do not include the amount used for electricity and heat generation. To estimate pre-tax subsidies, the VAT is subtracted from the IEA estimates, using the standard VAT rate in the country. Producer subsidies for coal are based on OECD producer support estimates that capture the amount of tax subsidies (such as special income tax treatment) or budgetary expenditures designed to support producer incomes (OECD, 2012a).

Electricity

Given the varying availability of data, a number of different approaches are taken to measure subsidies. For 40 countries from Africa and Middle East, and a few selected emerging economies of Europe, estimates of combined producer and consumer subsidies are compiled from various World Bank reports and IMF staff estimates; thus, they are not necessarily comparable. For these countries, subsidy estimates are based on average domestic prices and cost-recovery prices that cover production costs, investment cost, distributional loss and the non-payment of electricity bills. An upward adjustment is also made for the input subsidies that electricity producers may receive through their use of subsidized fossil fuel products. For 31 of these 40 countries, the latest year for which data are available is 2009.

For 37 countries, estimates of consumer price subsidies between 2007 and 2011 are taken from the International Energy Agency, based on the difference between costs (adjusted for any subsidy on fossil fuel inputs) and average domestic prices (IEA, 2011b). As these prices do not include investment cost, non-payment of electricity and distributional losses, the estimates may understate subsidies. In total, the sample covers 77 countries.

B. Post-tax Subsidies

Post-tax subsidies are estimated as pre-tax subsidies plus:

- *a corrective (or "Pigouvian") tax*, reflecting an (excise) tax on energy products to charge for externalities associated with CO_2 emissions, local pollution, and (in the case of gasoline and motor diesel) other externalities such as traffic congestion and accidents.
- a revenue component, reflecting an (ad valorem) tax on energy products that would be consistent with taxation of any other consumer good at the standard value-added tax (VAT) or general sales tax (GST) rate.

Corrective taxes

This section discusses the estimation of taxes needed to correct for externalities from petroleum products, coal, and natural gas. To avoid double counting we do not measure externalities from electricity generation and, due to the lack of available evidence, we do not measure externalities for

other generation fuels.[19] Environmental and transportation-related externalities have been quantified for the United States and just a few other countries.[20]

Petroleum products

Combustion of petroleum products (gasoline, diesel and kerosene) contributes to global warming through CO_2 emissions and local pollution. In addition, externalities associated with motor vehicle use—which we apportion to gasoline and diesel fuels—include traffic congestion and accidents, and (primarily in the case of trucks) road damage. Appendix Table 1 summarizes some estimates of motor fuel taxes to correct for these externalities that have been conducted for the United States, the United Kingdom, and Chile. The corrective tax estimate for Chile is higher, reflecting a combination of elevated local emission rates and a high incidence of pedestrian deaths and traffic congestion.

Appendix Table 1. Corrective Motor Fuel Taxes, Selected Countries
(Cents per liter, 2011 dollars)

	Gasoline (cars)			Diesel (trucks)	
	United States	United Kingdom	Chile	United States	Chile
Total	36	42	71	37	62
Contribution of:					
local pollution	3	4	18	10	16
carbon	6	5	6	6	6
congestion	15	26	19	10	16
accidents	12	8	28	3	12
noise	0	0	0	2	1
road damage	0	0	0	6	12

Sources: IFS (2012), Parry (2011), Parry and Strand (2012), and Parry and Small (2005).

Notes: The above studies estimate corrective diesel fuel taxes for the United States and Chile, but not for the United Kingdom.

[19]For example, for nuclear power it is extremely difficult to quantify the risks from radioactive waste and meltdowns.

[20]More detailed work for other countries is underway in the Fiscal Affairs Department to provide more precise estimates (IMF, forthcoming).

For CO_2 emissions, we assume an illustrative value for global warming damages of $25 per ton (in 2010 dollars) of CO_2 emissions, following the US IAWG (2010). The estimates in the literature have varied considerably, ranging from $12 per ton (Nordhaus, 2011) to $85 per ton (Stern, 2006). The $25 per ton of CO_2 emission translates into $0.05–$0.06 per liter of gasoline or diesel as shown Appendix Table 1. The same value ($25 per ton of CO_2 emissions) is used in the calculation of global warming damages from the consumption of coal and natural gas.

A careful assessment of the non-carbon corrective fuel taxes for other countries would take into account a variety of local factors that affect the willingness-to-pay for reductions in these negative externalities, including, most importantly, income, local emission rates, population density, travel delays, and the frequency of traffic accidents. Data on these factors across other countries are not readily available, except for income per capita. We make adjustments to the estimates of willingness to pay by comparing a given country's income (say Colombia) in purchasing parity terms with the United States, the United Kingdom, and Chile.[21] An income elasticity of 0.8 is assumed between the willingness to pay for reductions in externalities and per-capita income, following the OECD (OECD, 2012b). We then apply this correction to the estimates of externalities per liter described in Appendix Table 1 for the United States, the United Kingdom, and Chile. We then take the average across the three countries to arrive at our estimate for Colombia.

Coal

To estimate the corrective tax per ton of coal for global warming damages, we first derive CO_2 emissions per ton of coal, based on IEA data on coal consumption and CO_2 emissions from coal by country. The corrective tax per ton of coal is then calculated by multiplying CO_2 emission per ton of coal consumption with the global warming damages of $25 per ton of CO_2 emission.

Beyond its CO_2 emissions, the other major externality associated with coal combustion is local air pollution (most importantly fine particulates formed from SO_2 emissions). A state-of-the-art modeling exercise for the United States by a committee of experts (NRC, 2010) put the local pollution damages from the average coal plant in 2005 at about $65 (in 2010 dollars) per (short) ton. Local pollution damages are adjusted the same way as for petroleum products when extrapolating to other countries. This approach assumes that scrubber use and coal content in other countries are similar to that of the United States. We do not adjust for differences in the pollution content of coal, or for use of flue-gas de-sulfurization technologies (scrubbers) in other countries compared with the United States.

[21]Post-tax subsidies as a share of GDP for low-income countries would increase from 3.3 percent of GDP to 5.3 percent without this adjustment for non-carbon externalities of petroleum products and coal.

Natural gas

Natural gas is far less emissions-intensive than coal—it produces about half the carbon emissions per unit of energy, and only very minimal SO_2 emissions. Here only a carbon damage is applied to natural gas. Similar to coal, the corrective tax per thousand cubic feet of natural gas is calculated based on IEA data on natural gas consumption, CO_2 emissions from natural gas by country, and the global warming damages of $25 per ton of CO_2 emissions.

Revenue component

Here a scenario where energy products would be taxed just like other goods is considered. In principle, individual products should be taxed more heavily, or less heavily, than the average consumer good (on revenue-raising grounds), depending on whether taxing them causes a significant shift towards untaxed goods (i.e., leisure and products that are exempt from VAT). However, there is little empirical support on which to make these types of adjustments, and hence they are not pursued here. The estimates are based on VAT rates for 150 countries in 2011. For countries where VAT rates are not available or do not apply, the average VAT rate of countries with a similar level of income in the region is assumed.

Calculating subsidies with corrective tax and revenue components

To quantify the magnitude of subsidies, the subsidy-free post-tax prices are derived by applying the VAT/GST rates to both pre-tax international prices/cost recovery prices and excise tax for externalities. The subsidy-free post-tax prices are then compared with domestic prices and combined with consumption levels to compute subsidies. In the case of electricity, VAT/GST is only estimated for countries with pre-tax subsidies. This approach is followed because both domestic prices and cost recovery prices are unknown for other countries. In the case of coal and natural gas, it is assumed that domestic prices in countries without pre-tax subsidies are the same as international reference prices.

One complication is that revenue from VAT would only be effectively assessed on energy products as final consumption goods, not those as intermediate inputs for other consumption goods. To separate intermediate inputs from final consumption goods, we use IEA energy consumption data by industry type. It is assumed that energy products for residential use, commercial and public services, and gasoline for road use are final consumption goods. This approximation indicates that, on average, 99 percent of gasoline consumption, 7 percent of diesel consumption, 39 percent of kerosene consumption, 12 percent of coal consumption, 46 percent of natural gas consumption, and 51 percent of electricity consumption can be categorized as final consumption.

Appendix Table 2. Pre-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011[22]

(Percent of GDP by region)

Country	Petroleum products	Electricity	Natural gas	Coal
Advanced				
Australia	0.00	n.a.	n.a.	0.00
Austria	0.00	n.a.	n.a.	n.a.
Belgium	0.00	n.a.	n.a.	n.a.
Canada	0.00	n.a.	n.a.	0.00
Cyprus	0.00	n.a.	n.a.	n.a.
Czech Republic	0.00	n.a.	n.a.	0.00
Denmark	0.00	n.a.	n.a.	n.a.
Estonia	0.00	n.a.	n.a.	n.a.
Finland	0.00	n.a.	n.a.	n.a.
France	0.00	n.a.	n.a.	n.a.
Germany	0.00	n.a.	n.a.	0.07
Greece	0.00	n.a.	n.a.	n.a.
Hong Kong SAR	0.00	n.a.	n.a.	n.a.
Iceland	0.00	n.a.	n.a.	n.a.
Ireland	0.00	n.a.	n.a.	0.05
Israel	0.00	n.a.	n.a.	n.a.
Italy	0.00	n.a.	n.a.	n.a.
Japan	0.00	n.a.	n.a.	n.a.
Korea	0.00	n.a.	0.00	0.02
Luxembourg	0.00	n.a.	n.a.	n.a.
Malta	0.00	n.a.	n.a.	n.a.
Netherlands	0.00	n.a.	n.a.	n.a.
New Zealand	0.09	n.a.	n.a.	n.a.
Norway	0.00	n.a.	n.a.	n.a.
Portugal	0.00	n.a.	n.a.	n.a.
Singapore	0.00	n.a.	n.a.	n.a.
Slovak Republic	0.00	n.a.	n.a.	0.01
Slovenia	0.00	n.a.	n.a.	0.02
Spain	0.00	n.a.	n.a.	0.03
Sweden	0.00	n.a.	n.a.	n.a.
Switzerland	0.00	n.a.	n.a.	n.a.
Taiwan Province of China	n.a.	0.22	0.00	0.03
United Kingdom	0.00	n.a.	n.a.	n.a.
United States	0.05	n.a.	n.a.	0.00

[22]These subsidy estimates may differ from those in the country budget documents due to the methodologies described in this appendix.

Appendix Table 2. Pre-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011 (Continued)

(Percent of GDP by region)

Country	Petroleum products	Electricity	Natural gas	Coal
CEE-CIS				
Albania	0.00	n.a.	n.a.	n.a.
Armenia	0.45	0.05	n.a.	n.a.
Azerbaijan	0.84	0.73	1.16	0.00
Belarus	0.00	0.26	n.a.	n.a.
Bosnia and Herzegovina	0.00	n.a.	n.a.	n.a.
Bulgaria	0.00	n.a.	n.a.	n.a.
Croatia	0.00	n.a.	n.a.	n.a.
Georgia	0.55	n.a.	n.a.	n.a.
Hungary	0.00	n.a.	n.a.	0.00
Kazakhstan	0.65	0.94	0.15	0.28
Kosovo	0.00	n.a.	n.a.	n.a.
Kyrgyz Republic	3.47	5.43	n.a.	n.a.
Latvia	0.00	n.a.	n.a.	n.a.
Lithuania	0.00	n.a.	n.a.	n.a.
Macedonia, FYR	0.00	n.a.	n.a.	n.a.
Moldova	0.00	n.a.	n.a.	n.a.
Mongolia	0.00	n.a.	n.a.	n.a.
Montenegro, Rep. of	0.00	n.a.	n.a.	n.a.
Poland	0.00	n.a.	n.a.	0.14
Romania	0.00	n.a.	n.a.	n.a.
Russia	0.00	0.99	1.09	0.00
Serbia	0.00	n.a.	n.a.	n.a.
Tajikistan	0.00	1.95	n.a.	n.a.
Turkey	0.00	n.a.	n.a.	0.02
Turkmenistan	6.00	2.32	14.80	n.a.
Ukraine	0.00	1.61	3.59	n.a.
Uzbekistan	0.02	5.71	18.88	n.a.
Emerging and Developing Asia				
Afghanistan	0.00	0.11	n.a.	n.a.
Bangladesh	0.90	2.63	1.60	0.00
Bhutan	0.51	n.a.	n.a.	n.a.
Brunei Darussalam	2.34	0.98	0.00	0.00
Cambodia	0.00	n.a.	n.a.	n.a.
China	0.00	0.15	n.a.	n.a.
Fiji	0.01	n.a.	n.a.	n.a.
India	1.25	0.32	0.17	0.00
Indonesia	2.58	0.66	0.00	0.00
Kiribati	n.a.	n.a.	n.a.	n.a.
Lao P.D.R.	0.00	n.a.	n.a.	n.a.
Malaysia	1.24	0.33	0.31	0.00
Maldives	0.19	n.a.	n.a.	n.a.
Myanmar	0.54	n.a.	n.a.	n.a.
Nepal	0.00	n.a.	n.a.	n.a.
Pakistan	0.13	1.31	2.54	0.00
Papua New Guinea	n.a.	n.a.	n.a.	n.a.
Philippines	0.00	0.00	0.00	0.00
Samoa	n.a.	n.a.	n.a.	n.a.
Solomon Islands	0.00	n.a.	n.a.	n.a.
Sri Lanka	1.16	0.47	0.00	0.00
Thailand	0.15	1.64	0.14	0.25
Timor-Leste	0.00	n.a.	n.a.	n.a.
Tonga	0.00	n.a.	n.a.	n.a.
Tuvalu	0.00	n.a.	n.a.	n.a.
Vanuatu	0.00	n.a.	n.a.	n.a.

Appendix Table 2. Pre-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011 (Continued)

(Percent of GDP by region)

Country	Petroleum products	Electricity	Natural gas	Coal
LAC				
Antigua and Barbuda	0.49	n.a.	n.a.	n.a.
Argentina	0.00	1.03	0.77	0.00
Bahamas, The	0.00	n.a.	n.a.	n.a.
Barbados	0.04	n.a.	n.a.	n.a.
Belize	0.00	n.a.	n.a.	n.a.
Bolivia	2.40	n.a.	n.a.	n.a.
Brazil	0.00	n.a.	n.a.	n.a.
Chile	0.00	0.00	0.00	0.00
Colombia	0.00	0.00	0.00	0.00
Costa Rica	0.00	n.a.	n.a.	n.a.
Dominica	0.00	n.a.	n.a.	n.a.
Dominican Republic	0.00	n.a.	n.a.	n.a.
Ecuador	6.31	0.18	0.00	0.00
El Salvador	0.00	0.00	0.00	0.00
Grenada	0.00	n.a.	n.a.	n.a.
Guatemala	0.00	n.a.	n.a.	n.a.
Guyana	0.00	n.a.	n.a.	n.a.
Haiti	n.a.	n.a.	n.a.	n.a.
Honduras	0.02	n.a.	n.a.	n.a.
Jamaica	0.00	n.a.	n.a.	n.a.
Mexico	0.00	0.00	0.00	0.00
Nicaragua	0.00	n.a.	n.a.	n.a.
Panama	0.02	n.a.	n.a.	n.a.
Paraguay	0.00	n.a.	n.a.	n.a.
Peru	0.00	0.00	0.00	0.00
St. Kitts and Nevis	0.20	n.a.	n.a.	n.a.
St. Lucia	0.19	n.a.	n.a.	n.a.
St. Vincent and the Grenadines	0.00	n.a.	n.a.	n.a.
Suriname	0.00	n.a.	n.a.	n.a.
Trinidad and Tobago	2.75	n.a.	n.a.	n.a.
Uruguay	0.00	n.a.	n.a.	n.a.
Venezuela	5.58	1.02	0.59	n.a.

Appendix Table 2. Pre-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011 (Continued)

(Percent of GDP by region)

Country	Petroleum products	Electricity	Natural gas	Coal
MENA				
Algeria	4.30	1.08	5.36	0.00
Bahrain	5.37	2.57	n.a.	n.a.
Djibouti	0.00	0.45	n.a.	n.a.
Egypt	6.74	2.30	1.60	0.00
Iran	4.20	3.61	4.83	0.00
Iraq	9.92	1.39	0.25	0.00
Jordan	2.15	3.81	n.a.	n.a.
Kuwait	3.09	2.91	1.29	0.00
Lebanon	0.07	4.46	n.a.	n.a.
Libya	6.40	1.85	0.59	0.00
Mauritania	0.00	0.85	0.80	n.a.
Morocco	0.66	n.a.	n.a.	n.a.
Oman	3.01	0.76	2.20	n.a.
Qatar	1.22	1.20	1.07	0.00
Saudi Arabia	7.46	2.48	n.a.	0.00
Sudan	1.37	n.a.	n.a.	n.a.
Syria	n.a.	n.a.	n.a.	n.a.
Tunisia	0.77	2.23	n.a.	n.a.
United Arab Emirates	0.48	1.86	3.37	n.a.
Yemen	4.67	1.33	n.a.	n.a.
Sub-Saharan Africa				
Angola	1.30	0.27	0.00	0.00
Benin	0.00	1.78	n.a.	n.a.
Botswana	0.02	0.36	n.a.	n.a.
Burkina Faso	0.00	0.78	n.a.	n.a.
Burundi	0.00	n.a.	n.a.	n.a.
Cameroon	1.69	2.16	n.a.	n.a.
Cape Verde	0.00	2.17	n.a.	n.a.
Central African Republic	0.00	n.a.	n.a.	n.a.
Chad	0.00	0.00	n.a.	n.a.
Comoros	n.a.	n.a.	n.a.	n.a.
Congo, Democratic Republic of the	0.00	1.57	n.a.	n.a.
Congo, Republic of	1.20	2.62	n.a.	n.a.
Côte d'Ivoire	0.00	2.72	n.a.	n.a.
Equatorial Guinea	0.28	n.a.	n.a.	n.a.
Eritrea	n.a.	n.a.	n.a.	n.a.
Ethiopia	0.19	1.24	n.a.	n.a.
Gabon	0.16	n.a.	n.a.	n.a.
Gambia, The	0.00	n.a.	n.a.	n.a.
Ghana	0.62	2.86	n.a.	n.a.
Guinea	0.00	n.a.	n.a.	n.a.
Guinea-Bissau	0.00	n.a.	n.a.	n.a.
Kenya	0.00	0.00	n.a.	n.a.
Lesotho	0.00	0.85	n.a.	n.a.
Liberia	0.00	n.a.	n.a.	n.a.
Madagascar	0.11	0.89	n.a.	n.a.

Appendix Table 2. Pre-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011 (Concluded)

(Percent of GDP by region)

Country	Petroleum products	Electricity	Natural gas	Coal
Sub-Saharan Africa, concluded.				
Malawi	0.00	1.60	n.a.	n.a.
Mali	0.00	0.93	n.a.	n.a.
Mauritius	0.00	n.a.	n.a.	n.a.
Mozambique	0.00	4.93	n.a.	n.a.
Namibia	0.00	0.52	n.a.	n.a.
Niger	0.00	0.00	n.a.	n.a.
Nigeria	1.42	1.31	0.00	0.00
Rwanda	0.00	0.29	n.a.	n.a.
São Tomé and Príncipe	0.33	n.a.	n.a.	n.a.
Senegal	0.00	2.26	n.a.	n.a.
Seychelles	0.00	n.a.	n.a.	n.a.
Sierra Leone	0.00	n.a.	n.a.	n.a.
South Africa	0.01	0.55	0.00	0.00
Swaziland	0.00	n.a.	n.a.	n.a.
Tanzania	0.00	2.10	n.a.	n.a.
Togo	0.00	n.a.	n.a.	n.a.
Uganda	0.00	1.32	n.a.	n.a.
Zambia	0.00	4.85	n.a.	n.a.
Zimbabwe	n.a.	14.52	n.a.	n.a.
World	**0.30**	**0.22**	**0.16**	**0.01**

Note: Values are rounded to the nearest one-hundredth percent; electricity subsidies are taken from 2009 for 31 countries and natural gas data are taken from 2010 for four countries.

World estimates are calculated as identified subsidies divided by global GDP.

Sources: Staff estimates, Organisation for Economic Co-operation and Development, International Energy Agency, Deutsche Gesellschaft für Internationale Zusammenarbeit, IMF *World Economic Outlook*, and World Bank.

Appendix Table 3. Pre-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011[23]

(Percent of government revenues)

Country	Petroleum products	Electricity	Natural gas	Coal
Advanced				
Australia	0.00	n.a.	n.a.	0.01
Austria	0.00	n.a.	n.a.	n.a.
Belgium	0.00	n.a.	n.a.	n.a.
Canada	0.00	n.a.	n.a.	0.00
Cyprus	0.00	n.a.	n.a.	n.a.
Czech Republic	0.00	n.a.	n.a.	0.00
Denmark	0.00	n.a.	n.a.	n.a.
Estonia	0.00	n.a.	n.a.	n.a.
Finland	0.00	n.a.	n.a.	n.a.
France	0.00	n.a.	n.a.	n.a.
Germany	0.00	n.a.	n.a.	0.17
Greece	0.00	n.a.	n.a.	n.a.
Hong Kong SAR	0.00	n.a.	n.a.	n.a.
Iceland	0.00	n.a.	n.a.	n.a.
Ireland	0.00	n.a.	n.a.	0.14
Israel	0.00	n.a.	n.a.	n.a.
Italy	0.00	n.a.	n.a.	n.a.
Japan	0.00	n.a.	n.a.	n.a.
Korea	0.00	n.a.	0.00	0.06
Luxembourg	0.00	n.a.	n.a.	n.a.
Malta	0.00	n.a.	n.a.	n.a.
Netherlands	0.00	n.a.	n.a.	n.a.
New Zealand	0.30	n.a.	n.a.	n.a.
Norway	0.00	n.a.	n.a.	n.a.
Portugal	0.00	n.a.	n.a.	n.a.
Singapore	0.00	n.a.	n.a.	n.a.
Slovak Republic	0.00	n.a.	n.a.	0.02
Slovenia	0.00	n.a.	n.a.	0.05
Spain	0.00	n.a.	n.a.	0.08
Sweden	0.00	n.a.	n.a.	n.a.
Switzerland	0.00	n.a.	n.a.	n.a.
Taiwan Province of China	n.a.	1.16	0.00	0.17
United Kingdom	0.00	n.a.	n.a.	n.a.
United States	0.17	n.a.	n.a.	0.01

[23]These subsidy estimates may differ from those in the country budget documents due to the methodologies described in this appendix.

Appendix Table 3. Pre-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011 (Continued)

(Percent of government revenues)

Country	Petroleum products	Electricity	Natural gas	Coal
CEE-CIS				
Albania	0.00	n.a.	n.a.	n.a.
Armenia	2.06	0.22	n.a.	n.a.
Azerbaijan	1.85	1.59	2.54	0.00
Belarus	0.00	0.62	n.a.	n.a.
Bosnia and Herzegovina	0.00	n.a.	n.a.	n.a.
Bulgaria	0.00	n.a.	n.a.	n.a.
Croatia	0.00	n.a.	n.a.	n.a.
Georgia	1.95	n.a.	n.a.	n.a.
Hungary	0.00	n.a.	n.a.	0.00
Kazakhstan	2.33	3.38	0.55	1.01
Kosovo	0.00	n.a.	n.a.	n.a.
Kyrgyz Republic	10.41	16.30	n.a.	n.a.
Latvia	0.00	n.a.	n.a.	n.a.
Lithuania	0.00	n.a.	n.a.	n.a.
Macedonia, FYR	0.00	n.a.	n.a.	n.a.
Moldova	0.00	n.a.	n.a.	n.a.
Mongolia	0.00	n.a.	n.a.	n.a.
Montenegro, Rep. of	0.00	n.a.	n.a.	n.a.
Poland	0.00	n.a.	n.a.	0.36
Romania	0.00	n.a.	n.a.	n.a.
Russia	0.00	2.58	2.85	0.00
Serbia	0.00	n.a.	n.a.	n.a.
Tajikistan	0.00	7.85	n.a.	n.a.
Turkey	0.00	n.a.	n.a.	0.07
Turkmenistan	31.84	12.29	78.48	n.a.
Ukraine	0.00	3.80	8.47	n.a.
Uzbekistan	0.06	14.20	46.94	n.a.
Emerging and Developing Asia				
Afghanistan	0.00	0.52	n.a.	n.a.
Bangladesh	7.56	22.12	13.45	0.00
Bhutan	1.39	n.a.	n.a.	n.a.
Brunei Darussalam	3.77	1.57	0.00	0.00
Cambodia	0.00	n.a.	n.a.	n.a.
China	0.00	0.68	n.a.	n.a.
Fiji	0.05	n.a.	n.a.	n.a.
India	6.75	1.72	0.90	0.00
Indonesia	14.51	3.69	0.00	0.00
Kiribati	n.a.	n.a.	n.a.	n.a.
Lao P.D.R.	0.00	n.a.	n.a.	n.a.
Malaysia	5.67	1.49	1.41	0.00
Maldives	0.61	n.a.	n.a.	n.a.
Myanmar	9.35	n.a.	n.a.	n.a.
Nepal	0.00	n.a.	n.a.	n.a.
Pakistan	1.02	10.23	19.89	0.00
Papua New Guinea	n.a.	n.a.	n.a.	n.a.
Philippines	0.00	0.00	0.00	0.00
Samoa	n.a.	n.a.	n.a.	n.a.
Solomon Islands	0.00	n.a.	n.a.	n.a.
Sri Lanka	7.99	3.26	0.00	0.00
Thailand	0.66	7.24	0.61	1.08
Timor-Leste	0.00	n.a.	n.a.	n.a.
Tonga	0.00	n.a.	n.a.	n.a.
Tuvalu	0.00	n.a.	n.a.	n.a.
Vanuatu	0.00	n.a.	n.a.	n.a.

Appendix Table 3. Pre-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011 (Continued)

(Percent of government revenues)

Country	Petroleum products	Electricity	Natural gas	Coal
LAC				
Antigua and Barbuda	2.36	n.a.	n.a.	n.a.
Argentina	0.00	2.76	2.06	0.00
Bahamas, The	0.00	n.a.	n.a.	n.a.
Barbados	0.10	n.a.	n.a.	n.a.
Belize	0.00	n.a.	n.a.	n.a.
Bolivia	6.62	n.a.	n.a.	n.a.
Brazil	0.00	n.a.	n.a.	n.a.
Chile	0.00	0.00	0.00	0.00
Colombia	0.00	0.00	0.00	0.00
Costa Rica	0.00	n.a.	n.a.	n.a.
Dominica	0.00	n.a.	n.a.	n.a.
Dominican Republic	0.00	n.a.	n.a.	n.a.
Ecuador	15.44	0.44	0.00	0.00
El Salvador	0.00	0.00	0.00	0.00
Grenada	0.00	n.a.	n.a.	n.a.
Guatemala	0.00	n.a.	n.a.	n.a.
Guyana	0.00	n.a.	n.a.	n.a.
Haiti	n.a.	n.a.	n.a.	n.a.
Honduras	0.09	n.a.	n.a.	n.a.
Jamaica	0.00	n.a.	n.a.	n.a.
Mexico	0.00	0.00	0.00	0.00
Nicaragua	0.00	n.a.	n.a.	n.a.
Panama	0.08	n.a.	n.a.	n.a.
Paraguay	0.00	n.a.	n.a.	n.a.
Peru	0.00	0.00	0.00	0.00
St. Kitts and Nevis	0.55	n.a.	n.a.	n.a.
St. Lucia	0.68	n.a.	n.a.	n.a.
St. Vincent and the Grenadines	0.00	n.a.	n.a.	n.a.
Suriname	0.00	n.a.	n.a.	n.a.
Trinidad and Tobago	7.49	n.a.	n.a.	n.a.
Uruguay	0.00	n.a.	n.a.	n.a.
Venezuela	15.83	2.89	1.66	n.a.

Appendix Table 3. Pre-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011 (Continued)

(Percent of government revenues)

Country	Petroleum products	Electricity	Natural gas	Coal
MENA				
Algeria	10.84	2.72	13.52	0.00
Bahrain	18.96	9.08	n.a.	n.a.
Djibouti	0.00	1.32	n.a.	n.a.
Egypt	30.61	10.44	7.25	0.00
Iran	16.95	14.54	19.45	0.00
Iraq	12.69	1.78	0.32	0.00
Jordan	8.13	14.41	n.a.	n.a.
Kuwait	4.57	4.30	1.91	0.00
Lebanon	0.32	18.96	n.a.	n.a.
Libya	16.64	4.80	1.53	0.00
Mauritania	0.00	3.09	2.91	n.a.
Morocco	2.40	n.a.	n.a.	n.a.
Oman	7.28	1.83	5.31	n.a.
Qatar	3.17	3.12	2.78	0.00
Saudi Arabia	14.00	4.66	0.00	0.00
Sudan	7.33	n.a.	n.a.	n.a.
Syria	n.a.	n.a.	n.a.	n.a.
Tunisia	2.42	7.02	n.a.	n.a.
United Arab Emirates	1.38	5.32	9.61	n.a.
Yemen	19.03	5.42	n.a.	n.a.
Sub-Saharan Africa				
Angola	2.67	0.55	0.00	0.00
Benin	0.00	8.84	n.a.	n.a.
Botswana	0.07	1.21	n.a.	n.a.
Burkina Faso	0.00	3.59	n.a.	n.a.
Burundi	0.00	n.a.	n.a.	n.a.
Cameroon	8.92	11.42	n.a.	n.a.
Cape Verde	0.00	8.66	n.a.	n.a.
Central African Republic	0.00	n.a.	n.a.	n.a.
Chad	0.00	0.00	n.a.	n.a.
Comoros	n.a.	n.a.	n.a.	n.a.
Congo, Democratic Republic of the	0.00	5.75	n.a.	n.a.
Congo, Republic of	2.82	6.17	n.a.	n.a.
Côte d'Ivoire	0.00	13.43	n.a.	n.a.
Equatorial Guinea	0.92	n.a.	n.a.	n.a.
Eritrea	n.a.	n.a.	n.a.	n.a.
Ethiopia	1.12	7.40	n.a.	n.a.
Gabon	0.56	n.a.	n.a.	n.a.
Gambia, The	0.00	n.a.	n.a.	n.a.
Ghana	3.20	14.70	n.a.	n.a.
Guinea	0.00	n.a.	n.a.	n.a.
Guinea-Bissau	0.00	n.a.	n.a.	n.a.
Kenya	0.00	0.00	n.a.	n.a.
Lesotho	0.00	1.61	n.a.	n.a.
Liberia	0.00	n.a.	n.a.	n.a.
Madagascar	0.95	7.86	n.a.	n.a.

Appendix Table 3. Pre-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011 (Concluded)

(Percent of government revenues)

Country	Petroleum products	Electricity	Natural gas	Coal
Sub-Saharan Africa, concluded.				
Malawi	0.00	5.43	n.a.	n.a.
Mali	0.00	3.98	n.a.	n.a.
Mauritius	0.00	n.a.	n.a.	n.a.
Mozambique	0.00	16.40	n.a.	n.a.
Namibia	0.00	1.82	n.a.	n.a.
Niger	0.00	0.00	n.a.	n.a.
Nigeria	4.82	4.44	0.00	0.00
Rwanda	0.00	1.14	n.a.	n.a.
São Tomé and Príncipe	0.90	n.a.	n.a.	n.a.
Senegal	0.00	10.08	n.a.	n.a.
Seychelles	0.00	n.a.	n.a.	n.a.
Sierra Leone	0.00	n.a.	n.a.	n.a.
South Africa	0.02	2.01	0.00	0.00
Swaziland	0.00	n.a.	n.a.	n.a.
Tanzania	0.00	9.50	n.a.	n.a.
Togo	0.00	n.a.	n.a.	n.a.
Uganda	0.00	8.95	n.a.	n.a.
Zambia	0.00	21.59	n.a.	n.a.
Zimbabwe	n.a.	47.02	n.a.	n.a.
World	**0.91**	**0.64**	**0.48**	**0.03**

Note: Values are rounded to the nearest one-hundredth percent; electricity subsidies are taken from 2009 for 31 countries and natural gas data are taken from 2010 for four countries.

World estimates are calculated as identified subsidies divided by global government revenues.

Sources: Staff estimates, Organisation for Economic Co-operation and Development, International Energy Agency, Deutsche Gesellschaft für Internationale Zusammenarbeit, IMF *World Economic Outlook*, and World Bank.

Appendix Table 4. Post-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011[24]

(Percent of GDP by region)

Country	Petroleum products	Electricity	Natural gas	Coal
Advanced				
Australia	1.11	n.a.	0.13	0.55
Austria	0.13	n.a.	0.12	0.16
Belgium	0.00	n.a.	0.21	0.09
Canada	1.00	n.a.	0.31	0.21
Cyprus	0.58	n.a.	n.a.	0.01
Czech Republic	0.00	n.a.	0.27	1.37
Denmark	0.00	n.a.	0.08	0.18
Estonia	0.09	n.a.	0.15	2.58
Finland	0.00	n.a.	0.07	0.33
France	0.00	n.a.	0.10	0.07
Germany	0.00	n.a.	0.14	0.46
Greece	0.00	n.a.	0.08	0.44
Hong Kong SAR	0.40	n.a.	0.08	0.70
Iceland	0.00	n.a.	n.a.	0.11
Ireland	0.13	n.a.	0.13	0.22
Israel	0.00	n.a.	0.10	0.54
Italy	0.00	n.a.	0.23	0.11
Japan	0.35	n.a.	0.11	0.32
Korea	0.03	n.a.	0.24	1.23
Luxembourg	3.56	n.a.	0.12	0.03
Malta	0.07	n.a.	n.a.	n.a.
Netherlands	0.00	n.a.	0.31	0.17
New Zealand	1.58	n.a.	0.12	0.16
Norway	0.00	n.a.	0.07	0.04
Portugal	0.00	n.a.	0.12	0.15
Singapore	1.03	n.a.	0.19	0.01
Slovak Republic	0.00	n.a.	0.37	0.62
Slovenia	0.24	n.a.	0.09	0.50
Spain	0.13	n.a.	0.13	0.17
Sweden	0.09	n.a.	0.01	0.07
Switzerland	0.04	n.a.	0.03	0.00
Taiwan Province of China	n.a.	0.28	0.17	1.66
United Kingdom	0.00	n.a.	0.23	0.22
United States	2.42	n.a.	0.27	0.64

[24]The estimate for Luxembourg reflects, to a large extent, cross-border sales of petroleum products to neighboring countries, with buyers attracted by lower tax rates.

Appendix Table 4. Post-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011 (Continued)

(Percent of GDP by region)

Country	Petroleum products	Electricity	Natural gas	Coal
CEE-CIS				
Albania	0.00	n.a.	0.01	0.01
Armenia	0.84	0.40	0.86	n.a.
Azerbaijan	2.26	0.91	1.90	0.00
Belarus	0.00	0.98	2.46	n.a.
Bosnia and Herzegovina	0.00	n.a.	0.07	3.41
Bulgaria	0.00	n.a.	0.26	2.18
Croatia	0.00	n.a.	0.33	0.22
Georgia	0.74	n.a.	0.44	0.05
Hungary	0.08	n.a.	0.59	0.30
Kazakhstan	2.22	0.97	0.96	2.81
Kosovo	0.00	n.a.	n.a.	0.02
Kyrgyz Republic	6.80	5.71	0.27	1.36
Latvia	0.00	n.a.	0.41	0.11
Lithuania	0.00	n.a.	0.39	0.11
Macedonia, FYR	0.00	n.a.	0.09	1.28
Moldova	0.00	n.a.	1.54	0.12
Mongolia	0.00	n.a.	n.a.	4.56
Montenegro, Rep. of	0.00	n.a.	n.a.	0.00
Poland	0.06	n.a.	0.19	1.84
Romania	0.00	n.a.	0.42	0.55
Russia	1.52	1.27	2.47	1.03
Serbia	0.00	n.a.	0.37	2.46
Tajikistan	0.11	2.50	0.22	0.14
Turkey	0.00	n.a.	0.31	0.66
Turkmenistan	8.31	2.39	19.92	n.a.
Ukraine	0.20	1.85	6.91	2.71
Uzbekistan	0.92	5.95	25.50	0.27
Emerging and Developing Asia				
Afghanistan	0.04	0.19	n.a.	n.a.
Bangladesh	1.35	3.01	2.54	0.09
Bhutan	1.21	n.a.	n.a.	n.a.
Brunei Darussalam	5.92	1.37	1.12	0.00
Cambodia	0.00	n.a.	n.a.	0.00
China	0.20	0.30	0.09	3.23
Fiji	0.13	n.a.	n.a.	n.a.
India	1.90	0.36	0.33	1.87
Indonesia	3.87	0.72	0.30	0.47
Kiribati	n.a.	n.a.	n.a.	n.a.
Lao P.D.R.	0.00	n.a.	n.a.	n.a.
Malaysia	5.12	0.56	0.79	0.74
Maldives	1.55	n.a.	n.a.	n.a.
Myanmar	0.97	n.a.	n.a.	n.a.
Nepal	0.16	n.a.	n.a.	0.11
Pakistan	0.98	1.63	3.34	0.16
Papua New Guinea	n.a.	n.a.	n.a.	n.a.
Philippines	0.20	0.00	0.08	0.46
Samoa	n.a.	n.a.	n.a.	n.a.
Solomon Islands	0.00	n.a.	n.a.	n.a.

Appendix Table 4. Post-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011 (Continued)

(Percent of GDP by region)

Country	Petroleum products	Electricity	Natural gas	Coal
Emerging and Developing Asia, concluded.				
Sri Lanka	2.02	0.75	0.00	0.03
Thailand	1.40	1.76	0.72	0.84
Timor-Leste	0.01	n.a.	n.a.	n.a.
Tonga	0.00	n.a.	n.a.	n.a.
Tuvalu	0.00	n.a.	n.a.	n.a.
Vanuatu	0.00	n.a.	n.a.	n.a.
LAC				
Antigua and Barbuda	1.58	n.a.	n.a.	n.a.
Argentina	0.31	1.15	1.33	0.09
Bahamas, The	1.40	n.a.	n.a.	n.a.
Barbados	0.42	n.a.	n.a.	n.a.
Belize	0.00	n.a.	n.a.	n.a.
Bolivia	4.88	n.a.	0.70	n.a.
Brazil	0.06	n.a.	0.07	0.07
Chile	2.36	0.00	0.09	0.32
Colombia	0.00	0.00	0.17	0.20
Costa Rica	0.30	n.a.	n.a.	0.02
Dominica	1.13	n.a.	n.a.	n.a.
Dominican Republic	0.03	n.a.	0.11	0.13
Ecuador	9.70	0.33	0.05	0.00
El Salvador	0.75	0.00	0.00	0.00
Grenada	0.96	n.a.	n.a.	n.a.
Guatemala	0.72	n.a.	n.a.	0.33
Guyana	1.00	n.a.	n.a.	n.a.
Haiti	n.a.	n.a.	n.a.	n.a.
Honduras	0.43	n.a.	n.a.	0.01
Jamaica	0.41	n.a.	n.a.	0.04
Mexico	1.98	0.00	0.29	0.12
Nicaragua	0.01	n.a.	n.a.	n.a.
Panama	2.20	n.a.	n.a.	0.02
Paraguay	0.00	n.a.	n.a.	n.a.
Peru	0.22	0.00	0.24	0.03
St. Kitts and Nevis	1.19	n.a.	n.a.	n.a.
St. Lucia	0.82	n.a.	n.a.	n.a.
St. Vincent and the Grenadines	0.83	n.a.	n.a.	n.a.
Suriname	0.00	n.a.	n.a.	n.a.
Trinidad and Tobago	5.78	n.a.	4.45	n.a.
Uruguay	0.00	n.a.	0.01	0.00
Venezuela	8.11	1.24	1.05	0.00

Appendix Table 4. Post-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011 (Continued)

(Percent of GDP by region)

Country	Petroleum products	Electricity	Natural gas	Coal
MENA				
Algeria	6.11	1.15	6.07	0.00
Bahrain	10.01	2.96	1.87	n.a.
Djibouti	0.07	0.51	n.a.	n.a.
Egypt	8.60	2.50	2.59	0.05
Iran	7.66	3.64	6.39	0.02
Iraq	14.30	1.57	0.31	0.00
Jordan	5.27	4.10	0.34	n.a.
Kuwait	6.86	3.12	1.81	0.00
Lebanon	3.57	4.61	0.17	0.11
Libya	8.81	2.33	1.49	0.00
Mauritania	0.73	0.93	0.80	n.a.
Morocco	2.83	n.a.	0.04	0.33
Oman	6.54	0.94	3.34	n.a.
Qatar	5.42	1.26	1.76	0.00
Saudi Arabia	13.27	2.79	0.65	0.00
Sudan	2.26	n.a.	n.a.	n.a.
Syria	n.a.	n.a.	n.a.	n.a.
Tunisia	2.56	2.43	0.70	n.a.
United Arab Emirates	3.49	2.04	4.26	0.04
Yemen	6.89	1.47	1.05	n.a.
Sub-Saharan Africa				
Angola	2.51	0.31	0.04	0.00
Benin	0.17	2.01	n.a.	n.a.
Botswana	0.89	0.48	n.a.	0.34
Burkina Faso	0.29	0.94	n.a.	n.a.
Burundi	0.00	n.a.	n.a.	n.a.
Cameroon	2.49	2.41	0.05	n.a.
Cape Verde	0.00	2.57	n.a.	n.a.
Central African Republic	0.00	n.a.	n.a.	n.a.
Chad	0.00	0.02	n.a.	n.a.
Comoros	n.a.	n.a.	n.a.	n.a.
Congo, Democratic Republic of the	0.00	1.80	0.00	0.09
Congo, Republic of	2.08	2.66	0.01	n.a.
Côte d'Ivoire	0.00	2.96	0.39	n.a.
Equatorial Guinea	1.88	n.a.	n.a.	n.a.
Eritrea	n.a.	n.a.	n.a.	n.a.

Appendix Table 4. Post-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011 (Concluded)

(Percent of GDP by region)

Country	Petroleum products	Electricity	Natural gas	Coal
Sub-Saharan Africa, concluded				
Ethiopia	0.62	1.32	n.a.	n.a.
Gabon	0.74	n.a.	0.06	n.a.
Gambia, The	0.00	n.a.	n.a.	n.a.
Ghana	1.85	3.02	n.a.	n.a.
Guinea	0.00	n.a.	n.a.	n.a.
Guinea-Bissau	0.00	n.a.	n.a.	n.a.
Kenya	0.51	0.16	n.a.	0.01
Lesotho	0.03	0.94	n.a.	n.a.
Liberia	0.00	n.a.	n.a.	n.a.
Madagascar	0.41	0.98	n.a.	n.a.
Malawi	0.13	2.01	n.a.	n.a.
Mali	0.15	0.99	n.a.	n.a.
Mauritius	0.00	n.a.	n.a.	n.a.
Mozambique	0.24	5.07	0.09	0.01
Namibia	0.04	0.52	n.a.	0.07
Niger	0.20	0.17	n.a.	n.a.
Nigeria	2.04	1.34	0.19	0.00
Rwanda	0.00	0.39	n.a.	n.a.
São Tomé and Príncipe	0.59	n.a.	n.a.	n.a.
Senegal	0.00	2.51	0.01	0.16
Seychelles	0.00	n.a.	n.a.	n.a.
Sierra Leone	0.45	n.a.	n.a.	n.a.
South Africa	1.06	0.73	0.00	2.46
Swaziland	0.00	n.a.	n.a.	n.a.
Tanzania	0.00	2.26	0.19	0.03
Togo	0.72	n.a.	n.a.	n.a.
Uganda	0.00	1.45	n.a.	n.a.
Zambia	0.00	4.96	n.a.	0.00
Zimbabwe	n.a.	14.89	n.a.	2.13
World	**1.26**	**0.26**	**0.43**	**0.77**

Note: Values are rounded to the nearest one-hundredth percent; electricity subsidies are taken from 2009 for 31 countries and natural gas data are taken from 2010 for four countries.

World estimates are calculated as identified subsidies divided by global GDP.

Sources: Staff estimates, Organisation for Economic Co-operation and Development, International Energy Agency, Deutsche Gesellschaft für Internationale Zusammenarbeit, IMF *World Economic Outlook*, and World Bank.

Appendix Table 5. Post-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011[25]

(Percent of government revenues)

Country	Petroleum products	Electricity	Natural gas	Coal
Advanced				
Australia	3.46	n.a.	0.40	1.71
Austria	0.27	n.a.	0.26	0.34
Belgium	0.00	n.a.	0.42	0.19
Canada	2.61	n.a.	0.80	0.55
Cyprus	1.41	n.a.	n.a.	0.02
Czech Republic	0.00	n.a.	0.68	3.39
Denmark	0.00	n.a.	0.15	0.32
Estonia	0.20	n.a.	0.34	5.84
Finland	0.00	n.a.	0.14	0.60
France	0.00	n.a.	0.20	0.13
Germany	0.00	n.a.	0.31	1.04
Greece	0.00	n.a.	0.20	1.09
Hong Kong SAR	1.63	n.a.	0.33	2.85
Iceland	0.00	n.a.	n.a.	0.26
Ireland	0.38	n.a.	0.39	0.65
Israel	0.00	n.a.	0.26	1.34
Italy	0.00	n.a.	0.50	0.24
Japan	1.13	n.a.	0.37	1.06
Korea	0.11	n.a.	1.03	5.25
Luxembourg	8.58	n.a.	0.29	0.07
Malta	0.18	n.a.	n.a.	n.a.
Netherlands	0.00	n.a.	0.67	0.36
New Zealand	5.43	n.a.	0.43	0.53
Norway	0.00	n.a.	0.11	0.06
Portugal	0.00	n.a.	0.27	0.33
Singapore	4.15	n.a.	0.75	0.04
Slovak Republic	0.00	n.a.	1.13	1.91
Slovenia	0.59	n.a.	0.23	1.21
Spain	0.36	n.a.	0.36	0.48
Sweden	0.17	n.a.	0.03	0.15
Switzerland	0.11	n.a.	0.08	0.01
Taiwan Province of China	n.a.	1.48	0.92	8.82
United Kingdom	0.00	n.a.	0.61	0.61
United States	7.70	n.a.	0.87	2.05

[25]The estimate for Luxembourg reflects, to a large extent, cross-border sales of petroleum products to neighboring countries, with buyers attracted by lower tax rates.

Appendix Table 5. Post-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011 (Continued)

(Percent of government revenues)

Country	Petroleum products	Electricity	Natural gas	Coal
CEE-CIS				
Albania	0.00	n.a.	0.04	0.05
Armenia	3.86	1.81	3.93	n.a.
Azerbaijan	4.96	2.00	4.18	0.00
Belarus	0.00	2.32	5.86	n.a.
Bosnia and Herzegovina	0.00	n.a.	0.16	7.35
Bulgaria	0.00	n.a.	0.81	6.72
Croatia	0.00	n.a.	0.89	0.60
Georgia	2.62	n.a.	1.55	0.19
Hungary	0.15	n.a.	1.11	0.56
Kazakhstan	7.99	3.49	3.45	10.11
Kosovo	0.00	n.a.	n.a.	0.06
Kyrgyz Republic	20.39	17.13	0.81	4.07
Latvia	0.00	n.a.	1.14	0.30
Lithuania	0.00	n.a.	1.17	0.33
Macedonia, FYR	0.00	n.a.	0.31	4.46
Moldova	0.00	n.a.	4.20	0.34
Mongolia	0.00	n.a.	n.a.	11.49
Montenegro, Rep. of	0.00	n.a.	n.a.	0.00
Poland	0.15	n.a.	0.51	4.79
Romania	0.00	n.a.	1.34	1.74
Russia	3.96	3.30	6.45	2.67
Serbia	0.00	n.a.	0.89	6.00
Tajikistan	0.45	10.04	0.87	0.57
Turkey	0.00	n.a.	0.91	1.91
Turkmenistan	44.05	12.67	105.63	n.a.
Ukraine	0.48	4.36	16.31	6.40
Uzbekistan	2.28	14.80	63.40	0.67
Emerging and Developing Asia				
Afghanistan	0.20	0.86	n.a.	n.a.
Bangladesh	11.30	25.26	21.31	0.71
Bhutan	3.31	n.a.	n.a.	n.a.
Brunei Darussalam	9.51	2.19	1.81	0.00
Cambodia	0.00	n.a.	n.a.	0.01
China	0.88	1.34	0.42	14.27
Fiji	0.53	n.a.	n.a.	n.a.
India	10.24	1.97	1.79	10.08
Indonesia	21.74	4.04	1.67	2.62
Kiribati	n.a.	n.a.	n.a.	n.a.
Lao P.D.R.	0.00	n.a.	n.a.	n.a.
Malaysia	23.39	2.54	3.63	3.38
Maldives	4.97	n.a.	n.a.	n.a.
Myanmar	16.93	n.a.	n.a.	n.a.
Nepal	0.88	n.a.	n.a.	0.62
Pakistan	7.70	12.76	26.13	1.22
Papua New Guinea	n.a.	n.a.	n.a.	n.a.
Philippines	1.18	0.00	0.43	2.65
Samoa	n.a.	n.a.	n.a.	n.a.
Solomon Islands	0.00	n.a.	n.a.	n.a.

Appendix Table 5. Post-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011 (Continued)

(Percent of government revenues)

Country	Petroleum products	Electricity	Natural gas	Coal
Emerging and Developing Asia, concluded.				
Sri Lanka	13.89	5.17	0.00	0.19
Thailand	6.16	7.77	3.19	3.73
Timor-Leste	0.01	n.a.	n.a.	n.a.
Tonga	0.00	n.a.	n.a.	n.a.
Tuvalu	0.00	n.a.	n.a.	n.a.
Vanuatu	0.00	n.a.	n.a.	n.a.
LAC				
Antigua and Barbuda	7.64	n.a.	n.a.	n.a.
Argentina	0.84	3.08	3.58	0.25
Bahamas, The	7.79	n.a.	n.a.	n.a.
Barbados	1.16	n.a.	n.a.	n.a.
Belize	0.00	n.a.	n.a.	n.a.
Bolivia	13.48	n.a.	1.94	n.a.
Brazil	0.16	n.a.	0.21	0.21
Chile	9.55	0.00	0.35	1.28
Colombia	0.00	0.00	0.65	0.74
Costa Rica	2.20	n.a.	n.a.	0.14
Dominica	3.64	n.a.	n.a.	n.a.
Dominican Republic	0.21	n.a.	0.85	0.98
Ecuador	23.74	0.80	0.12	0.00
El Salvador	4.21	0.00	0.00	0.00
Grenada	4.30	n.a.	n.a.	n.a.
Guatemala	6.12	n.a.	n.a.	2.82
Guyana	3.63	n.a.	n.a.	n.a.
Haiti	n.a.	n.a.	n.a.	n.a.
Honduras	1.81	n.a.	n.a.	0.03
Jamaica	1.61	n.a.	n.a.	0.16
Mexico	8.95	0.00	1.29	0.55
Nicaragua	0.02	n.a.	n.a.	n.a.
Panama	8.88	n.a.	n.a.	0.06
Paraguay	0.00	n.a.	n.a.	n.a.
Peru	1.02	0.00	1.13	0.15
St. Kitts and Nevis	3.21	n.a.	n.a.	n.a.
St. Lucia	3.00	n.a.	n.a.	n.a.
St. Vincent and the Grenadines	3.17	n.a.	n.a.	n.a.
Suriname	0.00	n.a.	n.a.	n.a.
Trinidad and Tobago	15.71	n.a.	12.11	n.a.
Uruguay	0.00	n.a.	0.04	0.00
Venezuela	23.00	3.52	2.97	0.01

Appendix Table 5. Post-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011 (Continued)

(Percent of government revenues)

Country	Petroleum products	Electricity	Natural gas	Coal
MENA				
Algeria	15.40	2.89	15.31	0.00
Bahrain	35.36	10.44	6.61	n.a.
Djibouti	0.19	1.49	n.a.	n.a.
Egypt	39.07	11.35	11.79	0.23
Iran	30.89	14.66	25.75	0.07
Iraq	18.31	2.01	0.40	0.00
Jordan	19.94	15.49	1.30	n.a.
Kuwait	10.15	4.62	2.68	0.00
Lebanon	15.17	19.59	0.71	0.45
Libya	22.91	6.04	3.86	0.00
Mauritania	2.65	3.37	2.91	n.a.
Morocco	10.27	n.a.	0.13	1.21
Oman	15.80	2.27	8.06	n.a.
Qatar	14.05	3.26	4.56	0.00
Saudi Arabia	24.91	5.23	1.23	0.00
Sudan	12.11	n.a.	n.a.	n.a.
Syria	n.a.	n.a.	n.a.	n.a.
Tunisia	8.07	7.66	2.19	n.a.
United Arab Emirates	9.96	5.82	12.15	0.11
Yemen	28.05	5.99	4.26	n.a.
Sub-Saharan Africa				
Angola	5.13	0.64	0.07	0.00
Benin	0.83	9.98	n.a.	n.a.
Botswana	3.01	1.64	n.a.	1.16
Burkina Faso	1.31	4.30	n.a.	n.a.
Burundi	0.00	n.a.	n.a.	n.a.
Cameroon	13.17	12.76	0.25	n.a.
Cape Verde	0.00	10.23	n.a.	n.a.
Central African Republic	0.00	n.a.	n.a.	n.a.
Chad	0.00	0.06	n.a.	n.a.
Comoros	n.a.	n.a.	n.a.	n.a.
Congo, Democratic Republic of the	0.00	6.57	0.01	0.32
Congo, Republic of	4.88	6.25	0.02	n.a.
Côte d'Ivoire	0.00	14.59	1.91	n.a.
Equatorial Guinea	6.09	n.a.	n.a.	n.a.
Eritrea	n.a.	n.a.	n.a.	n.a.

Appendix Table 5. Post-tax Subsidies for Petroleum Products, Electricity, Natural Gas, and Coal, 2011 (Concluded)

(Percent of government revenues)

Country	Petroleum products	Electricity	Natural gas	Coal
Sub-Saharan Africa, concluded				
Ethiopia	3.69	7.89	n.a.	n.a.
Gabon	2.62	n.a.	0.22	n.a.
Gambia, The	0.00	n.a.	n.a.	n.a.
Ghana	9.53	15.50	n.a.	n.a.
Guinea	0.00	n.a.	n.a.	n.a.
Guinea-Bissau	0.00	n.a.	n.a.	n.a.
Kenya	2.04	0.66	n.a.	0.02
Lesotho	0.06	1.77	n.a.	n.a.
Liberia	0.00	n.a.	n.a.	n.a.
Madagascar	3.65	8.73	n.a.	n.a.
Malawi	0.44	6.83	n.a.	n.a.
Mali	0.64	4.24	n.a.	n.a.
Mauritius	0.00	n.a.	n.a.	n.a.
Mozambique	0.79	16.89	0.30	0.05
Namibia	0.12	1.82	n.a.	0.25
Niger	1.02	0.88	n.a.	n.a.
Nigeria	6.94	4.55	0.64	0.00
Rwanda	0.00	1.50	n.a.	n.a.
São Tomé and Príncipe	1.59	n.a.	n.a.	n.a.
Senegal	0.00	11.22	0.03	0.72
Seychelles	0.00	n.a.	n.a.	n.a.
Sierra Leone	2.64	n.a.	n.a.	n.a.
South Africa	3.86	2.65	0.00	8.93
Swaziland	0.00	n.a.	n.a.	n.a.
Tanzania	0.00	10.23	0.84	0.12
Togo	3.35	n.a.	n.a.	n.a.
Uganda	0.00	9.79	n.a.	n.a.
Zambia	0.00	22.07	n.a.	0.00
Zimbabwe	n.a.	48.22	n.a.	6.90
World	**3.77**	**0.77**	**1.28**	**2.31**

Note: Values are rounded to the nearest one-hundredth percent; electricity subsidies are taken from 2009 for 31 countries and natural gas data are taken from 2010 for four countries.

World estimates are calculated as identified subsidies divided by global government revenues.

Sources: Staff estimates, Organisation for Economic Co-operation and Development, International Energy Agency, Deutsche Gesellschaft für Internationale Zusammenarbeit, IMF *World Economic Outlook*, and World Bank.

Appendix II. Assessing the Environmental and Health Impacts of Energy Subsidy Reform

This appendix describes the methodologies used to provide calculations of the impact of energy subsidy reform on CO_2 emissions, SO_2 emissions and other local pollutants. Here we consider a scenario in which energy prices are raised to levels that would eliminate tax-inclusive subsidies for petroleum products, coal, natural gas, and electricity.

Petroleum products

CO_2 emissions. A price elasticity of -0.4 is assumed for gasoline, diesel and kerosene (Parry, 2011). The reduction in CO_2 emissions is then calculated by multiplying the reduction in consumption by the CO_2 coefficient of 0.0089 tons per gallon of gasoline. The CO_2 coefficient is assumed to be 16 percent higher for diesel and kerosene (Parry, 2011).

Local pollution. The reduction (in percentage terms) in other local pollutants due to fossil fuel combustion is approximated by the reduction in fuel consumption. Fuel combustion produces only a small amount of SO_2, and thus the impact of petroleum subsidy removal on SO_2 is not estimated.

Coal

CO_2 emissions. The reduction (in percent) in coal consumption is calculated assuming a price elasticity of -0.2 (EIA, 2012).[26] The reduction in CO_2 emissions due to the removal of coal subsidies is then estimated as the same reduction (in percent) in total CO_2 emissions from coal, based on OECD data.

SO_2 emissions. This is estimated using an SO_2 coefficient of 0.01 tons of SO_2 per short ton of coal (EPA, 2012; EIA, 2012). Local pollution other than SO_2 from coal is considered minor.

Natural gas

The reduction (in percent) in natural gas consumption is calculated assuming a price elasticity of -0.3 (EIA, 2012). The reduction in CO_2 emissions is then estimated as the same percent reduction in total CO_2 emissions from natural gas, based on OECD data. As noted previously, the impact of natural gas use on local pollution is assumed to be relatively small.

[26]An upward adjustment is made to the EIA estimate as it is generally viewed as being on the conservative side.

Electricity

Electricity subsidies increase the consumption of coal, natural gas and other generation fuels due to excess demand for electricity. However, for several reasons these effects on emissions are not quantified in this paper: (i) in some countries, part of the electricity subsidies are due to inefficiencies in the electricity sector. In other words, part of the problem is not that prices are too low, but that costs are too high. Thus, successful subsidy reforms could reduce these inefficiencies without raising prices and suppressing demand; (ii) data limitations make it difficult to quantify the environmental impact of electricity subsidy removal. For example, price and cost data are limited and there is a lack of information on the marginal energy source for electricity generation, which may be different from the average; and (iii) the environmental impact of price increases in fuel, coal and natural gas as inputs for electricity generation is already incorporated in the calculations of these energy products. In addition, electricity subsidies are relatively small as a share of total post-tax subsidies, and thus, this omission is expected to only have a small impact on the overall estimates.

Caveats

The proposed methods here are used to provide some rough estimates on the magnitude of the impacts and have several limitations. For example, they do not take into account the substitution between different energy products and resulting offsetting effects.

Income Inequality: Evidence and Policy Implications

Emmanuel Saez, UC Berkeley

Arrow Lecture, Stanford

January 2013

INTRODUCTION

Free market economies generate substantial inequality

$\Rightarrow$ Main criticism of capitalism

Raises 2 important issues for economists:

1) Measuring and understanding inequality: What is the level of inequality? How does it change overtime? What factors drive inequality?

2) Should the government reduce inequality using redistributive policies such as taxes, transfer programs, and other regulations?

TOP INCOME SHARES

Simple way to measure inequality: what share of total **pre-tax market income** goes to the top 10%, top 1%, etc.

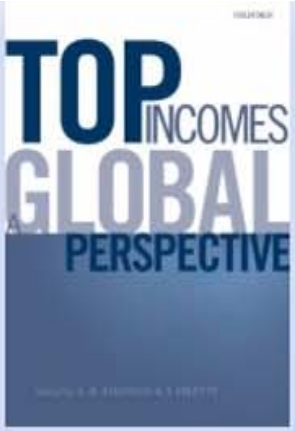
Income tax statistics are a valuable resource to construct such inequality series over long time periods and across countries [best source for top incomes]

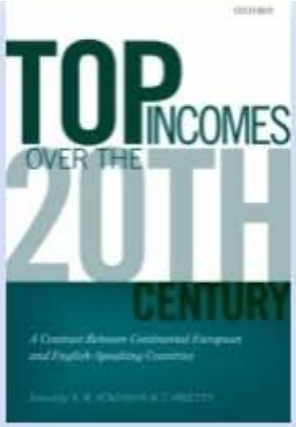
Piketty and Saez (2003) have analyzed US since 1913

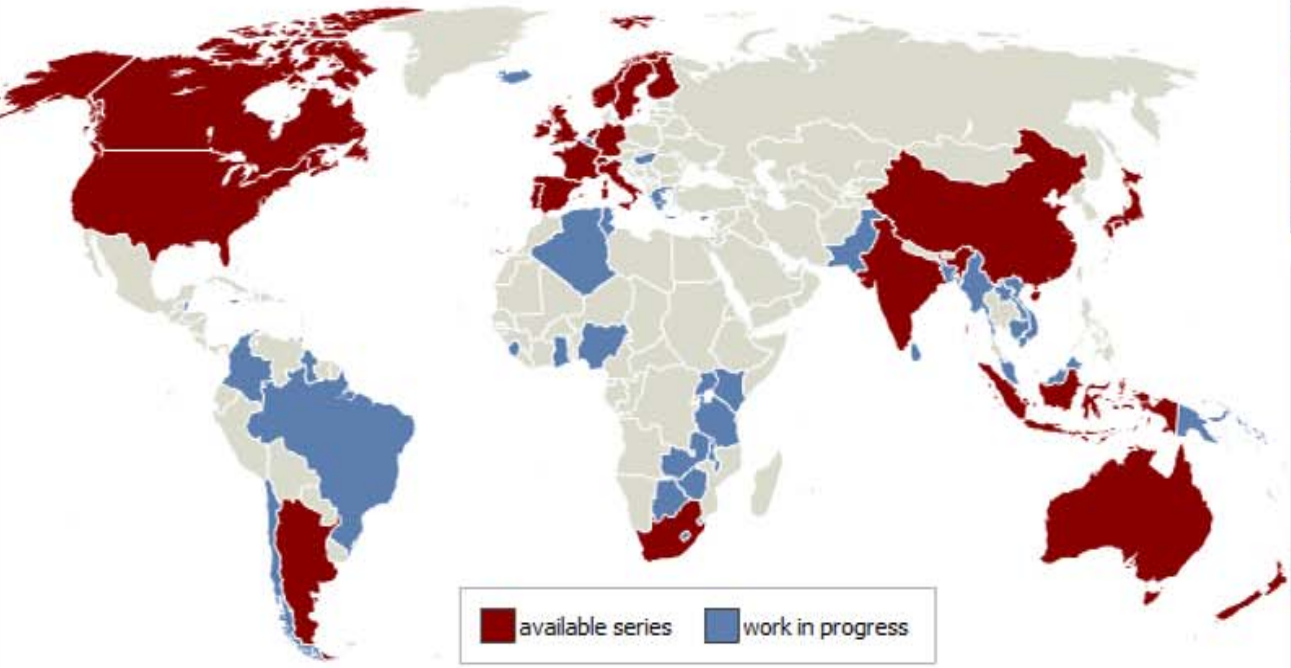
25 countries have now been analyzed

Studies summarized in Atkinson-Piketty-Saez JEL'11 and data online in **The World Top Incomes Database**

THE TOP INCOMES DATABASE







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- Graphics
- Country Information
- Work in Progress
- Acknowledgments

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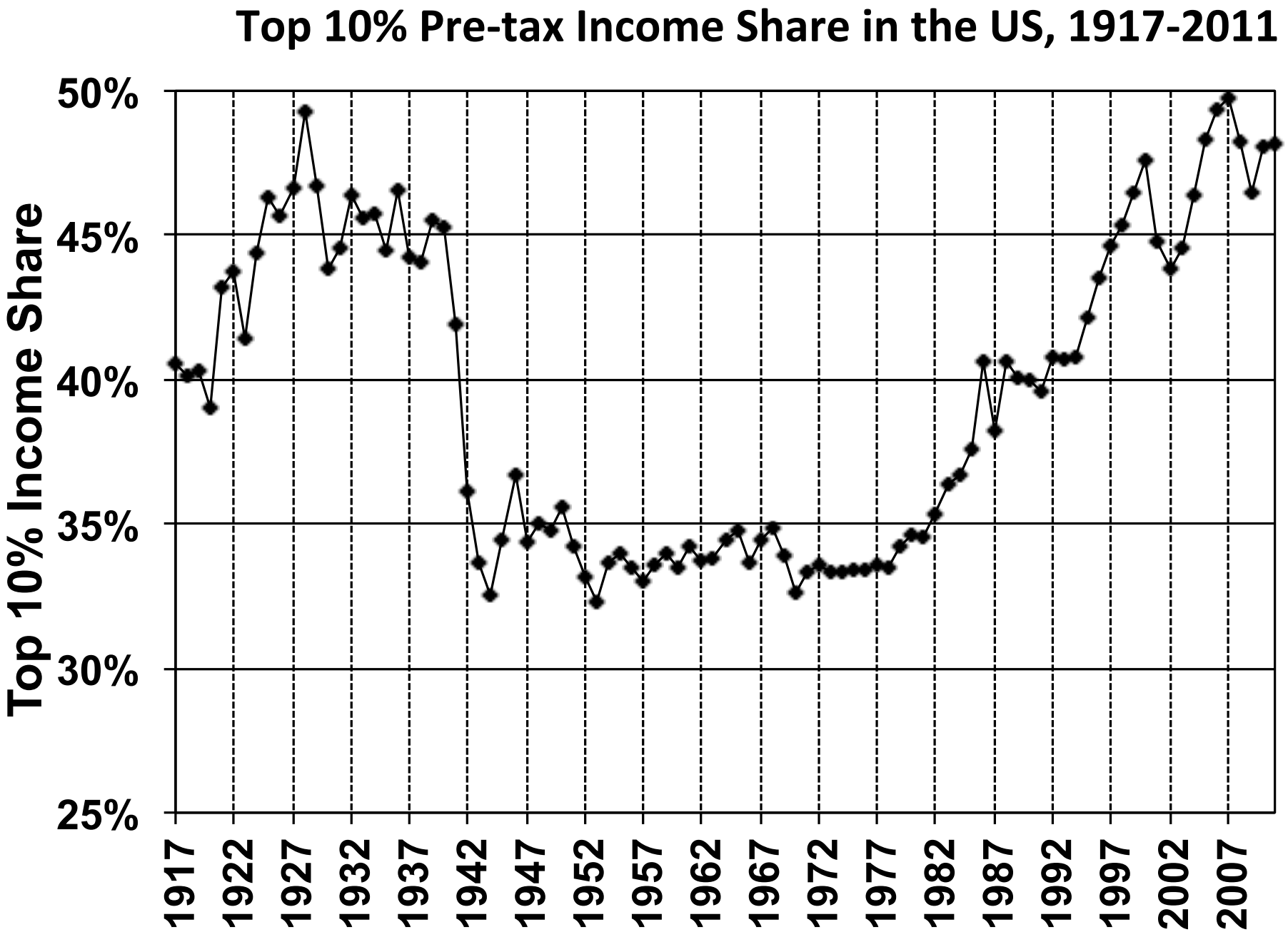
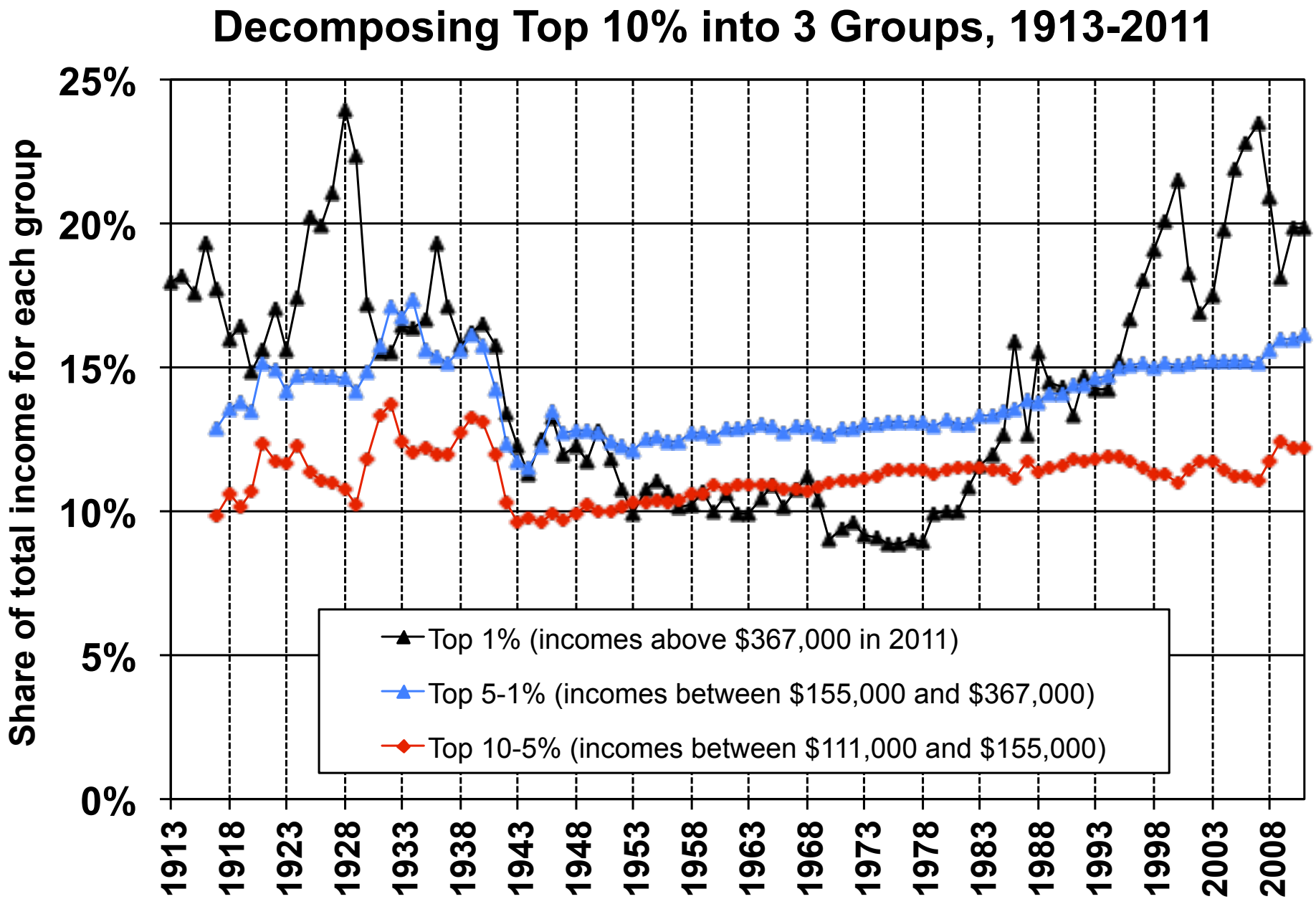
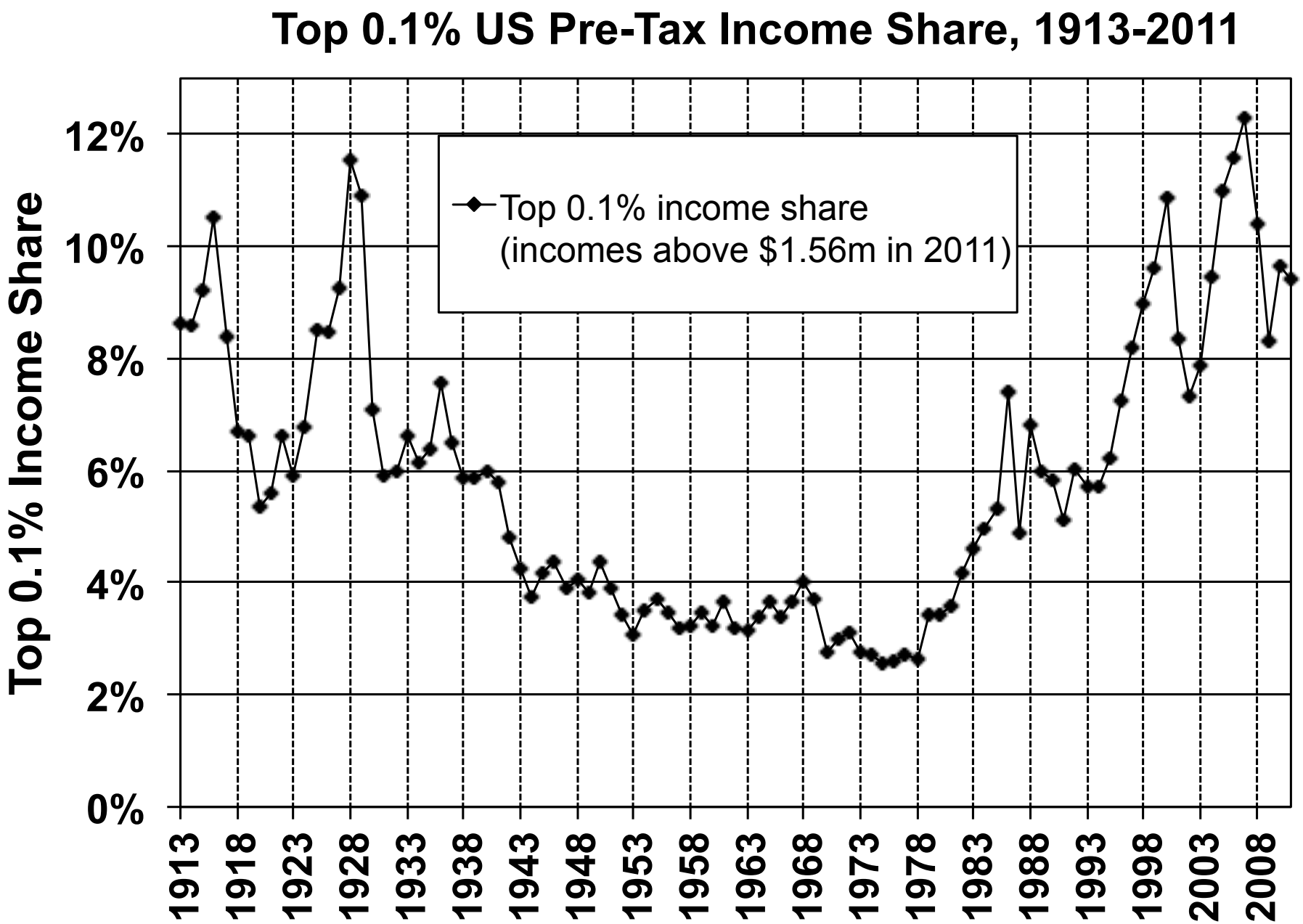


Source: Piketty and Saez, 2003 updated to 2011. Series based on pre-tax cash market income including realized capital gains and excluding government transfers.



Source: Piketty and Saez, 2003 updated to 2011. Series based on pre-tax cash market income including realized capital gains and excluding government transfers.



Source: Piketty and Saez, 2003 updated to 2011. Series based on pre-tax cash market income including or excluding realized capital gains, and always excluding government transfers.

WHY DO TOP INCOME SHARES MATTER?

1) Inequality matters because people evaluate their economic well-being relative to others, not in absolute terms

$\Rightarrow$ Public cares about inequality

2) Surge in US top 1% income share so large that income growth of bottom 99% is only half of average income growth

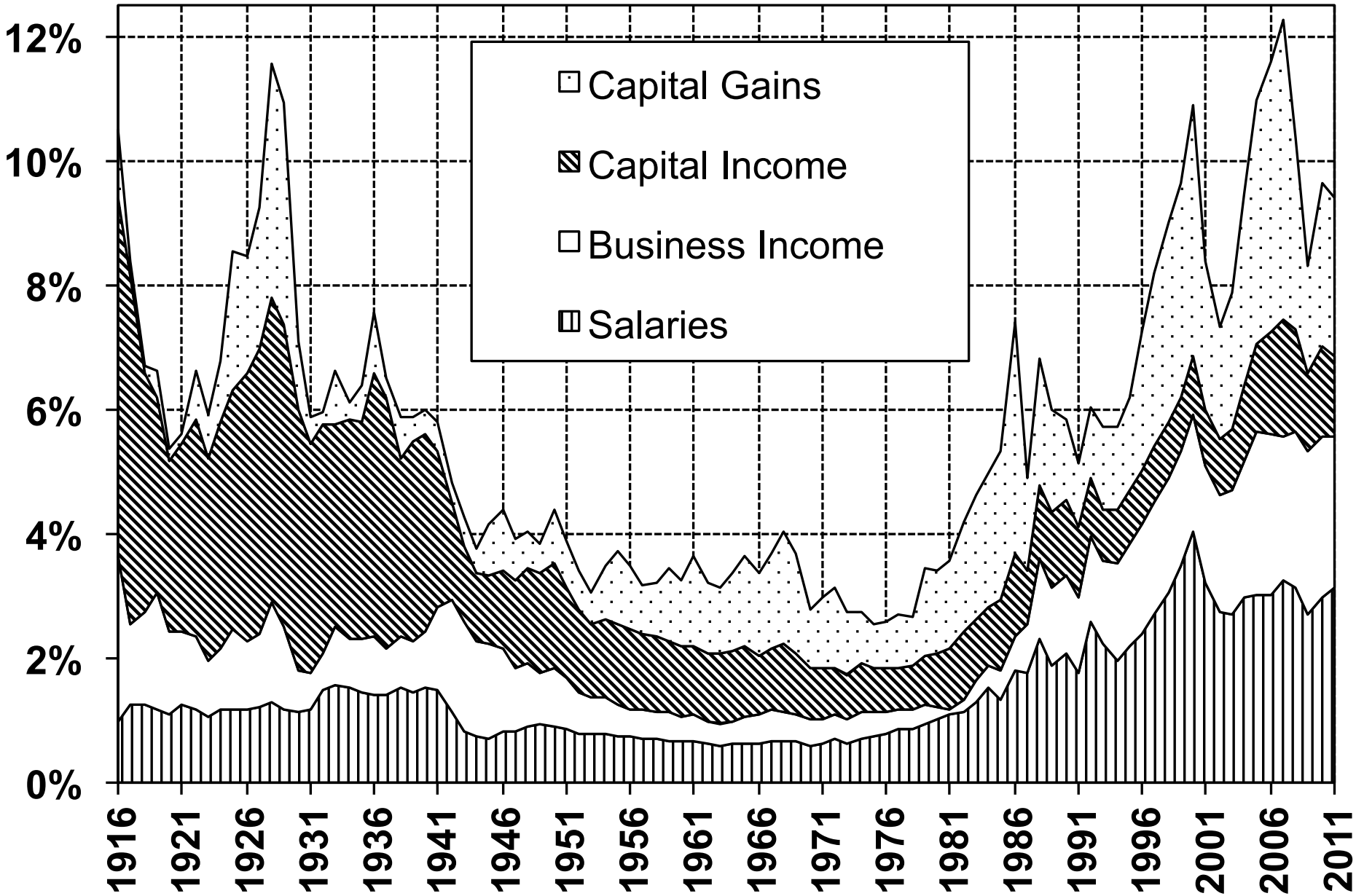
3) Surge in top incomes gives top earners more ability to influence political process (think-tanks, lobbying, campaign funds)

Table 1. Real Income Growth by Groups

	Average Income Real Growth (1)	Top 1% Incomes Real Growth (2)	Bottom 99% Incomes Real Growth (3)	Fraction of total growth (or loss) captured by top 1% (4)
Full period 1993-2011	**13.1%**	**57.5%**	**5.8%**	**62%**
Clinton Expansion 1993-2000	31.5%	98.7%	20.3%	45%
2001 Recession 2000-2002	-11.7%	-30.8%	-6.5%	57%
Bush Expansion 2002-2007	16.1%	61.8%	6.8%	65%
Great Recession 2007-2009	-17.4%	-36.3%	-11.6%	49%
Recovery 2009-2011	1.7%	11.2%	-0.4%	121%

Computations based on family market income including realized capital gains (before individual taxes).
Incomes exclude government transfers (such as unemployment insurance and social security) and non-taxable fringe benefits.
Incomes are deflated using the Consumer Price Index.

US Top 0.1% Pre-Tax Income Share and Composition



Source: Piketty and Saez, 2003 updated to 2011. Series based on pre-tax cash market income including or excluding realized capital gains, and always excluding government transfers.

SUMMARY OF US RESULTS

1) Dramatic reduction in income concentration during the first part of the 20th century

2) No Recovery in the 3 decades following World War II

3) Sharp increase in top 1% income share since 1970s

4) Top 1% income share today is similar to top 1% share in 1920s but "working rich" have partly replaced "rentiers"

WHAT TO EXPECT NEXT?

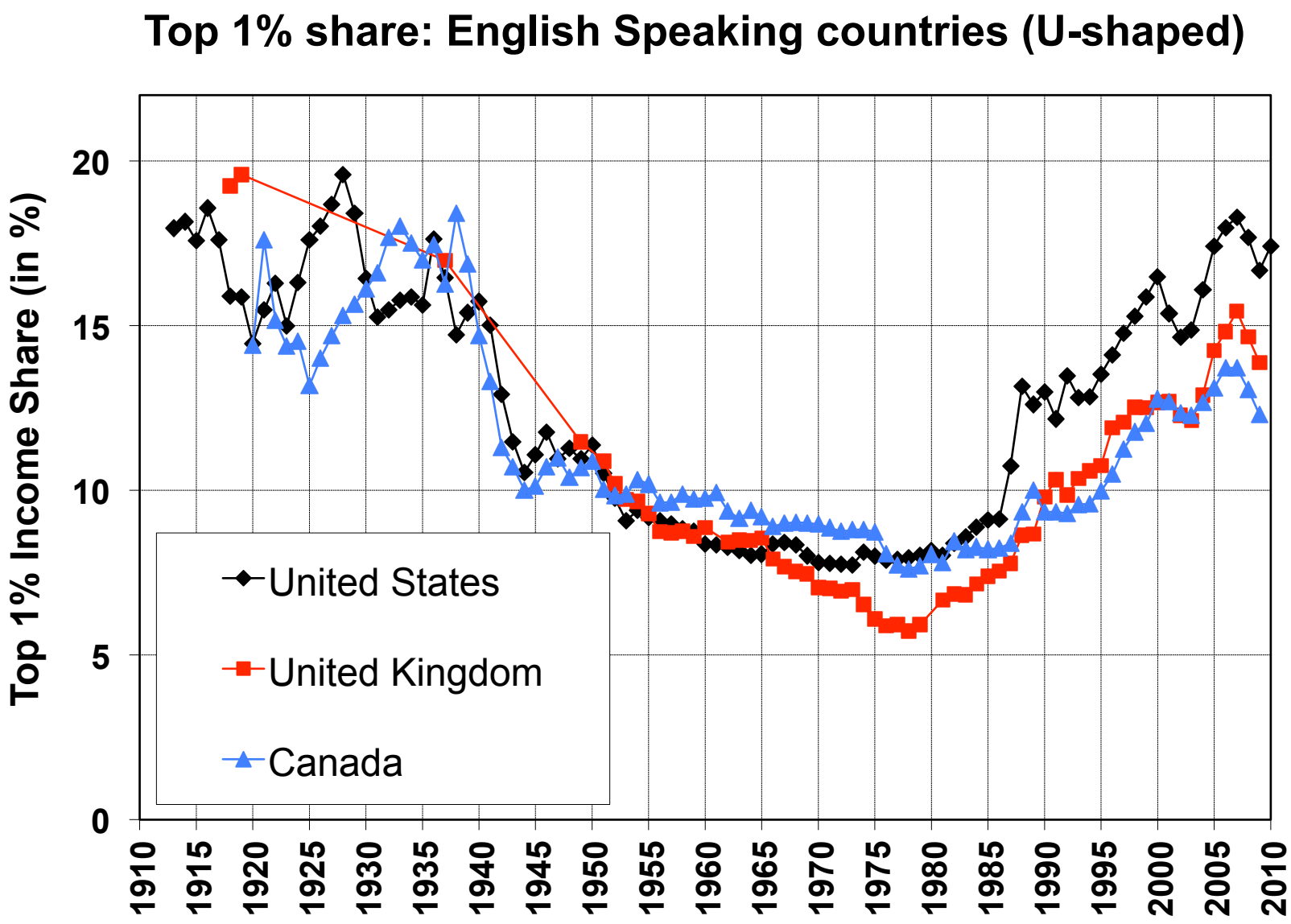
1) Short Run: Top 1% income shares have fallen during Great Recession because capital gains, stock-options, business profits collapse (wage earners in P90-99 do well)

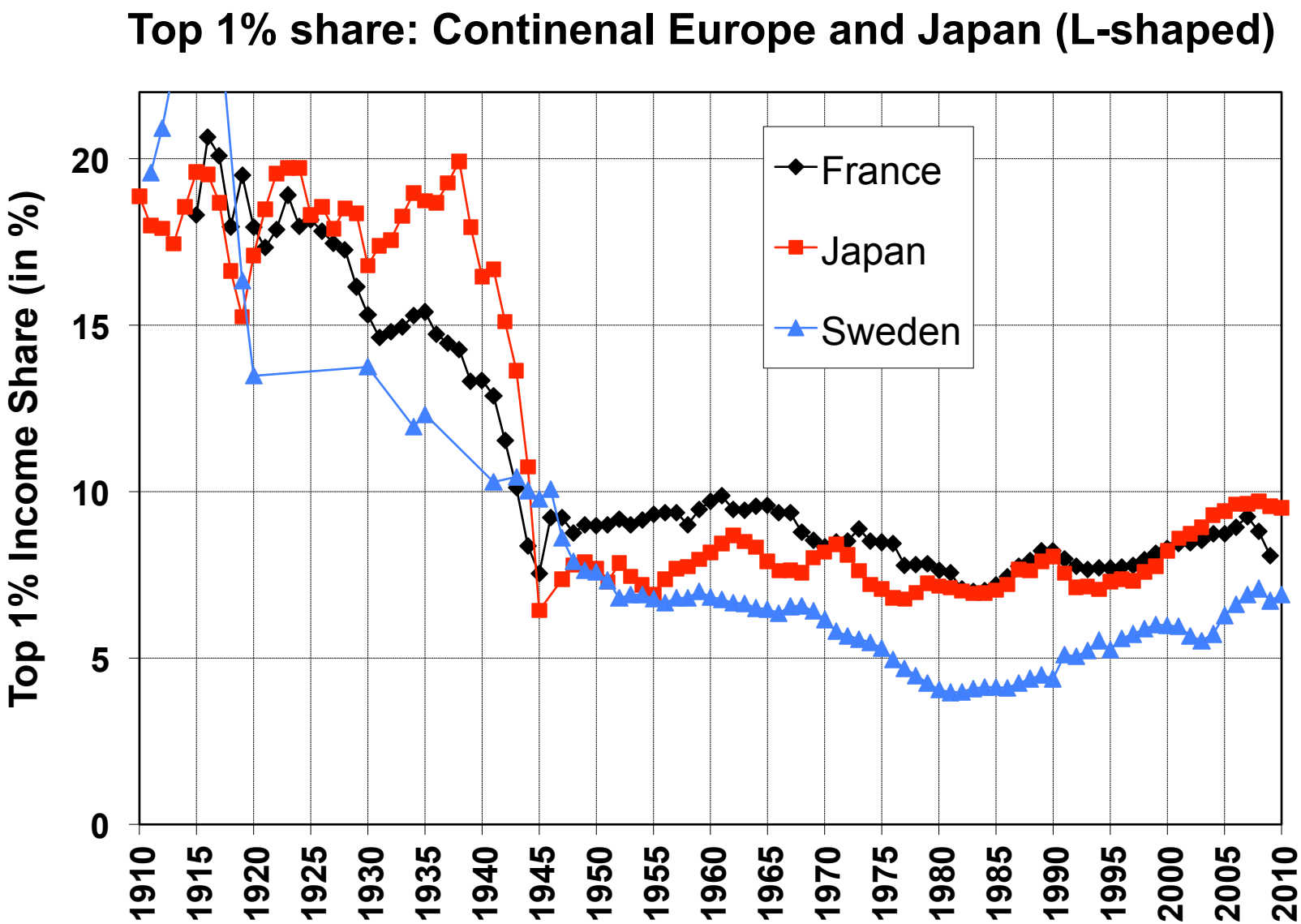
2) Medium Run: Based on historical record

a) Top 1% incomes recover faster than bottom 99% income if there is no drastic change in tax and regulation policies

b) Top incomes do not recover after Great Depression because of large tax and regulatory **New Deal** changes

US today seems more in scenario a) than b)


Top 1% share: English Speaking countries (U-shaped)
Top 1% Income Share (in %)
20
15
10
5
0
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
United States
United Kingdom
Canada


Top 1% share: Continenal Europe and Japan (L-shaped)
Top 1% Income Share (in %)
0
5
10
15
20
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
France
Japan
Sweden

RESULT 1: DROP IN TOP CAPITAL INCOMES

All advanced countries had very high income concentration one century ago

Most countries experience sharp reduction in income concentration during the first part of the 20th century

1) This is a capital income phenomenon

2) War and depression shocks hit top capital earners (drop follows each country specific history)

3) Government policies–regulations and very progressive income and inheritance taxation–make this drop permanent

RESULT 2: RECENT SURGE IN TOP INCOMES MAINLY IN ENGLISH SPEAKING COUNTRIES

1) Driven primarily by surge in top **labor** incomes $\Rightarrow$ Difference across countries rules out pure technical change explanation

2) Right-wing view: market for top earners hindered by regulations which have disappeared in the US, UK, Canada but not Continental Europe and Japan

3) Left-wing view: US top earners have increased their ability to extract rents at the expense of others because policy/regulation changes have favored the rich

$\Rightarrow$ Let us examine next the role of top tax rates

TOP INCOMES AND TAXES

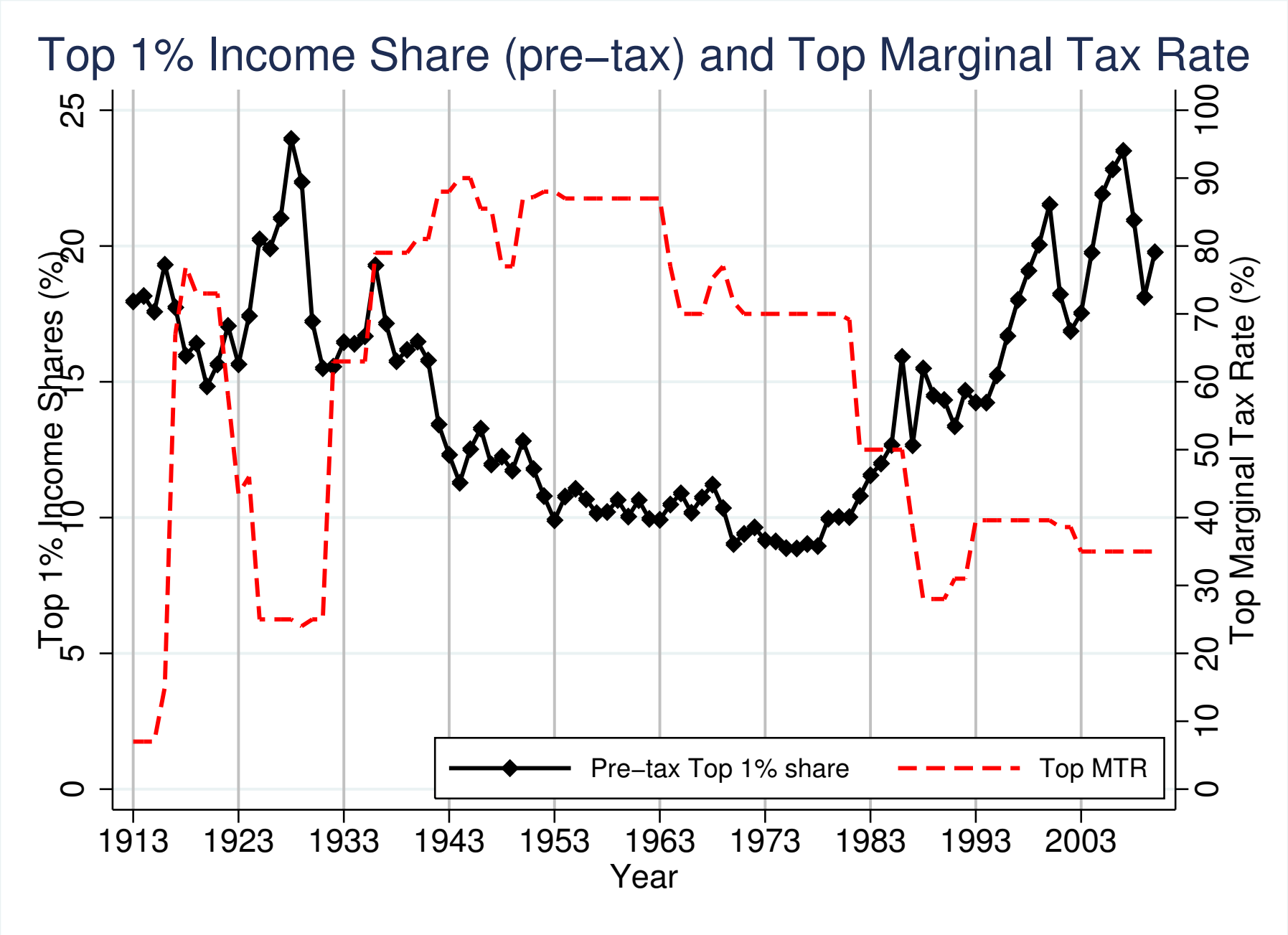
Pre-tax top US incomes have surged in recent decades: top 1% income share increased from 9% in 1970 to 20% in 2010

In 2010, top 1% income earners paid average Federal individual tax rate of 22% = 2.6 GDP points

Increasing the Federal individual tax rate on top 1% from 22% to 33% would raise revenue by 1.3 GDP points = $200bn/year

In 2013, top 1% tax increases by .4 GDP points

⇒ Top 1% has large potential tax capacity but higher taxes might discourage economic activity / encourage tax avoidance


Top 1% Income Share (pre–tax) and Top Marginal Tax Rate
Top 1% Income Shares (%)
0
5
10
15
20
25
Top Marginal Tax Rate (%)
0
10
20
30
40
50
60
70
80
90
100
1913
1923
1933
1943
1953
1963
1973
1983
1993
2003
Year
Pre–tax Top 1% share
Top MTR

ECONOMIC EFFECTS OF TAXING THE TOP 1%

Strong empirical evidence that **pre-tax** top incomes are affected by top tax rates

3 potential scenarios with very different policy consequences

1) Supply-Side: Top earners work less and earn less when top tax rate increases $\Rightarrow$ Top tax rates should not be too high

2) Tax Avoidance/Evasion: Top earners avoid/evade more when top tax rate increases

$\Rightarrow$ a) Eliminate loopholes, b) Then increase top tax rates

3) Rent-seeking: Top earners extract more pay (at the expense of the 99%) when top tax rates are low $\Rightarrow$ High top tax rates are desirable

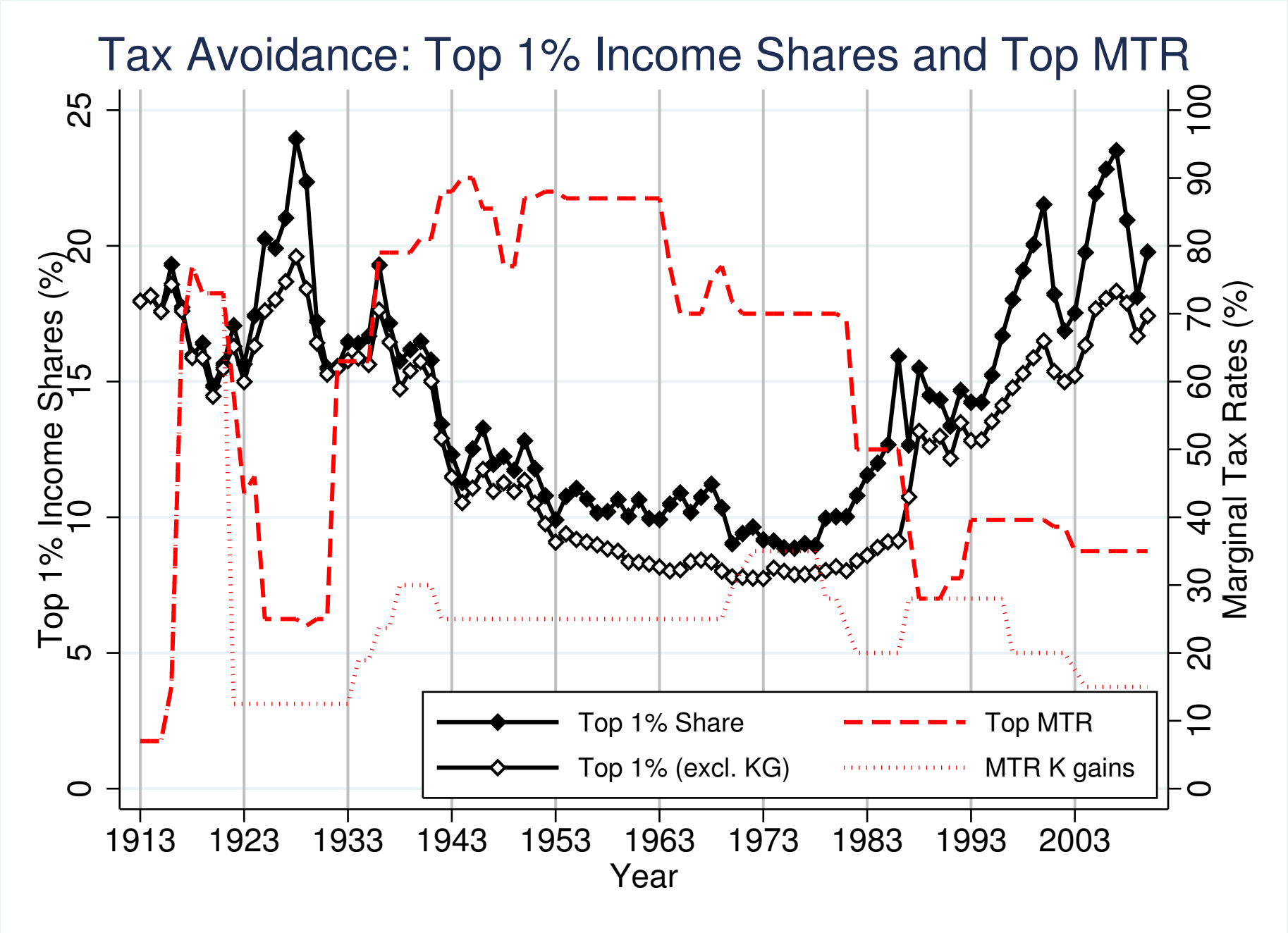
Real changes vs. tax Avoidance?

Correlation between **pre-tax** top incomes and top tax rates

If this is due to tax avoidance, real top income shares were as high as today in the 1960s-70s but top earners reported a smaller fraction of their incomes

$\Rightarrow$ correlation should be much stronger when using narrow taxable income definition than when using comprehensive income definition (including realized capital gains)

Empirical correlation is very similar ruling out the pure tax avoidance scenario


Tax Avoidance: Top 1% Income Shares and Top MTR
Top 1% Income Shares (%)
Marginal Tax Rates (%)
Year
0
5
10
15
20
25
0
10
20
30
40
50
60
70
80
90
100
1913
1923
1933
1943
1953
1963
1973
1983
1993
2003
Top 1% Share
Top 1% (excl. KG)
Top MTR
MTR K gains

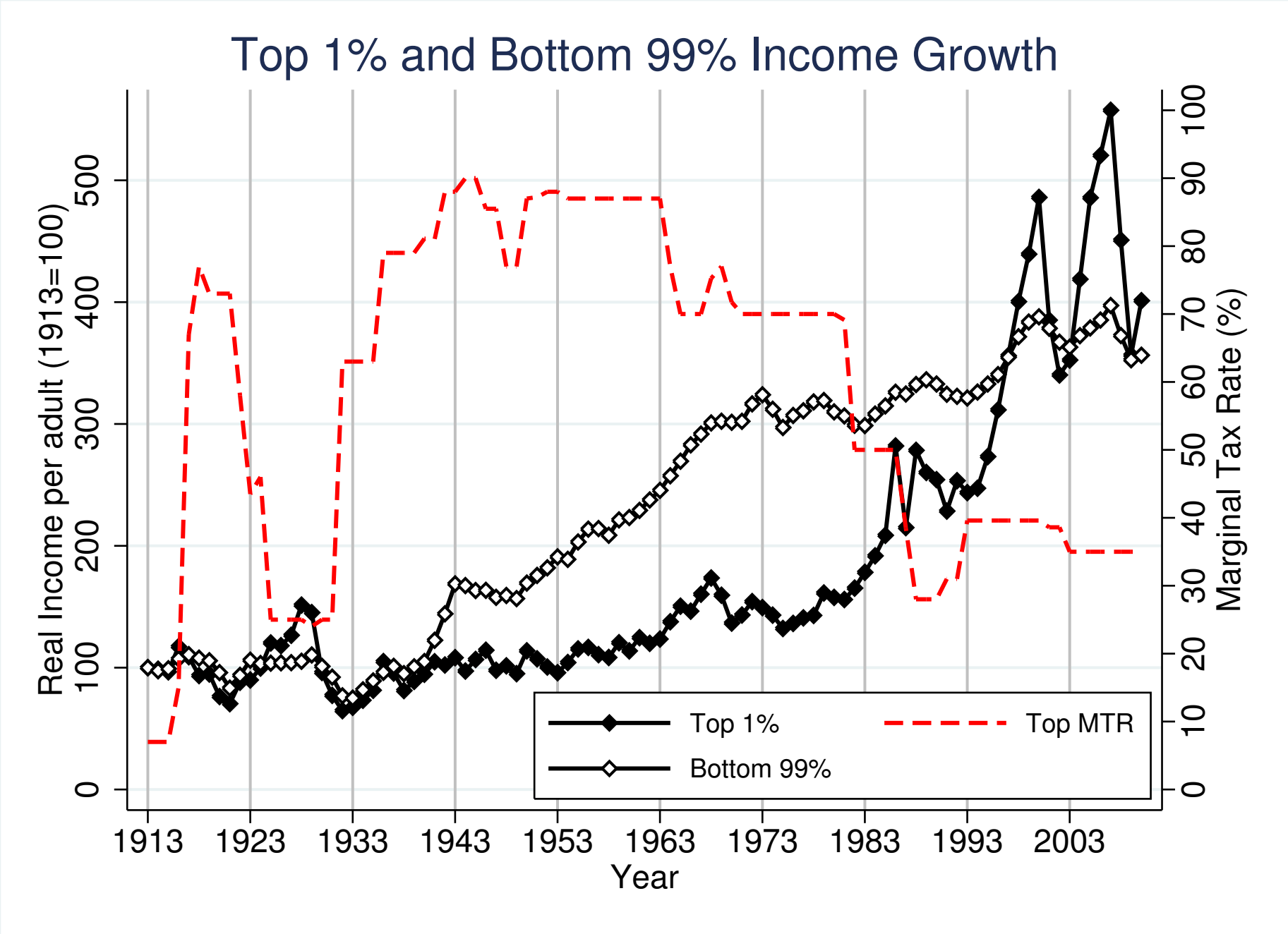
Supply-Side or Rent-Seeking?

Correlation between **pre-tax** top incomes and top tax rates

If rent-seeking: growth in top 1% incomes should come at the expense of bottom 99% (and conversely)

In the US, top 1% incomes grow slowly from 1933 to 1975 and fast afterwards. Bottom 99% incomes grow fast from 1933 to 1975 and slowly afterwards

$\Rightarrow$ Consistent with rent-seeking effects

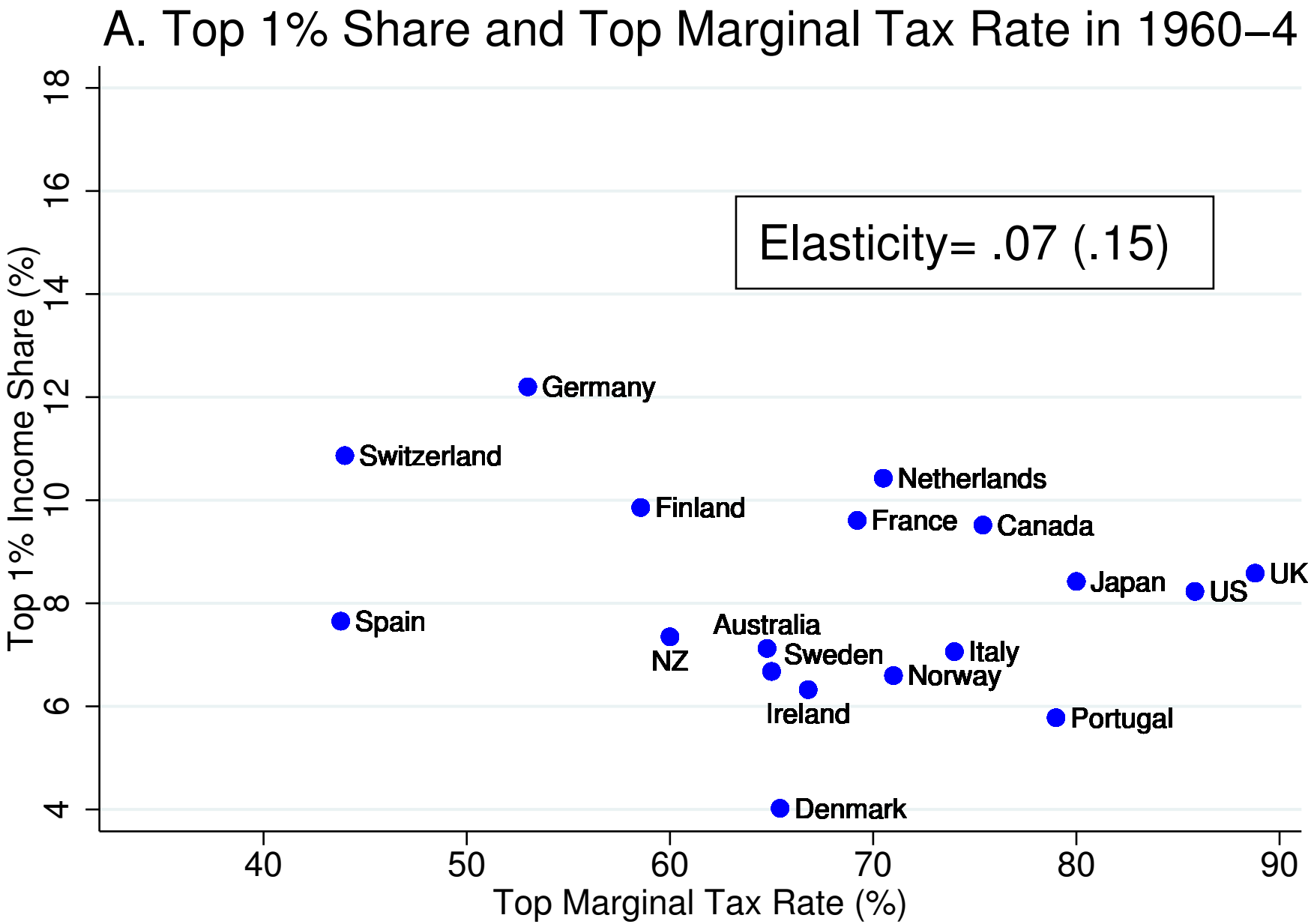

Top 1% and Bottom 99% Income Growth
Real Income per adult (1913=100)
0
100
200
300
400
500
Marginal Tax Rate (%)
0
10
20
30
40
50
60
70
80
90
100
1913
1923
1933
1943
1953
1963
1973
1983
1993
2003
Year
Top 1%
Top MTR
Bottom 99%

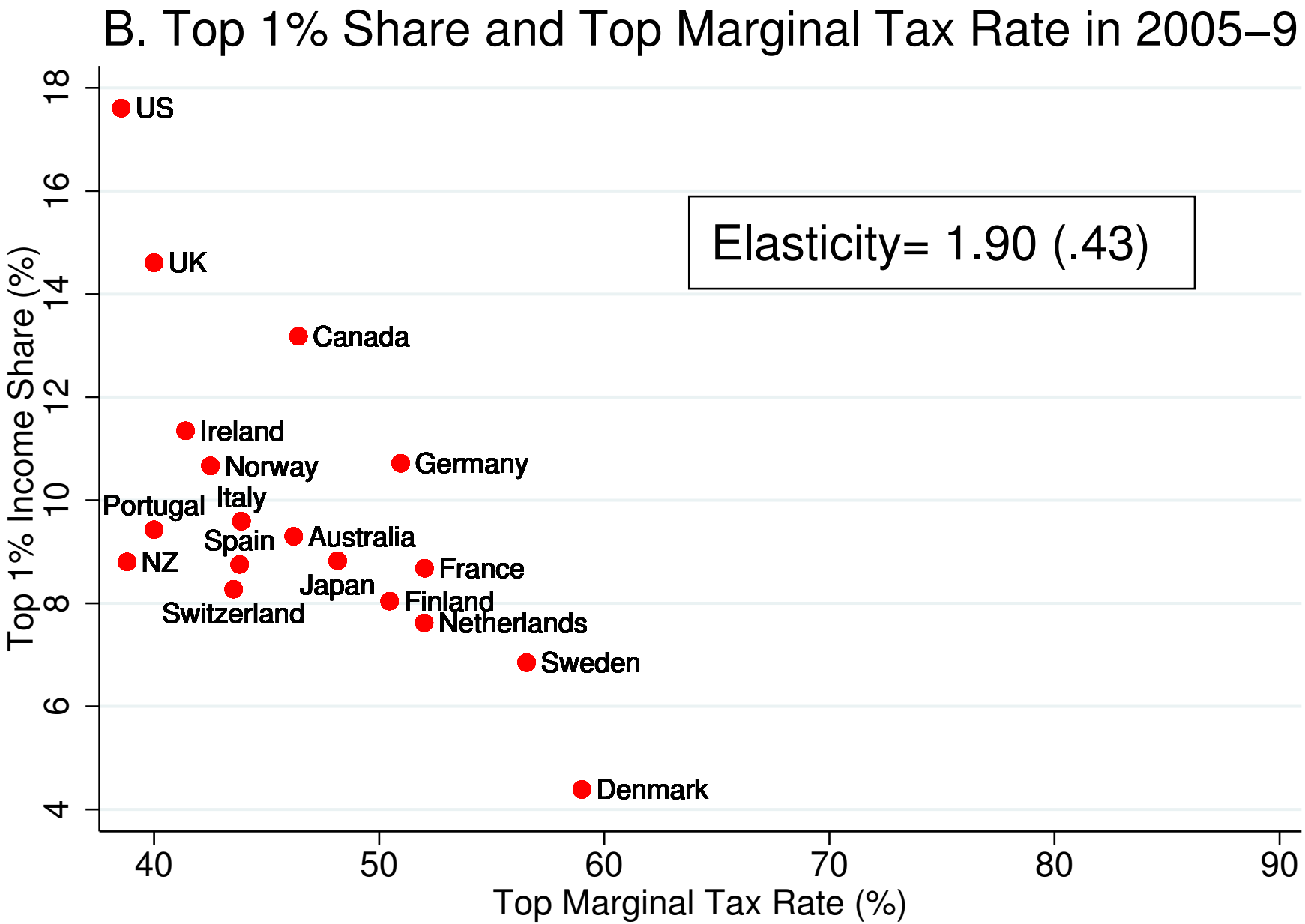
TOP RATES AND TOP INCOMES
INTERNATIONAL EVIDENCE

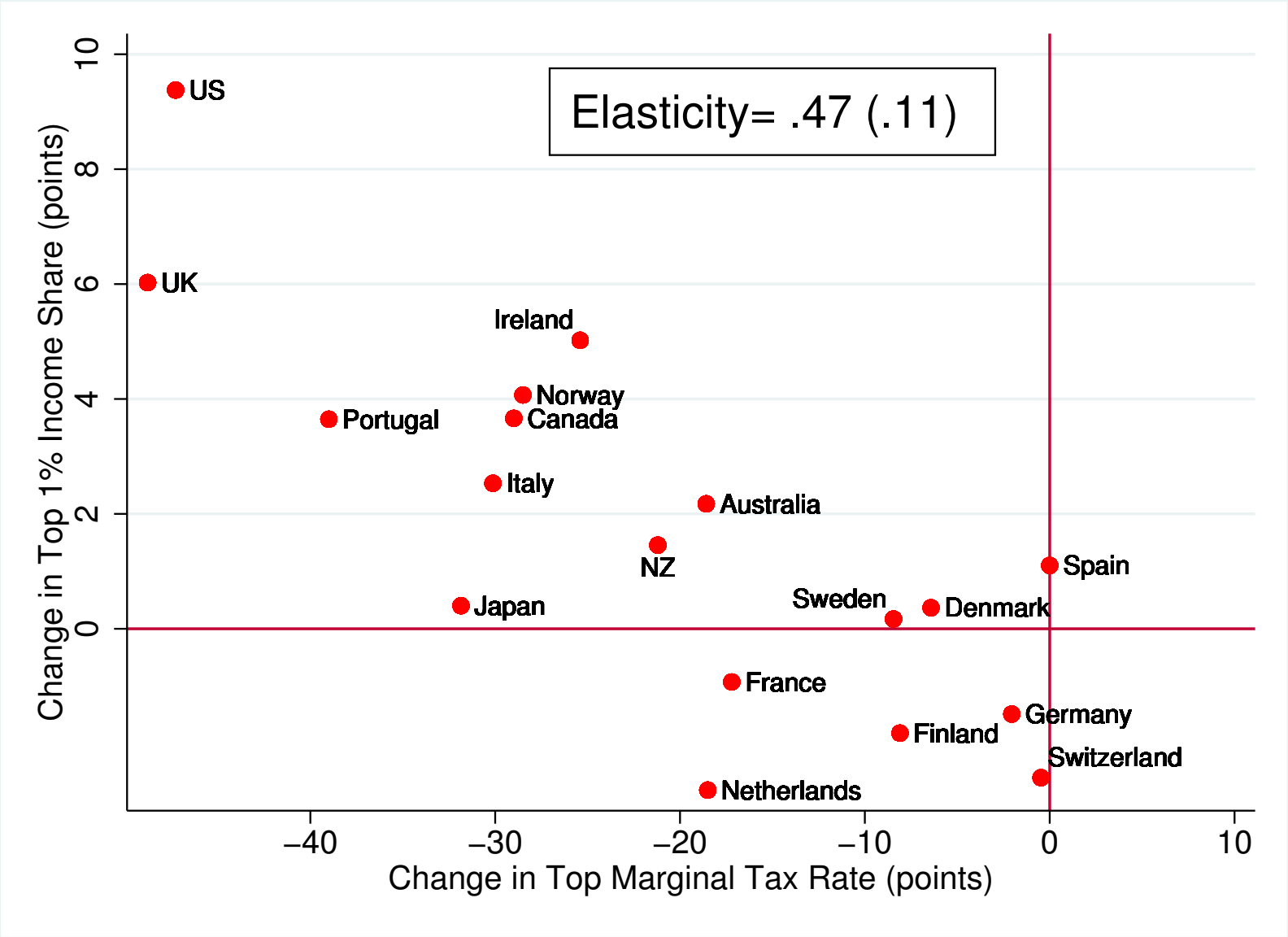
1) Use pre-tax top 1% income share data from 18 OECD countries since 1960 using the **World Top Incomes Database**

2) Compute top (statutory) individual income tax rates using OECD data [including both central and local income taxes].

Plot top 1% pre-tax income share against top MTR in 1960-4, in 2005-9, and 1960-4 vs. 2005-9


A. Top 1% Share and Top Marginal Tax Rate in 1960–4
Elasticity= .07 (.15)
Top 1% Income Share (%)
Top Marginal Tax Rate (%)
4
6
8
10
12
14
16
18
40
50
60
70
80
90
Germany
Switzerland
Netherlands
Finland
France
Canada
Japan
US
UK
Spain
Australia
NZ
Sweden
Italy
Norway
Ireland
Portugal
Denmark


B. Top 1% Share and Top Marginal Tax Rate in 2005–9
Elasticity= 1.90 (.43)
US
UK
Canada
Ireland
Norway
Germany
Portugal
Italy
Spain
Australia
NZ
France
Japan
Finland
Switzerland
Netherlands
Sweden
Denmark
Top 1% Income Share (%)
4
6
8
10
12
14
16
18
40
50
60
70
80
90
Top Marginal Tax Rate (%)



Change in Top Tax Rate and Top 1% Share, 1960-4 to 2005-9

TOP RATES AND TOP INCOMES EVIDENCE

1) Pre-tax Top income shares have increased significantly in some but not all countries [Atkinson-Piketty-Saez JEL'11]

2) Top tax rates have come down significantly in a number of countries since 1960s

3) Correlation between 1) and 2) is strong but not perfect: lower top tax rates are a necessary but not sufficient condition for surge in top incomes

$\Rightarrow$ Total elasticity is large but could be a mix of real effects, avoidance effects, or bargaining effects

DOES THE 1% GAIN AT THE EXPENSE OF 99%?

Supply-Side Scenario:

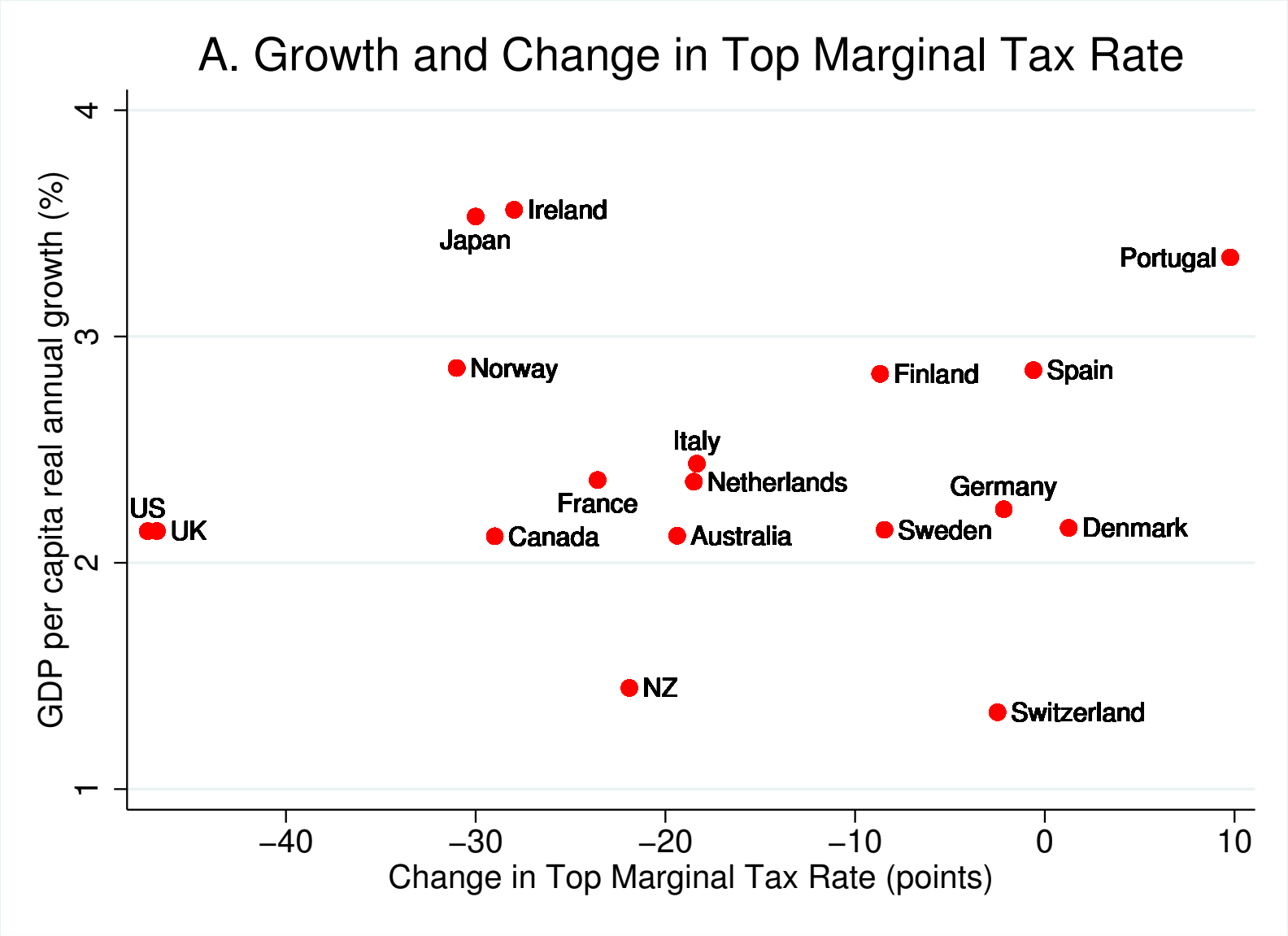
Lower top tax rates $\Rightarrow$ more economic activity among upper incomes benefits broader economy (job creators)

$\Rightarrow$ Surge in top income shares should come with more economic growth $\Rightarrow$ Low top tax rates are desirable

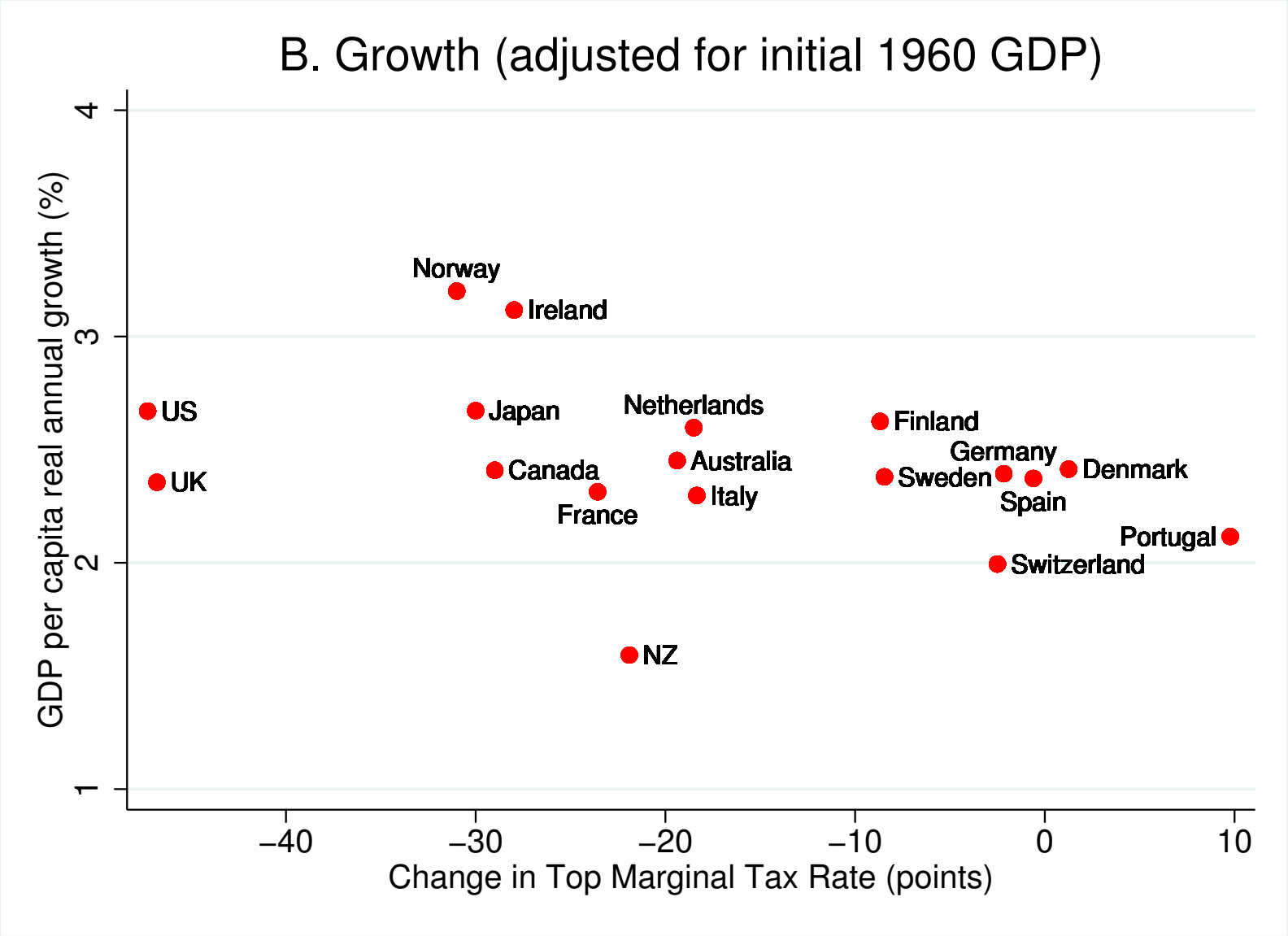
Rent-Seeking Scenario:

Lower top tax rates $\Rightarrow$ Upper incomes extract more compensation at the expense of others

$\Rightarrow$ Surge in top income shares should not be associated with more economic growth $\Rightarrow$ High top tax rates are desirable



Change in Top Tax Rate and GDP per capita growth since 1960



Change in Top Tax Rate and GDP per capita growth since 1960

POLICY CONCLUSIONS

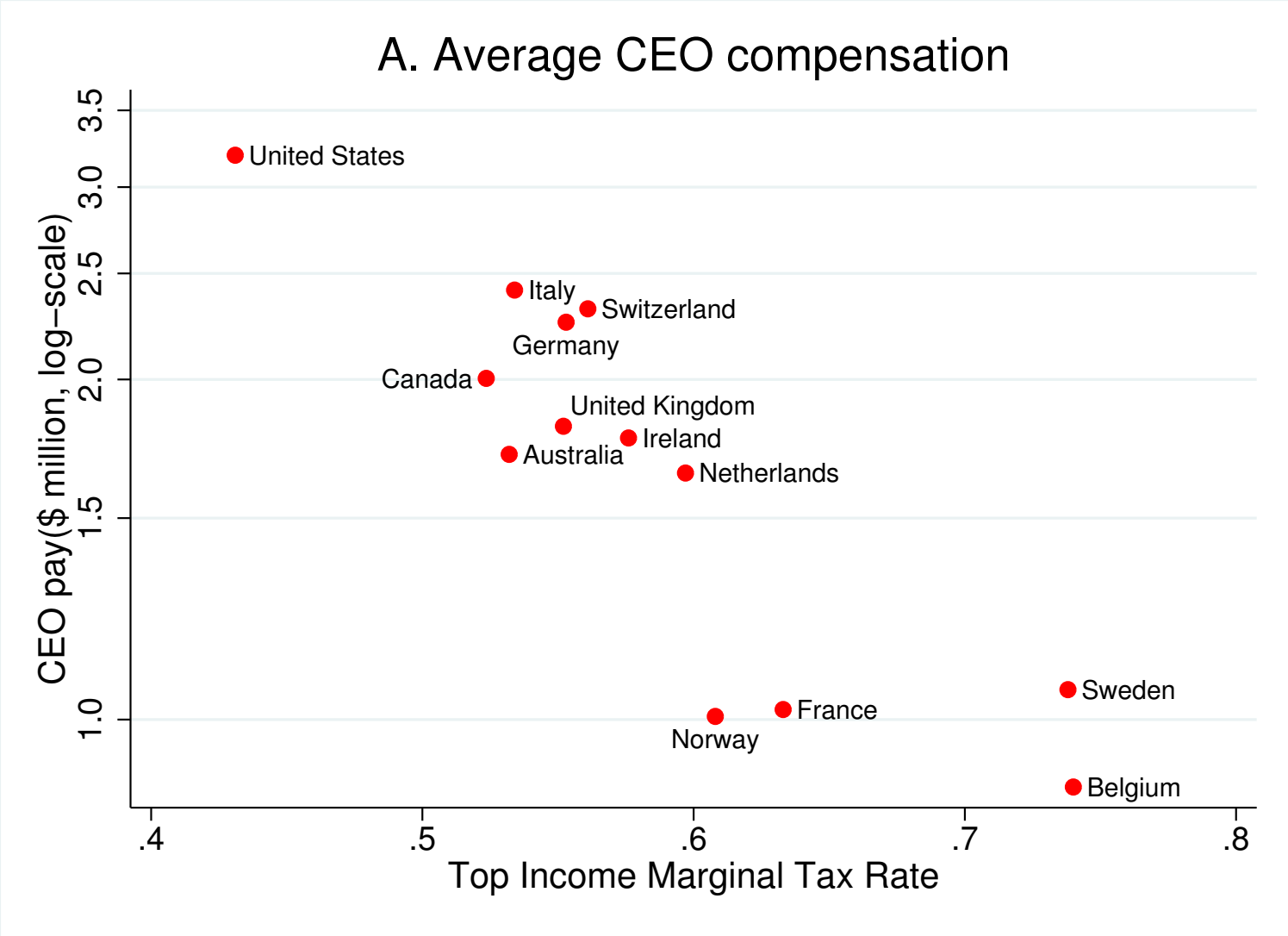
1) US historical evidence and international evidence shows that tax policy plays a key role in the shaping the income gap

2) High top tax rates reduce the **pre-tax** income gap without visible effect economic growth

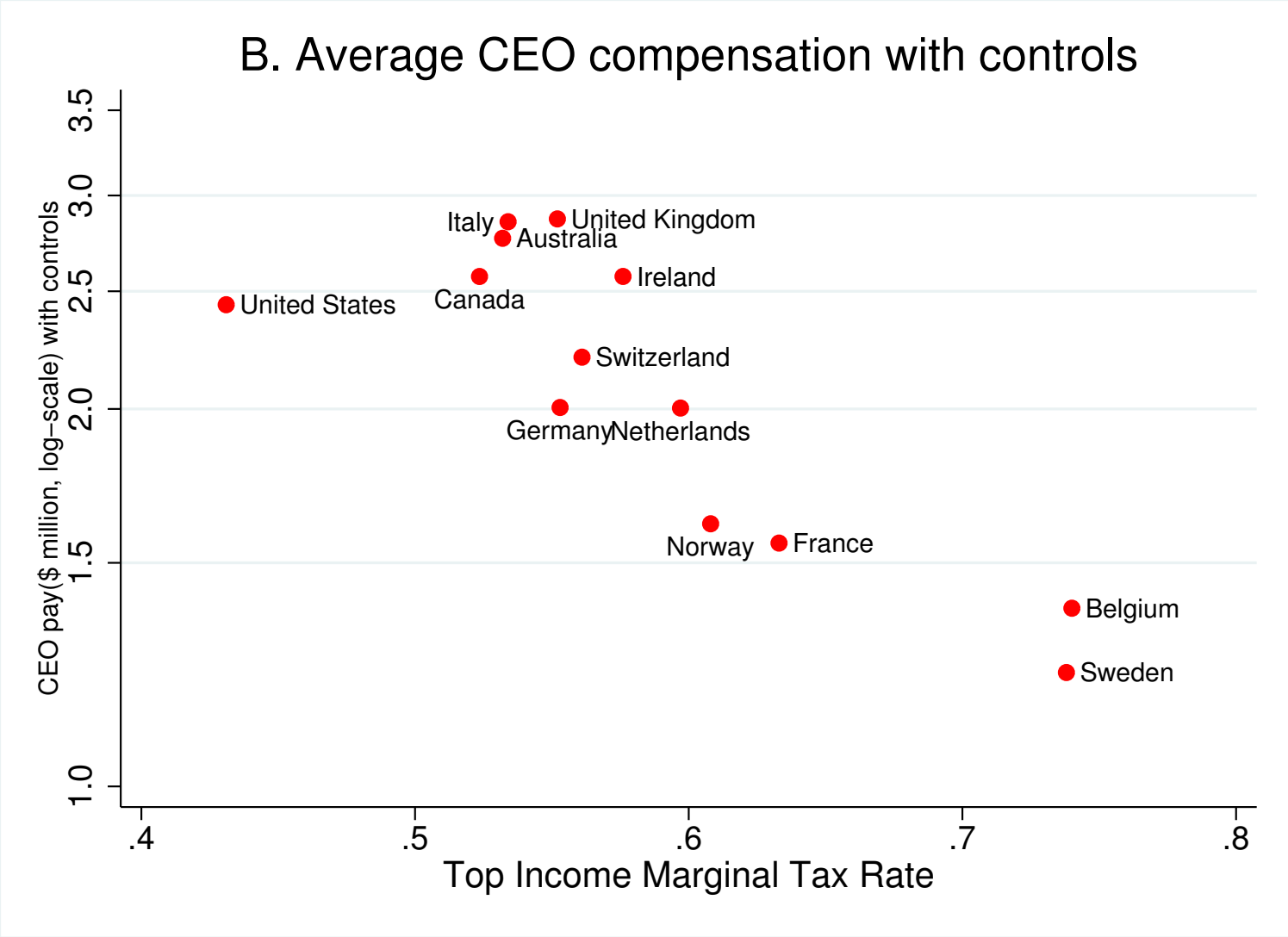
3) In globalized world, progressive taxation will require international coordination to keep tax avoidance/evasion low

4) Public will favor more progressive taxation only if it is convinced that top income gains are detrimental to the 99%

EXTRA SLIDES



Link between top tax rate and CEO pay in 2006 across countries



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The Social Cost of Carbon: A Primer and Overview of the U.S. Government's SCC Estimates

Elizabeth Kopits
National Center for Environmental Economics, U.S. EPA

Presentation at the 1st Session of the OECD/ITF Working Group on Assessment of Policies for Long-Term Transition to Sustainable Transport
December 12, 2013

The views expressed in this presentation are those of the presenter and do not necessarily represent those of the U.S. EPA.

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The Social Cost of Carbon: A Primer and Overview of the U.S. Government's SCC Estimates

Elizabeth Kopits National Center for Environmental Economics, U.S. EPA

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Outline

- What the Social Cost of Carbon Is and Is Not
- Overview of U.S Government's (USG) SCC Estimates
  - 2009-2010 Process
  - 2013 Update
- Discussion

NCEE

- What the Social Cost of Carbon Is and Is Not
- Overview of U.S Government's (USG) SCC Estimates

– 2009-2010 Process – 2013 Update

- Discussion

What is the Social Cost of Carbon?

- The SCC provides a measure of the marginal damage from CO_2 emissions – and thus the *marginal benefit of abatement*
  - The SCC is the theoretically consistent value to compare with the marginal cost of abatement in benefit cost analysis
- Specifically, the SCC is the monetized value of future worldwide economic damages associated with a one-ton increase in CO_2 emissions in a particular year discounted to the present.
  - This is identical to the avoided damages associated with a one-ton decrease.
- It is intended to be a comprehensive measure of climate change damages, including (but not limited to):
  - changes in net agricultural productivity
  - net energy demand
  - human health
  - property damages from increased flood risk
  - the value of ecosystem services

NCEE

3

• The SCC provides a measure of the marginal damage from CO

emissions – and thus the marginal benefit of abatement

– The SCC is the theoretically consistent value to compare with the marginal

cost of abatement in benefit cost analysis

• Specifically, the SCC is the monetized value of future worldwide economic damages associated with a one-ton increase in CO

emissions in a particular year discounted to the present.

– This is identical to the avoided damages associated with a one-ton decrease.

• It is intended to be a comprehensive measure of climate change damages, including (but not limited to):

– changes in net agricultural productivity – net energy demand – human health – property damages from increased flood risk – the value of ecosystem services

What the Social Cost of Carbon is Not

- The SCC is not the carbon shadow price derived from various policies (e.g., cap-and-trade program, performance standards)
- The carbon price associated with a policy that specifies an environmental target provides a measure of the *marginal cost of abatement.*
  - This is useful in evaluating policy cost-effectiveness
  - It is NOT an alternative way to value damages from CO_2 emissions
  - It does implicitly require a valuation of damages when setting the constraint
    - E.g., a target set to keep temperature increases to a certain amount to avoid "far too risky" outcomes implies a valuation of damages.
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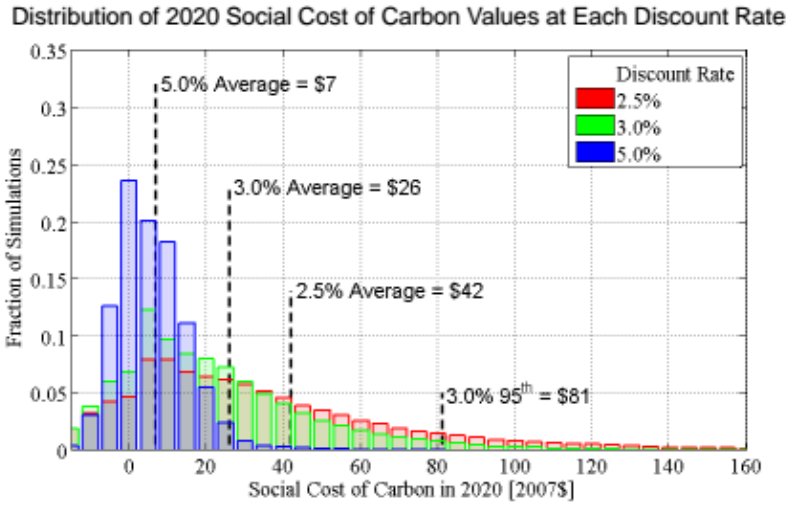

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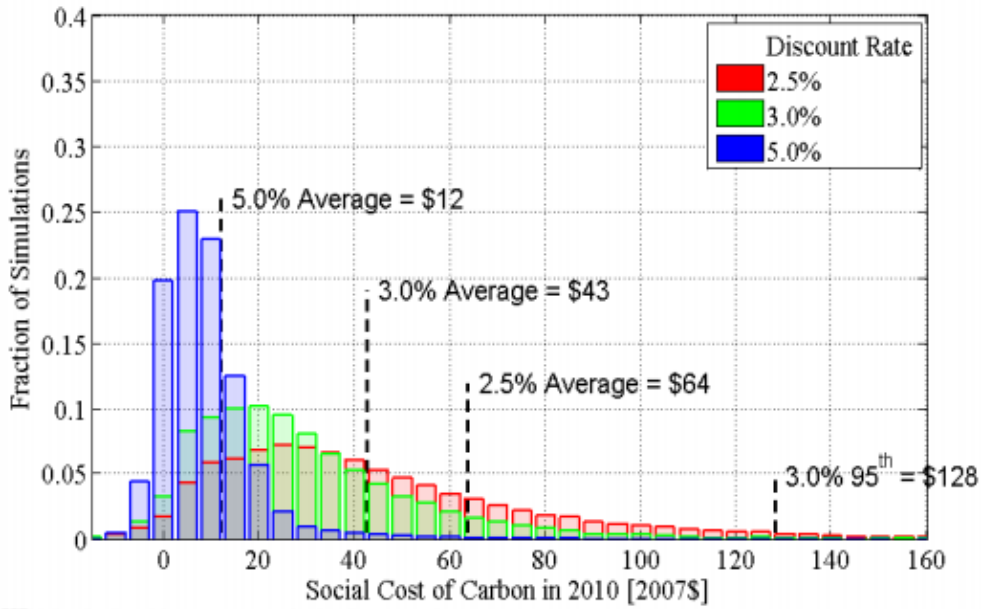

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The Social Cost of Carbon: A Primer and Overview of the U.S. Government's SCC Estimates

Elizabeth Kopits
National Center for Environmental Economics, U.S. EPA

Presentation at the 1st Session of the OECD/ITF Working Group on Assessment of Policies for Long-Term Transition to Sustainable Transport
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Outline

- What the Social Cost of Carbon Is and Is Not
- Overview of U.S Government's (USG) SCC Estimates
  - 2009-2010 Process
  - 2013 Update
- Discussion

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What is the Social Cost of Carbon?

- The SCC provides a measure of the marginal damage from CO_2 emissions – and thus the *marginal benefit of abatement*
  - The SCC is the theoretically consistent value to compare with the marginal cost of abatement in benefit cost analysis
- Specifically, the SCC is the monetized value of future worldwide economic damages associated with a one-ton increase in CO_2 emissions in a particular year discounted to the present.
  - This is identical to the avoided damages associated with a one-ton decrease.
- It is intended to be a comprehensive measure of climate change damages, including (but not limited to):
  - changes in net agricultural productivity
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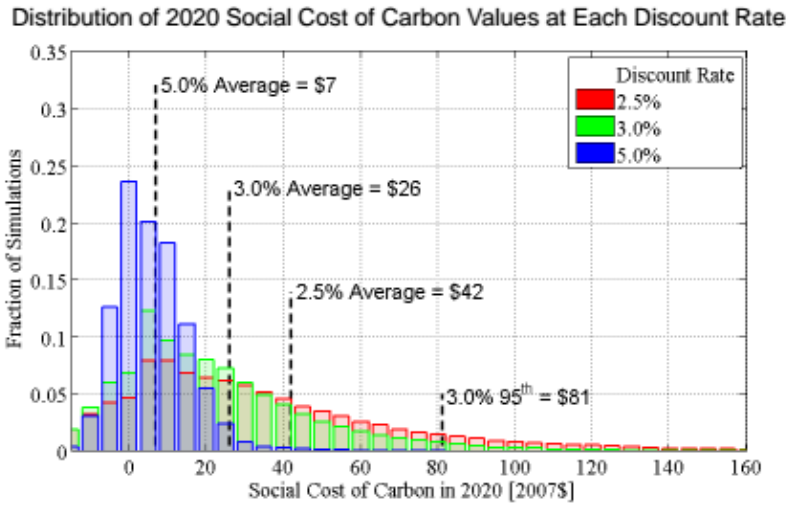

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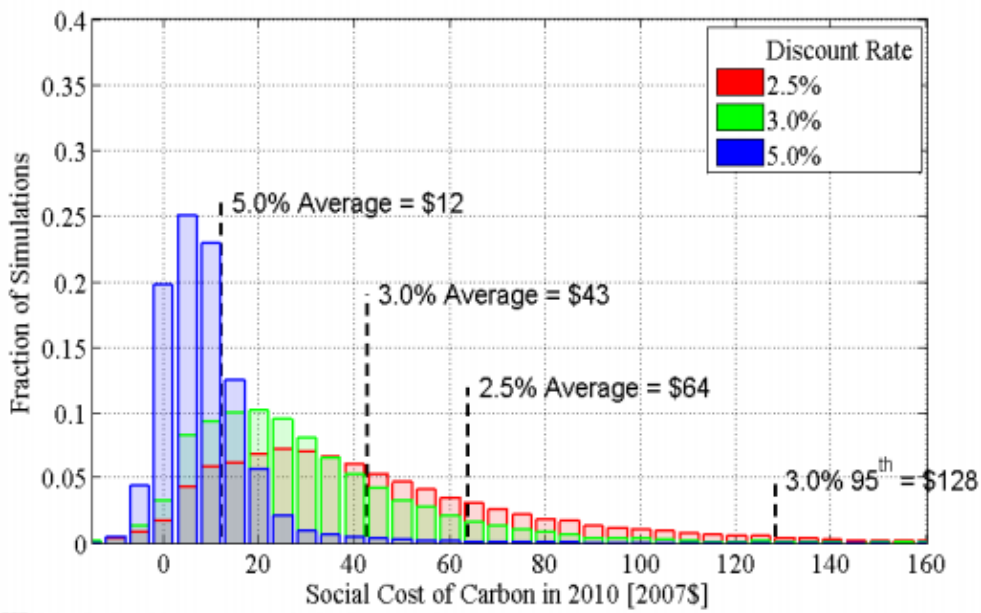

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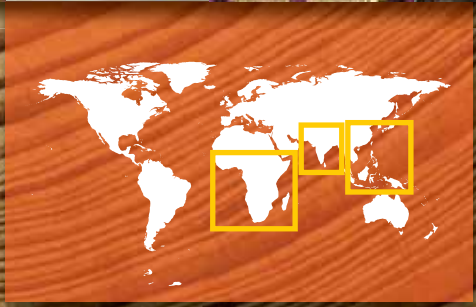
Climate Extremes, Regional Impacts, and the Case for Resilience



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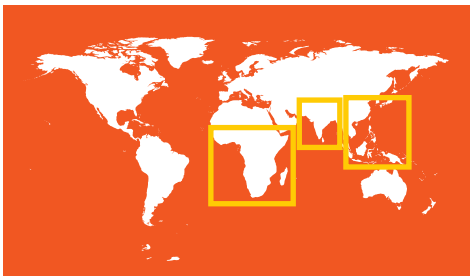

June 2013

A Report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics

THE WORLD BANK

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The ISI-MIP projections were undertaken by modeling groups at the following institutions: ORCHIDEE[1] (Institut Pierre Simon Laplace, France); JULES (Centre for Ecology and Hydrology, UK; Met Office Hadley Centre, UK; University of Exeter, UK); VIC (Norwegian Water Resources and Energy Directorate, Norway; Wageningen University, Netherlands); H08 (Institute for Environmental Studies, Japan); WaterGAP (Kassel University, Germany; Universität Frankfurt, Germany); MacPDM (University of Reading, UK; University of Nottingham, UK); WBM (City University of New York, USA); MPI-HM (Max Planck Institute for Meteorology, Germany); PCR-GLOBWB (Utrecht University, Netherlands); DBH (Chinese Academy of Sciences, China); MATSIRO (University of Tokyo, Japan); Hybrid (University of Cambridge, UK); Sheffield DGVM (University of Sheffield, UK; University of Bristol, UK); JeDi (Max Planck Institut für Biogeochemie, Germany); ANTHRO-BGC (Humboldt University of Berlin, Germany; Leibniz Centre for Agricultural Landscape Research, Germany); VISIT (National Institute for Environmental Studies, Japan); GEPIC (Eawag, Switzerland); EPIC (University of Natural Resources and Life Sciences, Vienna, Austria); pDSSAT (University of Chicago, USA); DAYCENT (Colorado State University, USA); IMAGE (PBL Netherlands Environmental Assessment Agency, Netherlands); PEGASUS (Tyndall Centre, University of East Anglia, UK); LPJ-GUESS (Lunds Universitet, Sweden); MAgPIE (Potsdam Institute, Germany); GLOBIOM (International Institute for Applied Systems Analysis, Austria); IMPACT (International Food Policy Research Institute, USA; International Livestock Research Institute, Kenya); DIVA (Global Climate Forum, Germany); MARA (London School of Hygiene and Tropical Medicine, UK); WHO CCRA Malaria (Umea University, Sweden); LMM 205 (The University of Liverpool, UK); MIASMA (Maastricht University, Netherlands); and VECTRI (Abdus Salam International Centre for Theoretical Physics, Italy).

[1] A full list of ISI-MIP modeling groups is given in Appendix 2.

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Foreword

The work of the World Bank Group is to end extreme poverty and build shared prosperity. Today, we have every reason to believe that it is within our grasp to end extreme poverty by 2030. But we will not meet this goal without tackling the problem of climate change.

Our first *Turn Down the Heat* report, released late last year, concluded the world would warm by 4°C by the end of this century if we did not take concerted action now.

This new report outlines an alarming scenario for the days and years ahead—what we could face in our lifetime. The scientists tell us that if the world warms by 2°C—warming which may be reached in 20 to 30 years—that will cause widespread food shortages, unprecedented heat-waves, and more intense cyclones. In the near-term, climate change, which is already unfolding, could batter the slums even more and greatly harm the lives and the hopes of individuals and families who have had little hand in raising the Earth's temperature.

Today, our world is 0.8°C above pre-industrial levels of the 18th century. We could see a 2°C world in the space of one generation.

The first *Turn Down the Heat* report was a wake-up call. This second scientific analysis gives us a more detailed look at how the negative impacts of climate change already in motion could create devastating conditions especially for those least able to adapt. The poorest could increasingly be hit the hardest.

For this report, we turned again to the scientists at the Potsdam Institute for Climate Impact Research and Climate Analytics. This time, we asked them to take a closer look at the tropics and prepare a climate forecast based on the best available evidence and supplemented with advanced computer simulations.

With a focus on Sub-Saharan Africa, South East Asia and South Asia, the report examines in greater detail the likely impacts for affected populations of present day, 2°C and 4°C warming on critical areas like agricultural production, water resources, coastal ecosystems and cities.

The result is a dramatic picture of a world of climate and weather extremes causing devastation and human suffering. In many cases, multiple threats of increasing extreme heat waves, sea-level rise, more severe storms, droughts and floods will have severe negative implications for the poorest and most vulnerable.

In Sub-Saharan Africa, significant crop yield reductions with 2°C warming are expected to have strong repercussions on food security, while rising temperatures could cause major loss of savanna grasslands threatening pastoral livelihoods. In South Asia, projected changes to the monsoon system and rising peak temperatures put water and food resources at severe risk. Energy security is threatened, too. While, across South East Asia, rural livelihoods are faced with mounting pressures as sea-level rises, tropical cyclones increase in intensity and important marine ecosystem services are lost as warming approaches 4°C.

Across all regions, the likely movement of impacted communities into urban areas could lead to ever higher numbers of people in informal settlements being exposed to heat waves, flooding, and diseases.

The case for resilience has never been stronger.

This report demands action. It reinforces the fact that climate change is a fundamental threat to economic development and the fight against poverty.

At the World Bank Group, we are concerned that unless the world takes bold action now, a disastrously warming planet threatens to put prosperity out of reach of millions and roll back decades of development.

In response we are stepping up our mitigation, adaptation, and disaster risk management work, and will increasingly look at all our business through a "climate lens."

But we know that our work alone is not enough. We need to support action by others to deliver bold ideas that will make the biggest difference.

I do not believe the poor are condemned to the future scientists envision in this report. In fact, I am convinced we can reduce poverty even in a world severely challenged by climate change.

We can help cities grow clean and climate resilient, develop climate smart agriculture practices, and find innovative ways to improve both energy efficiency and the performance of renewable energies. We can work with countries to roll back harmful fossil fuel subsidies and help put the policies in place that will eventually lead to a stable price on carbon.

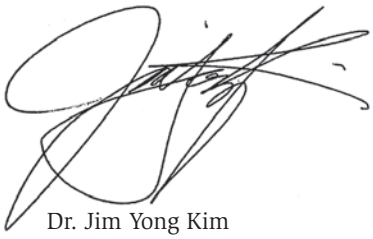
We are determined to work with countries to find solutions. But the science is clear. There can be no substitute for aggressive national emissions reduction targets.

Today, the burden of emissions reductions lies with a few large economies. Not all are clients of the World Bank Group, but all share a commitment to ending poverty.

I hope this report will help convince everyone that the benefits of strong, early action on climate change far outweigh the costs.

We face a future that is precarious because of our warming planet. We must meet these challenges with political will, intelligence, and innovation. If we do, I see a future that eases the hardships of others, allows the poor to climb out of poverty, and provides young and old alike with the possibilities of a better life.

Join us in our fight to make that future a reality. Our successes and failures in this fight will define our generation.



Dr. Jim Yong Kim
President, World Bank Group

Executive Summary

Executive Summary

This report focuses on the risks of climate change to development in Sub-Saharan Africa, South East Asia and South Asia. Building on the 2012 report, *Turn Down the Heat: Why a 4°C Warmer World Must be Avoided*[2], this new scientific analysis examines the likely impacts of present day, 2°C and 4°C warming on agricultural production, water resources, and coastal vulnerability for affected populations. It finds many significant climate and development impacts are already being felt in some regions, and in some cases multiple threats of increasing extreme heat waves, sea-level rise, more severe storms, droughts and floods are expected to have further severe negative implications for the poorest. Climate-related extreme events could push households below the poverty trap threshold. High temperature extremes appear likely to affect yields of rice, wheat, maize and other important crops, adversely affecting food security. Promoting economic growth and the eradication of poverty and inequality will thus be an increasingly challenging task under future climate change. Immediate steps are needed to help countries adapt to the risks already locked in at current levels of 0.8°C warming, but with ambitious global action to drastically reduce greenhouse gas emissions, many of the worst projected climate impacts could still be avoided by holding warming below 2°C.

Scope of the Report

The first *Turn Down the Heat* report found that projections of global warming, sea-level rise, tropical cyclone intensity, aridity and drought are expected to be felt disproportionately in the developing countries around the equatorial regions relative to the countries at higher latitudes. This report extends this previous analysis by focusing on the risks of climate change to development in three critical regions of the world: Sub-Saharan Africa, South East Asia and South Asia.

While covering a range of sectors, this report focuses on how climate change impacts on agricultural production, water resources, coastal zone fisheries, and coastal safety are likely to increase, often significantly, as global warming climbs from present levels of 0.8°C up to 1.5°C, 2°C and 4°C above pre-industrial levels. This report illustrates the range of impacts that much of the developing world is already experiencing, and would be further exposed to, and it indicates how these risks and disruptions could be felt differently in other parts of the world. Figure 1 shows projections of temperature and sea-level rise impacts at 2°C and 4°C global warming.

The Global Picture

Scientific reviews published since the first *Turn Down the Heat* report indicate that recent greenhouse gas emissions and future emissions trends imply higher 21st century emission levels than previously projected. As a consequence, the likelihood of 4°C warming being reached or exceeded this century has increased, in the absence of near-term actions and further commitments to reduce emissions. This report reaffirms the International Energy Agency's 2012 assessment that in the absence of further mitigation action there is a 40 percent chance of warming exceeding 4°C by 2100 and a 10 percent chance of it exceeding 5°C in the same period.

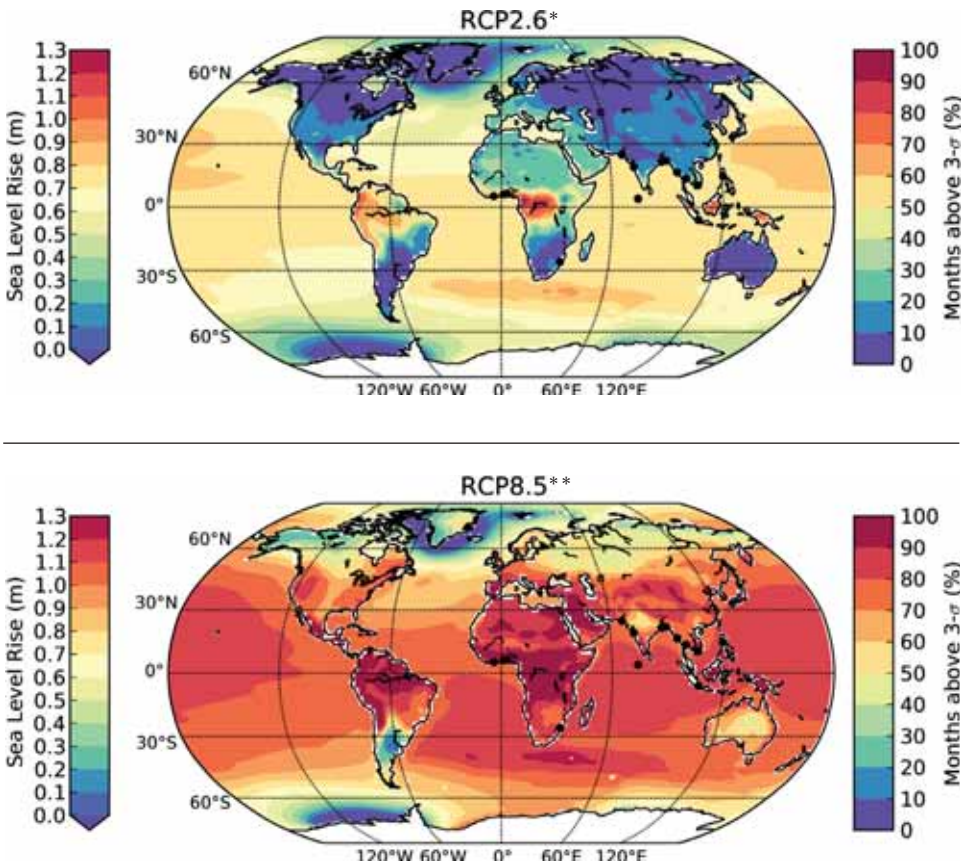
The 4°C scenario does not suggest that global mean temperatures would stabilize at this level; rather, emissions scenarios leading to such warming would very likely lead to further increases in both temperature and sea-level during the 22nd century. Furthermore,

2 *Turn Down the Heat: Why a 4°C Warmer World Must be Avoided*, launched by the World Bank in November 2012.

even at present warming of 0.8°C above pre-industrial levels, the observed climate change impacts are serious and indicate how dramatically human activity can alter the natural environment upon which human life depends.

The projected climate changes and impacts are derived from a combined approach involving a range of climate models of varying complexity, including the state of the art Coupled Model Intercomparison Project Phase 5 (CMIP5), semi-empirical modeling, the "Simple Climate Model" (SCM), the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC; see Appendix 1) and a synthesis of peer reviewed literature.

Figure 1 Projected sea-level rise and northern-hemisphere summer heat events over land in a 2°C World (upper panel) and a 4°C World (lower panel)



Upper panel: In a 2°C world, sea-level rise is projected to be less than 70 cm (yellow over oceans) and the likelihood that a summer month's heat is unprecedented is less than 30 percent (blue/purple colors over land)

Lower panel: In a 4°C world, sea-level rise is projected to be more than 100 cm (orange over oceans) and the likelihood that a summer month's heat is unprecedented is greater than 60 percent (orange/red colors over land)

*RCP2.6, IPCC AR5 scenario aiming to limit the increase of global mean temperature to 2°C above the pre-industrial period.

**RCP8.5, IPCC AR5 scenario with no-climate-policy baseline and comparatively high greenhouse gas emissions. In this report, this scenario is referred to as a 4°C World above the pre-industrial period.

Key Findings Across the Regions

Among the key issues highlighted in this report are the early onset of climate impacts, uneven regional distribution of climate impacts, and interaction among impacts which accentuates cascade effects. For example:

1. **Unusual and unprecedented heat extremes[3]:** Expected to occur far more frequently and cover much greater land areas, both globally and in the three regions examined. For example, heat extremes in South East Asia are projected to increase substantially in the near term, and would have significant and adverse effects on humans and ecosystems under 2°C and 4°C warming.

2. **Rainfall regime changes and water availability:** Even without any climate change, population growth alone is expected to put pressure on water resources in many regions in the future. With projected climate change, however, pressure on water resources is expected to increase significantly.
   - Declines of 20 percent in water availability are projected for many regions under a 2°C warming and of 50 percent for some regions under 4°C warming. Limiting warming to 2°C would reduce the global population exposed to declining water availability to 20 percent.
   - South Asian populations are likely to be increasingly vulnerable to the greater variability of precipitation changes, in addition to the disturbances in the monsoon system and rising peak temperatures that could put water and food resources at severe risk.

3. **Agricultural yields and nutritional quality:** Crop production systems will be under increasing pressure to meet growing global demand in the future. Significant crop yield impacts are already being felt at 0.8°C warming.
   - While projections vary and are uncertain, clear risks emerge as yield reducing temperature thresholds for important crops have been observed, and crop yield improvements appear to have been offset or limited by observed warming (0.8°C) in many regions. There is also some empirical evidence that higher atmospheric levels of carbon dioxide (CO_2) could result in lower protein levels of some grain crops.
   - For the regions studied in this report, global warming above 1.5°C to 2°C increases the risk of reduced crop yields and production losses in Sub-Saharan Africa, South East Asia and South Asia. These impacts would have strong repercussions on food security and are likely to negatively influence economic growth and poverty reduction in the impacted regions.

4. **Terrestrial ecosystems:** Increased warming could bring about ecosystem shifts, fundamentally altering species compositions and even leading to the extinction of some species.
   - By the 2030s (with 1.2–1.3°C warming), some ecosystems in Africa, for example, are projected to experience maximum extreme temperatures well beyond their present range, with all African eco-regions exceeding this range by 2070 (2.1–2.7°C warming).
   - The distribution of species within savanna ecosystems are projected to shift from grasses to woody plants, as CO_2 fertilization favors the latter, although high temperatures and precipitation deficits might counter this effect. This shift will reduce available forage for livestock and stress pastoral systems and livelihoods.

5. **Sea-level rise:** Has been occurring more rapidly than previously projected and a rise of as much as 50 cm by the 2050s may be unavoidable as a result of past emissions: limiting warming to 2°C may limit global sea-level rise to about 70 cm by 2100.
   - As much as 100 cm sea-level rise may occur if emission increases continue and raise the global average temperature to 4°C by 2100 and higher levels thereafter. While the unexpectedly rapid rise over recent decades can now be explained by the accelerated loss of ice from the Greenland and Antarctic ice sheets, significant uncertainty remains as to the rate and scale of future sea-level rise.
   - The sea-level nearer to the equator is projected to be higher than the global mean of 100 cm at the end of the century. In South East Asia for example, sea-level rise is projected to be 10–15 percent higher than the global mean. Coupled with storm surges and tropical cyclones, this increase is projected to have devastating impacts on coastal systems.

6. **Marine ecosystems:** The combined effects of warming and ocean acidification are projected to cause major damages to coral reef systems and lead to losses in fish production, at least regionally.
   - Substantial losses of coral reefs are projected by the time warming reaches 1.5–2°C from both heat and ocean

[3] In this report, "unusual" and "unprecedented" heat extremes are defined by using thresholds based on the historical variability of the current local climate. The absolute level of the threshold thus depends on the natural year-to-year variability in the base period (1951–1980), which is captured by the standard deviation (sigma). Unusual heat extremes are defined as 3-sigma events. For a normal distribution, 3-sigma events have a return time of 740 years. The 2012 US heat wave and the 2010 Russian heat wave classify as 3-sigma events. Unprecedented heat extremes are defined as 5-sigma events. They have a return time of several million years. These events which have almost certainly never occurred to date are projected for the coming decades. See also Chapter 2 (Box 2.2).

acidification effects, with a majority of coral systems no longer viable at current locations. Most coral reefs appear unlikely to survive by the time 4°C warming is reached.

- Since the beginning of the Industrial Revolution, the pH of surface ocean waters has fallen by 0.1 pH units. Since the pH scale, like the Richter scale, is logarithmic, this change represents approximately a 30 percent increase in acidity. Future predictions indicate that ocean acidity will further increase as oceans continue to absorb carbon dioxide. Estimates of future carbon dioxide levels, based on business as usual emission scenarios, indicate that by the end of this century the surface waters of the ocean could be nearly 150 percent more acidic, resulting in pH levels that the oceans have not experienced for more than 20 million years.

Sub-Saharan Africa: Food Production at Risk

Sub-Saharan Africa is a rapidly developing region of over 800 million people, with 49 countries, and great ecological, climatic and cultural diversity. Its population for 2050 is projected to approach 1.5 billion people.

The region is confronted with a range of climate risks that could have far-reaching repercussions for Sub-Saharan Africa´s societies and economies in future. Even if warming is limited below 2°C, there are very substantial risks and projected damages, and as warming increases these are only expected to grow further. Sub-Saharan Africa is particularly dependent on agriculture for food, income, and employment, almost all of it rain-fed. Under 2°C warming, large regional risks to food production emerge; these risks would become stronger if adaptation measures are inadequate and the CO_2 fertilization effect is weak. Unprecedented heat extremes are projected over an increasing percentage of land area as warming goes from 2 to 4°C, resulting in significant changes in vegetative cover and species at risk of extinction. Heat and drought would also result in severe losses of livestock and associated impacts on rural communities.

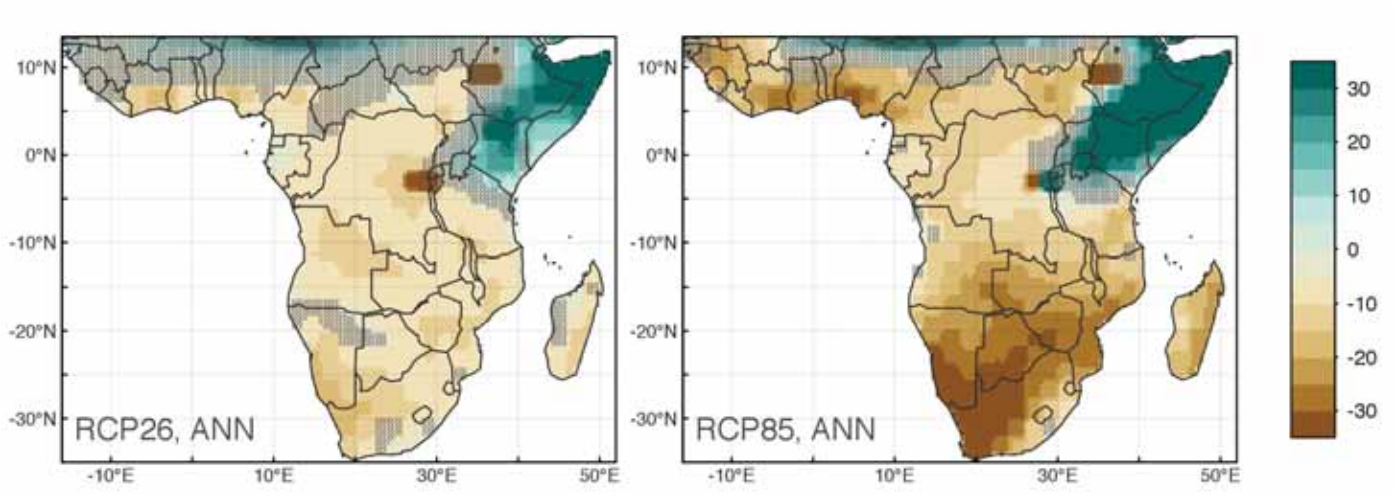
Likely Physical and Biophysical Impacts as a Function of Projected Climate Change

- **Water availability:** Under 2°C warming the existing differences in water availability across the region could become more pronounced.
    - In southern Africa, annual precipitation is projected to decrease by up to 30 percent under 4°C warming, and parts of southern and west Africa may see decreases in groundwater recharge rates of 50–70 percent. This is projected to lead to an overall increase in the risk of drought in southern Africa.
    - Strong warming and an ambiguous precipitation signal over central Africa is projected to increase drought risk there.
    - In the Horn of Africa and northern part of east Africa substantial disagreements exists between high-resolution regional and global climate models. Rainfall is projected by many global climate models to increase in the Horn of Africa and the northern part of east Africa, making these areas somewhat less dry. The increases are projected to occur during higher intensity rainfall periods, rather than evenly during the year, which increases the risk of floods. In contrast, high-resolution regional climate models project an increasing tendency towards drier conditions. Recent research showed that the 2011 Horn of Africa drought, particularly severe in Kenya and Somalia, is consistent with an increased probability of long-rains failure under the influence of anthropogenic climate change.
- **Projected aridity trends:** Aridity is projected to spread due to changes in temperature and precipitation, most notably in southern Africa (Figure 2). In a 4°C world, total hyper-arid and arid areas are projected to expand by 10 percent compared to the 1986–2005 period. Where aridity increases, crop yields are likely to decline as the growing season shortens.

Sector Based and Thematic Impacts

- **Agricultural production is expected to be affected in the near-term,** as warming shifts the climatic conditions that are conducive to current agricultural production. The annual average temperature is already above optimal values for wheat during the growing season over much of the Sub-Saharan Africa region and non-linear reductions in maize yield above certain temperature thresholds have been reported. Significant impacts are expected well before mid-century even for relatively low levels of warming. For example, a 1.5°C warming by the 2030s could lead to about 40 percent of present maize cropping areas being no longer suitable for current cultivars. In addition, under 1.5°C warming, significant negative impacts on sorghum suitability in the western Sahel and southern Africa are projected. Under warming of less than 2°C by the 2050s, total crop production could be reduced by 10 percent. For higher levels of warming there are indications that yields may decrease by around 15–20 percent across all crops and regions.
- **Crop diversification strategies will be increasingly important:** The study indicates that sequential cropping is the preferable option over single cropping systems under changing climatic conditions. Such crop diversification strategies have long been

Figure 2 Projected impact of climate change on the annual Aridity Index in Sub-Saharan Africa



Multi-model mean of the percentage change in the annual Aridity Index in a 2°C world (left) and a 4°C world (right) for Sub-Saharan Africa by 2071–2099 relative to 1951–1980. In non-hatched areas, at least 4/5 (80 percent) of models agree. In hatched areas, 2/5 (40 percent) of the models disagree. Note that a negative change corresponds to a shift to more arid conditions. Particular uncertainty remains for east Africa, where regional climate model projections tend to show an increase in precipitation, which would be associated with a decrease in the Aridity Index. A decrease in aridity does not necessarily imply more favorable conditions for agriculture or livestock, as it may be associated with increased flood risks.

practiced in Africa, providing a robust knowledge base and opportunity for scaled up approaches in this area.

- **Diversification options for agro-pastoral systems are likely to decline** (e.g. switching to silvopastoral systems, irrigated forage production, and mixed crop-livestock systems) as climate change reduces the carrying capacity of the land and livestock productivity. For example, pastoralists in southern Ethiopia lost nearly 50 percent of their cattle and about 40 percent of their sheep and goats to droughts between 1995 and 1997.
- **Regime shifts in African ecosystems are projected** and could result in the extent of savanna grasslands being reduced. By the time 3°C global warming is reached, savannas are projected to decrease to approximately one-seventh of total current land area, reducing the availability of forage for grazing animals. Projections indicate that species composition of local ecosystems might shift, and negatively impact the livelihood strategies of communities dependent on them.
- **Health is expected to be significantly affected by climate change.** Rates of undernourishment are already high, ranging between 15–65 percent, depending on sub-region. With warming of 1.2–1.9°C by 2050, the proportion of the population undernourished is projected to increase by 25–90 percent compared to the present. Other impacts expected to accompany climate change include mortality and morbidity due to extreme events such as extreme heat and flooding.
- **Climate change could exacerbate the existing development challenge of ensuring that the educational needs of all children are met.** Several factors that are expected to worsen with climate change, including undernourishment, childhood stunting, malaria and other diseases, can undermine childhood educational performance. The projected increase in extreme monthly temperatures within the next few decades may also have an adverse effect on learning conditions.

South East Asia: Coastal Zones and Productivity at Risk

South East Asia has seen strong economic growth and urbanization trends, but poverty and inequality remain significant challenges in the region. Its population for 2050 is projected to approach 759 million people with 65 percent of the population living in urban areas. In 2010, the population was 593 million people with 44 percent of the population living in urban areas.

South East Asia has a high and increasing exposure to slow onset impacts associated with rising sea-level, ocean warming and increasing acidification combined with sudden-onset impacts associated with tropical cyclones and rapidly increasingly heat extremes. When these impacts combine they are likely to have adverse effects on several sectors simultaneously, ultimately undermining coastal livelihoods in the region. The deltaic areas of South East Asia that have relatively high coastal population densities are particularly vulnerable to sea-level rise and the projected increase in tropical cyclones intensity.

Likely Physical and Biophysical Impacts as a Function of Projected Climate Change

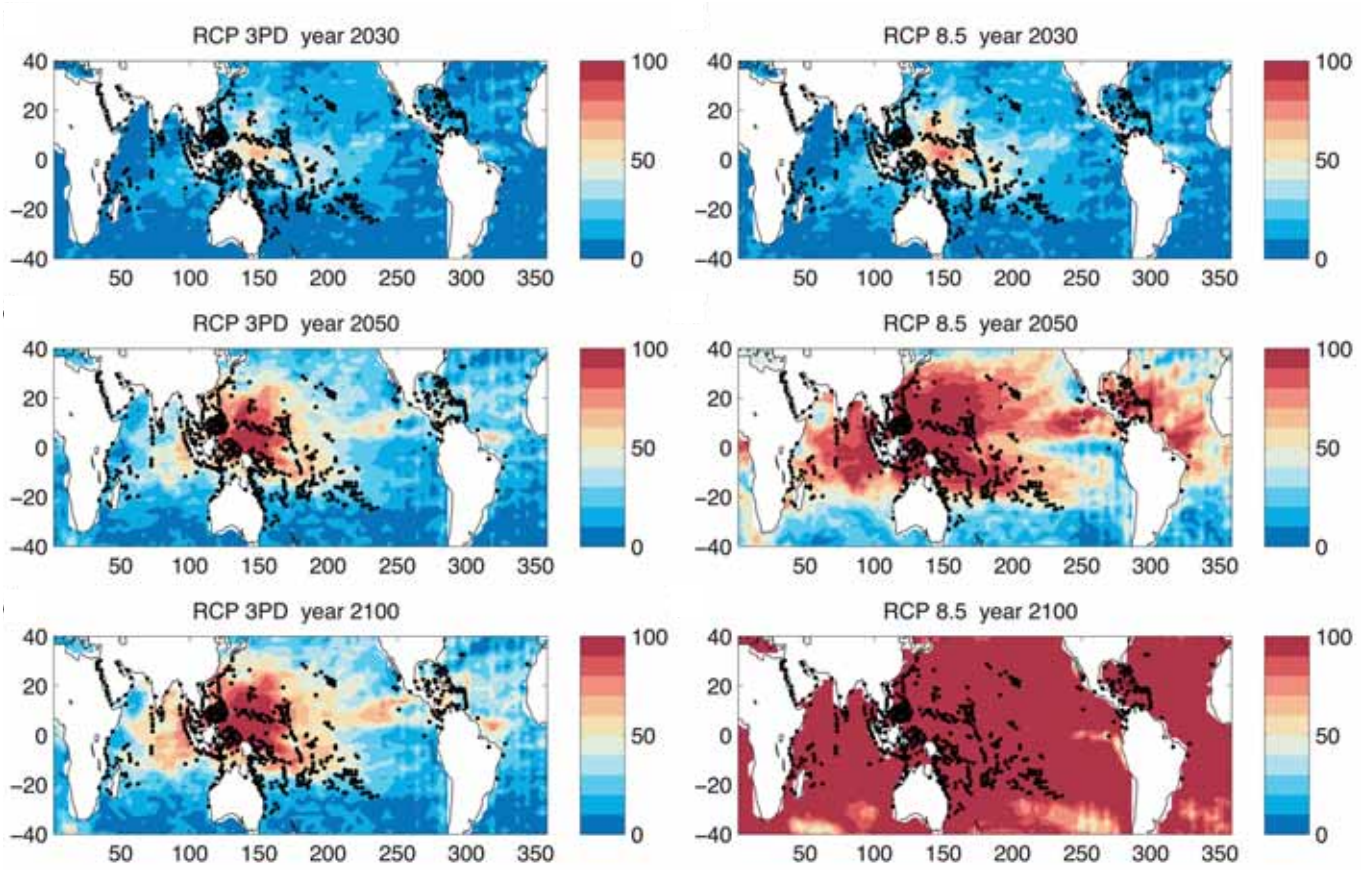
- **Heat extremes:** The South East Asian region is projected to see a strong increase in the near term in monthly heat extremes. Under 2°C global warming, heat extremes that are virtually absent at present will cover nearly 60–70 percent of total land area in summer, and unprecedented heat extremes up to 30–40 percent of land area in northern-hemisphere summer. With 4°C global warming, summer months that in today´s climate would be termed unprecedented, would be the new normal, affecting nearly 90 percent of the land area during the northern-hemisphere summer months.
- **Sea-level rise:** For the South East Asian coastlines, projections of sea-level rise by the end of the 21st century relative to 1986–2005 are generally 10–15 percent higher than the global mean. The analysis for Manila, Jakarta, Ho Chi Minh City, and Bangkok indicates that regional sea-level rise is likely to exceed 50 cm above current levels by about 2060, and 100 cm by 2090.
- **Tropical cyclones:** The intensity and maximum wind speed of tropical cyclones making landfall is projected to increase significantly for South East Asia; however, the total number of land-falling cyclones may reduce significantly. Damages may still rise as the greatest impacts are caused by the most intense storms. Extreme rainfall associated with tropical cyclones is expected to increase by up to a third reaching 50–80 mm per hour, indicating a higher level of flood risk in susceptible regions.
- **Saltwater intrusion:** A considerable increase of salinity intrusion is projected in coastal areas. For example, in the case of the Mahaka River region in Indonesia for a 100 cm sea-level rise by 2100, the land area affected by saltwater intrusion is expected to increase by 7–12 percent under 4°C warming.

Sector Based and Thematic Impacts

- **River deltas are expected to be impacted by projected sea-level rise and increases in tropical cyclone intensity,** along with land subsidence caused by human activities. These factors will increase the vulnerability of both rural and urban populations to risks including flooding, saltwater intrusion and coastal erosion. The three river deltas of the Mekong, Irrawaddy and Chao Phraya, all with significant land areas less than 2 m above sea-level, are particularly at risk. Aquaculture, agriculture, marine capture fisheries and tourism are the most exposed sectors to climate change impacts in these deltas.
- **Fisheries would be affected** as primary productivity in the world´s oceans is projected to decrease by up to 20 percent by 2100 relative to pre-industrial conditions. Fish in the Java Sea and the Gulf of Thailand are projected to be severely affected by increased water temperature and decreased oxygen levels, with very large reductions in average maximum body size by 2050. It is also projected that maximum catch potential in the southern Philippines could decrease by about 50 percent.
- **Aquaculture farms may be affected by several climate change stressors.** Increasing tropical cyclone intensity, salinity intrusion and rising temperatures may exceed the tolerance thresholds of regionally important farmed species. Aquaculture is a rapidly growing sector in South East Asia, which accounts for about 5 percent of Vietnam's GDP. As nearly 40 percent of dietary animal protein intake in South East Asia comes from fish, this sector also significantly contributes to food security in the region.
- **Coral reef loss and degradation would have severe impacts for marine fisheries and tourism.** Increasing sea surface temperatures have already led to major, damaging coral bleaching events in the last few decades.[4] Under 1.5°C warming and increasing ocean acidification, there is a high risk (50 percent probability) of annual bleaching events occurring as early as 2030 in the region (Figure 3). Projections indicate that all coral reefs in the South East Asia region are very likely to experience severe thermal stress by the year 2050, as well as chemical stress due to ocean acidification.

[4] Coral bleaching can be expected when a regional warm season maximum temperature is exceeded by 1°C for more than four weeks and bleaching becomes progressively worse at higher temperatures and/or longer periods over which the regional threshold temperature is exceeded. Whilst corals can survive a bleaching event they are subject to high mortality and take several years to recover. When bleaching events become too frequent or extreme coral reefs can fail to recover.

Figure 3 Projected impact of climate change on coral systems in South East Asia



Probability of a severe bleaching event (DHW>8) occurring during a given year under scenario RCP2.6 (approximately 2°C, left) and RCP8.5 (approximately 4°C, right). Source: Meissner et al. (2012).

Reprinted from Springer; Coral Reefs, 31(2), 2012, 309–319, Large-scale stress factors affecting coral reefs:open ocean sea surface temperature and surface seawater aragonite saturation over the next 400 years, Meissner et al., Figure 3, with kind permission from Springer Science and Business Media B.V. Further permission required for reuse.

- **Agricultural production, particularly for rice in the Mekong Delta, is vulnerable to sea-level rise.** The Mekong Delta produces around 50 percent of Vietnam's total agricultural production and contributes significantly to the country's rice exports. It has been estimated that a sea-level rise of 30 cm, which could occur as early as 2040, could result in the loss of about 12 percent of crop production due to inundation and salinity intrusion relative to current levels.
- **Coastal cities concentrate increasingly large populations and assets exposed to climate change risks** including increased tropical storm intensity, long-term sea-level rise and sudden-onset coastal flooding. Without adaptation, the area of Bangkok projected to be inundated due to flooding linked to extreme rainfall events and sea-level rise increases from around 40 percent under 15 cm sea-level rise above present (which could occur by the 2030s), to about 70 percent under an 88cm sea-level rise scenario (which could occur by the 2080s under 4°C warming). Further, the effects of heat extremes are particularly pronounced in urban areas due to the urban heat island effect and could result in high human mortality and morbidity rates in cities. High levels of growth of both urban populations and GDP further increase financial exposure to climate change impacts in these areas. The urban poor are particularly vulnerable to excessive heat and humidity stresses. In 2005, 41 percent of the urban population of Vietnam and 44 percent of that of the Philippines lived in informal settlements. Floods associated with sea-level rise and storm surges carry significant risks in informal settlements, where lack of drainage and damages to sanitation and water facilities are accompanied by health threats.

South Asia: Extremes of Water Scarcity and Excess

South Asia is home to a growing population of about 1.6 billion people, which is projected to rise to over 2.2 billion people by 2050. It has seen robust economic growth in recent years, yet poverty remains widespread, with the world's largest concentration of poor people residing in the region. The timely arrival of the summer monsoon, and its regularity, are critical for the rural economy and agriculture in South Asia.

In South Asia, climate change shocks to food production and seasonal water availability appear likely to confront populations with ongoing and multiple challenges to secure access to safe drinking water, sufficient water for irrigation and hydropower production, and adequate cooling capacity for thermal power production. Potential impact hotspots such as Bangladesh are projected to be confronted by increasing challenges from extreme river floods, more intense tropical cyclones, rising sea-level and very high temperatures. While the vulnerability of South Asia's large and poor populations can be expected to be reduced in the future by economic development and growth, climate projections indicate that high levels of local vulnerability are likely to remain and persist.

Many of the climate change impacts in the region, which appear quite severe with relatively modest warming of 1.5–2°C, pose a significant challenge to development. Major investments in infrastructure, flood defense, development of high temperature and drought resistant crop cultivars, and major improvements in sustainability practices, for example in relation to groundwater extraction would be needed to cope with the projected impacts under this level of warming.

Likely Physical and Biophysical Impacts as a Function of Projected Climate Change

- **Heat extremes:** Irrespective of future emission paths, in the next twenty years a several-fold increase in the frequency of unusually hot and extreme summer months is projected. A substantial increase in mortality is expected to be associated with such heat extremes and has been observed in the past.
- **Precipitation:** Climate change will impact precipitation with variations across spatial and temporal scales. Annual precipitation is projected to increase by up to 30 percent in a 4°C world, however projections also indicate that dry areas such as in the north west, a major food producing region, would get drier and presently wet areas, get wetter. The seasonal distribution of precipitation is expected to become amplified, with a decrease of up to 30 percent during the dry season and a 30 percent increase during the wet season under a 4°C world (Figure 4). The projections show large sub-regional variations, with precipitation increasing during the monsoon season for currently wet areas (south, northeast) and precipitation decreasing for currently dry months and areas (north, northwest), with larger uncertainties for those regions in other seasons.
- **Monsoon:** Significant increases in inter-annual and intra-seasonal variability of monsoon rainfall are to be expected. With global mean warming approaching 4°C, an increase in intra-seasonal variability in the Indian summer monsoon precipitation of approximately 10 percent is projected. Large uncertainty, however, remains about the fundamental behavior of the Indian summer monsoon under global warming.
- **Drought:** The projected increase in the seasonality of precipitation is associated with an increase in the number of dry days, leading to droughts that are amplified by continued warming, with adverse consequences for human lives. Droughts are expected to pose an increasing risk in parts of the region. Although drought projections are made difficult by uncertain precipitation projections and differing drought indicators, some regions emerge to be at particularly high risk. These include north-western India, Pakistan and Afghanistan. Over southern India, increasing wetness is projected with broad agreement between climate models.
- **Glacial loss, snow cover reductions and river flow:** Over the past century, most of the Himalayan glaciers have been retreating. Melting glaciers and loss of snow cover pose a significant risk to stable and reliable water resources. Major rivers, such as the Ganges, Indus and Brahmaputra, depend significantly on snow and glacial melt water, which makes them highly susceptible to climate change-induced glacier melt and reductions in snowfall. Well before 2°C warming, a rapid increase in the frequency of low snow years is projected with a consequent shift towards high winter and spring runoff with increased flooding risks, and substantial reductions in dry season flow, threatening agriculture. These risks are projected to become extreme by the time 4°C warming is reached.
- **Sea-level rise:** With South Asian coastlines located close to the equator, projections of local sea-level rise show a stronger increase compared to higher latitudes. Sea-level rise is projected to be approximately 100–115 cm in a 4°C world and 60–80 cm in a 2°C world by the end of the 21st century relative to 1986–2005, with the highest values expected for the Maldives.

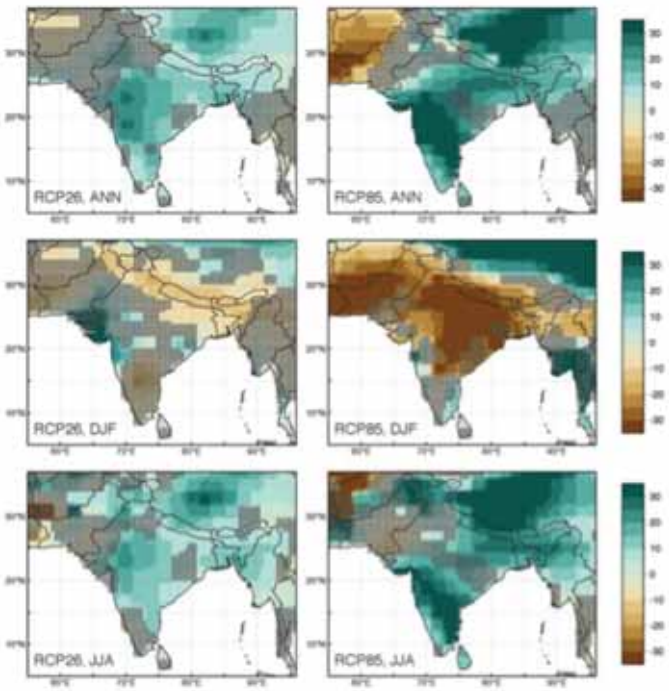
Sector Based and Thematic Impacts

- **Crop yields are vulnerable to a host of climate-related factors in the region,** including seasonal water scarcity, rising temperatures and salinity intrusion due to sea-level rise. Projections indicate an increasingly large and likely negative impact on crop yields with rising temperatures. The projected

CO_2 fertilization effect could help to offset some of the yield reduction due to temperature effects, but recent data shows that the protein content of grains may be reduced. For warming greater than 2°C, yield levels are projected to drop even with CO_2 fertilization.

- **Total crop production and per-capita calorie availability is projected to decrease significantly** with climate change. Without climate change, total crop production is projected to increase significantly by 60 percent in the region. Under a 2°C warming, by the 2050s, more than twice the imports might be required to meet per capita calorie demand when compared to a case without climate change. Decreasing food availability is related to significant health problems for affected populations, including childhood stunting, which is projected to increase by 35 percent compared to a scenario without climate change by 2050, with likely long-term consequences for populations in the region.
- **Water resources are already at risk in the densely populated countries of South Asia,** according to most methods for assessing this risk. For global mean warming approaching 4°C, a 10 percent increase in annual-mean monsoon intensity and a 15 percent increase in year-to-year variability of Indian summer monsoon precipitation is projected compared to normal levels during the first half of the 20th century. Taken together, these changes imply that an extreme wet monsoon that currently has a chance of occurring only once in 100 years is projected to occur every 10 years by the end of the century.
- **Deltaic regions and coastal cities are particularly exposed to compounding climate risks** resulting from the interacting effects of increased temperature, growing risks of river flooding, rising sea-level and increasingly intense tropical cyclones, posing a high risk to areas with the largest shares of poor populations. Under 2°C warming, Bangladesh emerges as an impact hotspot with sea-level rise causing threats to food production, livelihoods, urban areas and infrastructure. Increased river flooding combined with tropical cyclone surges also present significant risks. Human activity (building of irrigation dams, barrages, river embankments and diversions in the inland basins of rivers) can seriously exacerbate the risk of flooding downstream from extreme rainfall events higher up in river catchments.
- **Energy security is expected to come under increasing pressure from climate-related impacts to water resources.** The two dominant forms of power generation in the region are hydropower and thermal power generation (e.g., fossil fuel, nuclear and concentrated solar power), both of which can be undermined by inadequate water supply. Thermal power generation may also be affected through pressure placed on cooling systems due to increases in air and water temperatures.

Figure 4 Projected impact of climate change on annual, wet and dry season rainfall in South Asia



Multi-model mean of the percentage change in annual (top), dry-season (DJF, middle) and wet-season (JJA, bottom) precipitation for RCP2.6 (left) and RCP8.5 (right) for South Asia by 2071–2099 relative to 1951–1980. Hatched areas indicate uncertainty regions, with 2 out of 5 models disagreeing on the direction of change compared to the remaining 3 models.

Tipping Points, Cascading Impacts and Consequences for Human Development

This report shows that the three highly diverse regions of Sub-Saharan Africa, South East Asia, and South Asia that were analyzed are exposed to the adverse effects of climate change (Tables 1-3). Most of the impacts materialize at relatively low levels of warming, well before warming of 4°C above pre-industrial levels is reached.

Each of the regions is projected to experience a rising incidence of unprecedented heat extremes in the summer months by the mid-2020s, well before a warming of even 1.5°C. In fact, with temperatures at 0.8°C above pre-industrial levels, the last decade has seen extreme events taking high death tolls across all regions and causing wide-ranging damage to assets and agricultural production. As warming approaches 4°C, the severity of impacts is expected to grow with regions being affected differently (see Box 1).

Box 1: Regional Tipping Points, Cascading Impacts, and Development Implications

- **Sub-Saharan Africa's** food production systems are increasingly at risk from the impacts of climate change. Significant yield reductions already evident under 2°C warming are expected to have strong repercussions on food security and may negatively influence economic growth and poverty reduction in the region. Significant shifts in species composition and existing ecosystem boundaries could negatively impact pastoral livelihoods and the productivity of cropping systems and food security.
- **South East Asian** rural livelihoods are faced with mounting pressures as sea-level rises and important marine ecosystem services are expected to be lost as warming approaches 4°C. Coral systems are threatened with extinction and their loss would increase the vulnerability of coastlines to sea-level rise and storms. The displacement of impacted rural and coastal communities resulting from the loss of livelihood into urban areas could lead to ever higher numbers of people in informal settlements being exposed to multiple climate impacts, including heat waves, flooding, and disease.
- **South Asian** populations in large parts depend on the stability of the monsoon, which provides water resources for most of the agricultural production in the region. Disturbances to the monsoon system and rising peak temperatures put water and food resources at severe risk. Particularly in deltaic areas, populations are exposed to the multiple threats of increasing tropical cyclone intensity, sea-level rise, heat extremes and extreme precipitation. Such multiple impacts can have severe negative implications for poverty eradication in the region.

Tipping Points and Cascading Impacts

As temperatures continue to rise, there is an increased risk of critical thresholds being breached. At such "tipping points", elements of human or natural systems—such as crop yields, dry season irrigation systems, coral reefs, and savanna grasslands—are pushed beyond critical thresholds, leading to abrupt system changes and negative impacts on the goods and services they provide. Within the agricultural sector, observed high temperature sensitivity in some crops (e.g., maize), where substantial yield reductions occur when critical temperatures are exceeded, points to a plausible threshold risk in food production regionally. In a global context, warming induced pressure on food supplies could have far-reaching consequences.

Some major risks cannot yet be quantified adequately: For example, while large uncertainty remains, the monsoon has been identified as a potential tipping element of the Earth system. Physically plausible mechanisms for an abrupt change in the Indian monsoon towards a drier, lower rainfall state could precipitate a major crisis in the South Asian region.

Climate impacts can create a domino-effect and thereby ultimately affect human development. For example, decreased yields and lower nutritional value of crops could cascade throughout society by increasing the level of malnutrition and childhood stunting, causing adverse impacts on educational performance. These effects can persist into adulthood with long-term consequences for human capital that could substantially increase future development challenges. Most of the impacts presented in the regional analyses are not unique to these regions. For example, global warming impacts on coral reefs worldwide could have cascading impacts on local livelihoods, and tourism.

Multi-Sectoral Hotspots

Under 4°C warming, most of the world's population is likely to be affected by impacts occurring simultaneously in multiple sectors. Furthermore, these cascading impacts will likely not be confined to one region only; rather they are expected to have far-reaching repercussions across the globe. For example, impacts in the agricultural sector are expected to affect the global trade of food commodities, so that production shocks in one region can have wide-ranging consequences for populations in others. Thus, vulnerability could be greater than suggested by the sectoral analysis of the assessed regions due to the global interdependence, and impacts on populations are by no means limited to those that form the focus of this report. Many of the climatic risk factors are concentrated in the tropics. However, no region is immune to the impacts of climate change. In fact, under 4°C warming, most of the world´s population is likely to be affected by impacts occurring simultaneously in multiple sectors.

Results from the recent Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) were used to assess 'hotspots' where considerable impacts in one location occur concurrently in more than one sector (agriculture, water resources, ecosystems and health (malaria)). The proportion of the global population affected contemporaneously by multiple impacts increases significantly under higher levels of warming. Assuming fixed year-2000 population levels and distribution, the proportion of people exposed to multiple stressors across these sectors would increase by 20 percent under 2°C warming to more than 80 percent under 4°C warming above pre-industrial levels. This novel analysis[5] finds exposure hotspots to be the southern Amazon Basin, southern Europe, east Africa and the north of South Asia. The Amazon and

[5] Based on the first inter-sectoral climate model intercomparison, the first round of which was concluded in early 2013. Papers are in revision at the time of writing this report.

the East African highlands are particularly notable due to their exposure to three overlapping sectors. Small regions in Central America and West Africa are also affected.

Consequences for Development

Climate change is already undermining progress and prospects for development and threatens to deepen vulnerabilities and erode hard-won gains. Consequences are already being felt on every continent and in every sector. Species are being lost, lands are being inundated, and livelihoods are being threatened. More droughts, more floods, more strong storms, and more forest fires are taxing individuals, businesses and governments. Climate-related extreme events can push households below the poverty trap threshold, which could lead to greater rural-urban migration (see Box 2). Promoting economic growth and the eradication of poverty and inequality will thus be an increasingly challenging task under future climate change.

Actions must be taken to mitigate the pace of climate change and to adapt to the impacts already felt today. It will be impossible to lift the poorest on the planet out of poverty if climate change proceeds unchecked. Strong and decisive action must be taken to avoid a 4°C world—one that is unmanageable and laden with unprecedented heat waves and increased human suffering. It is not too late to hold warming near 2°C, and build resilience to temperatures and other climate impacts that are expected to still pose significant risks to agriculture, water resources, coastal infrastructure, and human health. A new momentum is needed. Dramatic technological change, steadfast and visionary political will, and international cooperation are required to change the trajectory of climate change and to protect people and ecosystems. The window for holding warming below 2°C and avoiding a 4°C world is closing rapidly, and the time to act is now.

Box 2: New Clusters of Vulnerability—Urban Areas

One of the common features that emerge from the regional analyses is of new clusters of vulnerability appearing in urban areas.

Urbanization rates are high in developing regions. For example, by 2050, it is projected that up to 56 percent of Sub-Saharan Africa's population will live in urban areas compared to 36 percent in 2010. Although the urbanization trend is driven by a host of factors, climate change is becoming an increasingly significant driver as it places rural and coastal livelihoods under mounting pressure.

While rural residents are expected to be exposed to a variety of climatic risk factors in each region, a number of factors define the particular vulnerability of urban dwellers, especially the urban poor, to climate change impacts. For example:

- Extreme heat is felt more acutely in cities where the built-up environments amplify temperatures.
- As many cities are located in coastal areas, they are often exposed to flooding and storm surges.
- Informal settlements concentrate large populations and often lack basic services, such as electricity, sanitation, health, infrastructure and durable housing. In such areas, people are highly exposed to extreme weather events, such as storms and flooding. For example, this situation is the case in Metro Manila in the Philippines, or Kolkata in India, where poor households are located in low-lying areas or wetlands that are particularly vulnerable to tidal and storm surges.
- Informal settlements often provide conditions particularly conducive to the transmission of vector and water borne diseases, such as cholera and malaria that are projected to become more prevalent with climate change.
- The urban poor have been identified as the group most vulnerable to increases in food prices following production shocks and declines that are projected under future climate change.

Climate change poses a particular threat to urban residents and at the same time is expected to further drive urbanization, ultimately placing more people at risk to the clusters of impacts outlined above. Urban planning and enhanced social protection measures, however, provide the opportunity to build more resilient communities in the face of climate change.

Table 1: Climate Impacts in Sub-Saharan Africa

RISK/IMPACT		0.8°C WARMING (Observed)	2°C WARMING (2040s)[1]	4°C WARMING (2080s)
Heat extremes	Unusual heat extremes	Virtually absent	About 45 percent of land in austral summer months (DJF)	>85 percent of land in austral summer months (DJF)
	Unprecedented heat extremes	Absent	About 15 percent of land in austral summer months (DJF)	>55 percent of land in austral summer months (DJF)
Drought		Increasing drought trends observed since 1950	Likely risk of severe drought in southern and central Africa, increased risk in west Africa, possible decrease in east Africa but west and east African projections are uncertain[2]	Likely risk of extreme drought in southern Africa and severe drought in central Africa, increased risk in west Africa, possible decrease in east Africa, but west and east African projections are uncertain[3]
Aridity		Increased drying[4]	Area of hyper-arid and arid regions grows by 3 percent	Area of hyper-arid and arid regions grows by 10 percent
Sea-level rise			70cm (60–80cm) by 2080–2100	105 (85–125cm) by 2080–2100
Ecosystem shifts			10–15 percent Sub-Saharan species at risk of extinction (assuming warming too rapid to allow migration of species) [5]	
Water availability (Run-off / Groundwater recharge)			50–70 percent decrease in recharge rates in western southern Africa and southern west Africa; 30 percent increase in recharge rate in some parts of eastern southern Africa and east Africa[6]	Increase in blue water availability in east Africa and parts of west Africa[7]; decrease in green water availability in most of Africa, except parts of east Africa
Crop yields, areas and food production	Crop growing areas		Projected climate over less than 15 percent of maize, millet and sorghum areas overlaps with present-day climate of crop-growing areas	Reduced length of growing period by more than 20 percent
	Crop production	Baseline of approximately 81 million tonnes in 2000, about 121 kg/capita	Without climate change, a large projected increase of total production to 192 million tonnes that fails to keep up with population growth, hence decrease to 111 kg/capita. With climate change smaller increase to 176 million tonnes and further decrease to 101 kg/capita[8]	
Yields	All crops		Increased crop losses and damages (maize, sorghum, wheat, millet, groundnut, cassava)[9]	
Livestock		Severe drought impacts on livestock[10]		10 percent increase in yields of *B. decumbens* (pasture species) in east and southern Africa; 4 percent and 6 percent decrease in central and west Africa[11]
Marine fisheries			Significant reduction in available protein; economic and job losses projected[12]	
Coastal areas				Approximately 18 million people flooded per year without adaptation[13]
Health and poverty			Undernourishment is expected to increase significantly, and those affected by moderate and severe stunting is expected to increase[14]	

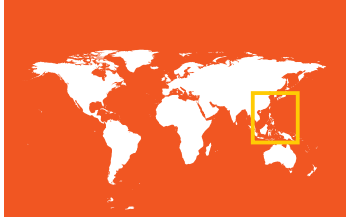


Table 2: Climate Impacts in South East Asia

RISK/IMPACT		0.8°C WARMING (Observed)	2°C WARMING (2040s)[1]	4°C WARMING (2080s)
Heat extremes	Unusual heat extremes	Virtually absent	About 60–70 percent of land in boreal summer months (JJA)	>90 percent of land in boreal summer months (JJA)
	Unprecedented heat extremes	Absent	30–40 percent of land area during boreal summer months (JJA)[15]	>80 percent of land area during boreal summer months (JJA)
Tropical cyclones			Overall decrease in tropical cyclone frequency [16,17]; global increase in tropical cyclone rainfall; increasing frequency of category 5 storms[18]	Decreased number of tropical cyclones making landfall, but maximum wind velocity at the coast is projected to increase by about 6 percent for mainland South East Asia and about 9 percent for the Philippines
Sea-level rise			75cm (65–85cm) by 2080–2100	110 cm (85–130cm) by 2080–2100, lower around Bangkok by 5 cm
Sea-level rise impacts	Coastal erosion (loss of land)	For the south Hai Thinh commune in the Vietnamese Red River delta, about 34 percent (12 percent) of the increase of erosion rate between 1965 and 1995 (1995 and 2005) has been attributed to the direct effect of sea-level rise[19]		Mekong delta significant increase in coastal erosion[20]
	Population exposure	20 million people in South East Asian cities exposed to coastal flooding in 2005[21]		8.5 million people more than at present are projected to be exposed to coastal flooding by 2100 for global sea-level rise of 1 m[22]
	City exposure			Ho Chi Minh City—up to 60 percent of the built-up area projected to be exposed[23] to 1 m sea-level rise
Salinity intrusion		Mekong River delta (2005): Long An province's sugar cane production diminished by 5–10 percent; and significant rice in Duc Hoa district was destroyed[24]		Mahakam river region in Indonesia, increase in land area affected by 7–12 percent[25]
Ecosystem impacts (Coral reefs / coastal wetlands)			Nearly all coral reefs experience severe thermal stress under warming levels of 1.5–2°C	Coral reefs subject to severe bleaching events annually and coastal wetland area decrease[26]
Aquaculture			Estimations of the costs of adapting[27] aquaculture in South East Asia range from US$130–190 million per year from 2010–2050	
Marine fisheries			Decrease in maximum catch potential around the Philippines and Vietnam[28]	Markedly negative trend in bigeye tuna[29]
Health and poverty			The relative risk of diarrhoea is expected to increase[30]	
Tourism			Thailand, Indonesia, the Philippines, Myanmar and Cambodia among the most vulnerable tourism destinations[31]	

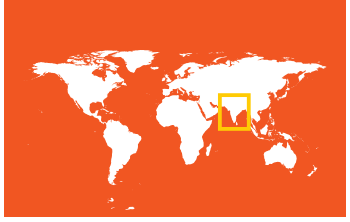


Table 3: Climate Impacts in South Asia

RISK/IMPACT		0.8°C WARMING (Observed)	2°C WARMING (2040s)[1]	4°C WARMING (2080s)
Heat extremes	Unusual heat extremes	Virtually absent	About 20 percent of land in boreal summer months (JJA)	>70 percent of land in boreal summer months (DJF)
	Unprecedented heat extremes	Absent	<5 percent of land in boreal summer months (JJA), except for the southernmost tip of India and Sri Lanka with 20-30 percent of summer months experiencing unprecedented heat	>40 percent of land in boreal summer months (DJF)
Drought				Increased drought over northwestern India, Pakistan, and Afghanistan[32]. Increased length of dry spells in eastern India and Bangladesh[33]
Sea-level rise			70cm (60–80cm) by 2080–2100[34]	105 cm (85–125cm) by 2080–2100, higher by 5–10 cm around Maldives, Kolkata
Tropical cyclones			Increasingly severe tropical cyclone impacts[35]	
Flooding			Increasingly severe flooding[36]	By 2070 approximately 1.5 million people are projected to be affected by coastal floods in the coastal cities of Bangladesh[37]
River run-off	Indus		Mean flow increase of about 65 percent[38]	
	Ganges		20 percent increase in run-off[39]	50 percent increase in run-off
	Brahmaputra		Very substantial reductions in late spring and summer flow[40]	
Water availability	Overall	In India, gross per capita water availability is projected to decline due to population growth[41]	Food water requirements in India projected to exceed green water availability[42, 43]. Around 3°C, it is very likely that per capita water availability in South Asia will decrease by more than 10 percent[44]	
	Groundwater recharge	Groundwater resources already under stress[45]	Climate change is projected to further aggravate groundwater stress	
Crop production			Overall crop production is projected to increase by only 12 percent above 2000 levels (instead of a 60 percent increase without climate change), leading to a one third decline in per capita crop production[46]	
Yields	All crops	Reduced rice yields, especially in rain-fed areas	Crop yield decreases regardless of potentially positive effects	
Health and poverty	Malnutrition and childhood stunting		With climate change percentages increase to 14.6 percent and about 5 percent respectively[47]	
	Malaria		Relative risk of malaria projected to increase by 5 percent in 2050[48]	
	Diarrheal disease		Relative risk of diarrheal disease increase by 1.4 percent compared to 2010 baseline by 2050	
	Heat waves vulnerability	New Delhi exhibits a 4 percent increase in heat-related mortality per 1°C above the local heat threshold of 20°C[49]	Most South Asian countries are likely to experience a very substantial increase in excess mortality due to heat stress by the 2090s[50]	

Endnotes

[1] Years indicate the decade during which warming levels are exceeded in a business-as-usual scenario, not in mitigation scenarios limiting warming to these levels, or below, since in that case the year of exceeding would always be 2100, or not at all.

[2] This is the general picture from CMIP5 global climate models; however, significant uncertainty appears to remain. Observed drought trends (Lyon and DeWitt 2012) and attribution of the 2011 drought in part to human influence (Lott et al. 2013) leaves significant uncertainty as to whether the projected increased precipitation and reduced drought are robust (Tierney, Smerdon, Anchukaitis, and Seager 2013).

[3] Dai (2012). CMIP5 models under RCP4.5 for drought changes 2050–99, warming of about 2.6°C above pre-industrial levels.

[4] see Endnote 2.

[5] Parry et al. (2007).

[6] Temperature increase of 2.3°C and 2.1°C for the period 2041–2079 under SRES A2 and B2 (Döll, 2009).

[7] Gerten et al. (2011).

[8] Nelson et al. (2010).

[9] Schlenker and Lobell (2010).

[10] FAO (2008).

[11] Thornton et al. (2011).

[12] Lam, Cheung, Swartz, & Sumaila (2012). Applying the same method and scenario as (Cheung et al., 2010).

[13] Hinkel et al. (2011) high SLR scenario 126 cm by 2100. In the no sea-level rise scenario, only accounting for delta subsidence and increased population, up to 9 million people would be affected.

[14] Lloyd, Kovats, and Chalabi (2011) estimate the impact of climate-change-induced changes to crop productivity on undernourished and stunted children under five years of age by 2050 and find that the proportion of undernourished children is projected to increase by 52 percent, 116 percent, 82 percent, and 142 percent in central, east, south, and west Sub-Saharan Africa, respectively. The proportion of stunting among children is projected to increase by 1 percent (for moderate stunting) or 30 percent (for severe stunting); 9 percent or 55 percent; 23 percent or 55 percent; and 9 percent or 36 percent for central, east, south, and west Sub-Saharan Africa.

[15] Beyond 5-sigma under 2°C warming by 2071–2099.

[16] Held and Zhao (2011).

[17] Murakami, Wang, et al. (2012).

[18] Murakami, Wang, et al. (2012). Future (2075–99) projections SRES A1B scenario.

[19] Duc, Nhuan, & Ngoi (2012).

[20] 1m sea-level rise by 2100 (Mackay and Russell, 2011).

[21] Hanson et al. (2011).

[22] Brecht et al. (2012). In this study, urban population fraction is held constant over the 21st century.

[23] Storch & Downes (2011). In the absence of adaptation, the planned urban development for the year 2025 contributes to increase Ho Chi Minh City exposure to sea-level rise by 17 percent.

[24] MoNRE (2010) states "Sea-level rise, impacts of high tide and low discharge in dry season contribute to deeper salinity intrusion. In 2005, deep intrusion (and more early than normal), high salinity and long-lasting salinization occurred frequently in Mekong Delta provinces."

[25] Under 4°C warming and 1 m sea-level rise by 2100 (Mcleod, Hinkel et al., 2010).

[26] Meissner, Lippmann, & Sen Gupta (2012).

[27] US$190.7 million per year for the period 2010–2020 (Kam, Badjeck, Teh, Teh, & Tran, 2012); US$130 million per year for the period 2010–2050 (World Bank, 2010).

[28] Maximum catch potential (Cheung et al., 2010).

[29] Lehodey et al. (2010). In a 4°C world, conditions for larval spawning in the western Pacific are projected to have deteriorated due to increasing temperatures. Overall adult mortality is projected to increase, leading to a markedly negative trend in biomass by 2100.

[30] Kolstad & Johansson (2011) derived a relationship between diarrhoea and warming based on earlier studies. (Scenario A1B).

[31] Perch-Nielsen (2009). Assessment allows for adaptive capacity, exposure and sensitivity in a 2°C warming and 50cm SLR scenario for the period 2041–2070.

[32] Dai (2012).

[33] Sillmann & Kharin (2013).

[34] For a scenario in which warming peaks above 1.5°C around the 2050s and drops below 1.5°C by 2100. Due to slow response of oceans and ice sheets the sea-level response is similar to a 2°C scenario during the 21st century, but deviates from it after 2100.

[35] World Bank (2010a). Based on the assumption that landfall occurs during high-tide and that wind speed increases by 10 percent compared to cyclone Sidr.

[36] Mirza (2010).

[37] Brecht et al. (2012). In this study, urban population fraction is held constant over the 21st century.

[38] Van Vliet et al. (2013), for warming of 2.3°C and of 3.2°C.

[39] Fung, Lopez, & New (2011) SRES A1B warming of about 2.7°C above pre-industrial levels.

[40] For the 2045 to 2065 period (global-mean warming of 2.3°C above pre-industrial) (Immerzeel, Van Beek, & Bierkens, 2010).

[41] Bates, Kundzewicz, Wu, & Palutikof (2008); Gupta & Deshpande (2004).

[42] When taking a total availability of water below 1300m^3 per capita per year as a benchmark for water amount required for a balanced diet.

[43] Gornall et al. (2010). Consistent with increased precipitation during the wet season for the 2050s, with significantly higher flows in July, August and September than in 2000. Increase in overall mean annual soil moisture content is expected for 2050 with respect to 1970–2000, but the soil is also subject to drought conditions for an increased length of time.

[44] Gerten et al. (2011). For a global warming of approximately 3°C above pre-industrial and the SRES A2 population scenario for 2080.

[45] Rodell, Velicogna, & Famiglietti (2009). (Döll, 2009; Green et al., 2011).

[46] Nelson et al. (2010).

[47] Lloyd et al. (2011). South Asia by 2050 for a warming of approximately 2°C above pre-industrial (SRES A2).

[48] Pandey (2010). 116,000 additional incidents, 1.8°C increase in SRES A2 scenario.

[49] McMichael et al. (2008).

[50] Takahashi, Honda, & Emori (2007), global mean warming for the 2090s of about 3.3°C above pre-industrial under the SRES A1B scenario and estimated an increase in the daily maximum temperature change over South Asia in the range of 2 to 3°C.

Abbreviations

°C	degrees Celsius
3-sigma events	Events that are three standard deviations outside the historical mean
5-sigma events	Events that are five standard deviations outside the historical mean
AI	Aridity Index
ANN	Annual
AOGCM	Atmosphere-Ocean General Circulation Model
AR4	Fourth Assessment Report of the Intergovernmental Panel on Climate Change
AR5	Fifth Assessment Report of the Intergovernmental Panel on Climate Change
BAU	Business as Usual
$CaCO_3$	Calcium Carbonate
CAT	Climate Action Tracker
CMIP5	Coupled Model Intercomparison Project Phase 5
CO_2	Carbon Dioxide
DIVA	Dynamic Interactive Vulnerability Assessment
DJF	December January February
ECS	Equilibrium Climate Sensitivity
GCM	General Circulation Model
GDP	Gross Domestic Product
FPU	Food Productivity Units
GFDRR	Global Facility for Disaster Reduction and Recovery
IAM	Integrated Assessment Model
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ISI-MIP	Inter-Sectoral Impact Model Intercomparison Project
JJA	June July August
MAGICC	Model for the Assessment of Greenhouse-gas Induced Climate Change
MGIC	Mountain Glaciers and Ice Caps
NH	Northern Hemisphere
OECD	Organisation for Economic Cooperation and Development
PDSI	Palmer Drought Severity Index
ppm	parts per million
RCP	Representative Concentration Pathway
SCM	Simple Climate Model
SLR	Sea-level Rise
SRES	IPCC Special Report on Emissions Scenarios
SREX	IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation
SSA	Sub-Saharan Africa
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNRCO	United Nations Resident Coordinator's Office
USAID	United States Agency for International Development
WBG	World Bank Group

Glossary

Aridity Index The Aridity Index (AI) is an indicator designed for identifying structurally "arid" regions, that is, regions with a long-term average precipitation deficit. AI is defined as total annual precipitation divided by potential evapotranspiration, with the latter a measure of the amount of water a representative crop type would need as a function of local conditions such as temperature, incoming radiation and wind speed, over a year to grow, which is a standardized measure of water demand.

Biome A biome is a large geographical area of distinct plant and animal groups, one of a limited set of major habitats, classified by climatic and predominant vegetative types. Biomes include, for example, grasslands, deserts, evergreen or deciduous forests, and tundra. Many different ecosystems exist within each broadly defined biome, which all share the limited range of climatic and environmental conditions within that biome.

C3/C4 plants refers to two types of photosynthetic biochemical "pathways". C3 plants include more than 85 percent of plants on Earth (e.g. most trees, wheat, rice, yams and potatoes) and respond well to moist conditions and to additional carbon dioxide in the atmosphere. C4 plants (for example savanna grasses, maize, sorghum, millet, sugarcane) are more efficient in water and energy use and outperform C3 plants in hot and dry conditions.

CAT The Climate Action Tracker (CAT) is an independent science-based assessment, which tracks the emission commitments and actions by individual countries. The estimates of future emissions deducted from this assessment serve to analyse warming scenarios that would result from current policy: (a) *CAT Reference BAU*: a lower reference 'business-as-usual' (BAU) scenario that includes existing climate policies, but not pledged emission reductions; and (b) CAT Current Pledges: a scenario additionally incorporating reductions currently pledged internationally by countries.

CMIP5 The Coupled Model Intercomparison Project Phase 5 (CMIP5) brought together 20 state-of-the-art GCM groups, which generated a large set of comparable climate-projections data. The project provided a framework for coordinated climate change experiments and includes simulations for assessment in the IPCC´s AR5.

CO_2 fertilization The CO_2 fertilization effect may increase the rate of photosynthesis mainly in C3 plants and increase water use efficiency, thereby producing increases in agricultural C3 crops in grain mass and/or number. This effect may to some extent offset the negative impacts of climate change, although grain protein content may decline. Long-term effects are uncertain as they heavily depend on a potential physiological long-term acclimation to elevated CO_2, as well as on other limiting factors including soil nutrients, water and light.

GCM A General Circulation Model is the most advanced type of climate model used for projecting changes in climate due to increasing greenhouse-gas concentrations, aerosols and external forcings like changes in solar activity and volcanic eruptions. These models contain numerical representations of physical processes in the atmosphere, ocean, cryosphere and land surface on a global three-dimensional grid, with the current generation of GCMs having a typical horizontal resolution of 100 to 300 km.

GDP (Gross Domestic Product) is the sum of the gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without deductions for

depreciation of fabricated assets or for depletion and degradation of natural resources.

GDP (PPP) per capita is GDP on a purchasing power parity basis divided by population. Please note: Whereas PPP estimates for OECD countries are quite reliable, PPP estimates for developing countries are often rough approximations.

Hyper-aridity Land areas with very low Aridity Index (AI), generally coinciding with the great deserts. There is no universally standardized value for hyper-aridity, and values between 0 and 0.05 are classified in this report as hyper-arid.

IPCC AR4, AR5 The Intergovernmental Panel on Climate Change (IPCC) is the leading body of global climate change assessments. It comprises hundreds of leading scientists worldwide and on a regular basis publishes assessment reports which give a comprehensive overview over the most recent scientific, technical and socio-economic information on climate change and its implications. The Fourth Assessment Report (AR4) was published in 2007. The upcoming Fifth Assessment Report (AR5) will be completed in 2013/2014.

ISI-MIP The first Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) is a community-driven modeling effort which provides cross-sectoral global impact assessments, based on the newly developed climate [Representative Concentration Pathways (RCPs)] and socio-economic scenarios. More than 30 models across five sectors (agriculture, water resources, biomes, health and infrastructure) participated in this modeling exercise.

MAGICC Carbon-cycle/climate model of "reduced complexity," here applied in a probabilistic set-up to provide "best-guess" global-mean warming projections, with uncertainty ranges related to the uncertainties in carbon-cycle, climate system and climate sensitivity. The model is constrained by historical observations of hemispheric land/ocean temperatures and historical estimates for ocean heat-uptake, reliably determines the atmospheric burden of CO_2 concentrations compared to high-complexity carbon-cycle models and is also able to project global-mean near-surface warming in line with estimates made by GCMs.

Pre-industrial levels (what it means to have present 0.8°C warming) The instrumental temperature records show that the 20-year average of global-mean near-surface air temperature in 1986–2005 was about 0.6°C higher than the average over 1851–1879. There are, however, considerable year-to-year variations and uncertainties in data. In addition the 20-year average warming over 1986–2005 is not necessarily representative of present-day warming. Fitting a linear trend over the period 1901 to 2010 gives a warming of 0.8°C since "early industrialization." Global-mean near-surface air temperatures in the instrumental records of surface-air temperature have been assembled dating back to about 1850. The number of measurement stations in the early years is small and increases rapidly with time. Industrialization was well on its way by 1850 and 1900, which implies using 1851–1879 as a base period, or 1901 as a start for linear trend analysis might lead to an underestimate of current and future warming, but global greenhouse-gas emissions at the end of the 19th century were still small and uncertainties in temperature reconstructions before this time are considerably larger.

RCP Representative Concentration Pathways (RCPs) are based on carefully selected scenarios for work on integrated assessment modeling, climate modeling, and modeling and analysis of impacts. Nearly a decade of new economic data, information about emerging technologies, and observations of environmental factors, such as land use and land cover change, are reflected in this work. Rather than starting with detailed socioeconomic storylines to generate emissions scenarios, the RCPs are consistent sets of projections of only the components of radiative forcing (the change in the balance between incoming and outgoing radiation to the atmosphere caused primarily by changes in atmospheric composition) that are meant to serve as input for climate modeling. These radiative forcing trajectories are not associated with unique socioeconomic or emissions scenarios, and instead can result from different combinations of economic, technological, demographic, policy, and institutional futures.

RCP2.6 RCP2.6 refers to a scenario which is representative of the literature on mitigation scenarios aiming to limit the increase of global mean temperature to 2°C above the pre-industrial period. This emissions path is used by many studies that are being assessed for the IPCC´s Fifth Assessment Report and is the underlying low emissions scenario for impacts assessed in other parts of this report. In this report we refer to the RCP2.6 as a 2°C World.

RCP8.5 RCP8.5 refers to a scenario with no-climate-policy baseline with comparatively high greenhouse gas emissions which is used by many studies that are being assessed for the upcoming IPCC Fifth Assessment Report (AR5). This scenario is also the underlying high emissions scenario for impacts assessed in other parts of this report. In this report we refer to the RCP8.5 as a 4°C World above the pre-industrial period.

Severe & extreme Indicating uncommon (negative) consequences. These terms are often associated with an additional qualifier

like "unusual" or "unprecedented" that has a specific quantified meaning (see "Unusual & unprecedented").

SRES The Special Report on Emissions Scenarios (SRES), published by the IPCC in 2000, has provided the climate projections for the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC). They do not include mitigation assumptions. The SRES study includes consideration of 40 different scenarios, each making different assumptions about the driving forces determining future greenhouse gas emissions. Scenarios are grouped into four families, corresponding to a wide range of high and low emission scenarios.

SREX In 2012 the IPCC published a special report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX). The report provides an assessment of the physical as well as social factors shaping vulnerability to climate-related disasters and gives an overview of the potential for effective disaster risk management.

Unusual & unprecedented In this report, unusual and unprecedented heat extremes are defined using thresholds based on the historical variability of the current local climate. The absolute level of the threshold thus depends on the natural year-to-year variability in the base period (1951–1980), which is captured by the standard deviation (sigma). Unusual heat extremes are defined as 3-sigma events. For a normal distribution, 3-sigma events have a return time of 740 years. The 2012 U.S. heat wave and the 2010 Russian heat wave classify as 3-sigma and thus unusual events. Unprecedented heat extremes are defined as 5-sigma events. They have a return time of several million years. Monthly temperature data do not necessarily follow a normal distribution (for example, the distribution can have "long" tails, making warm events more likely) and the return times can be different from the ones expected in a normal distribution. Nevertheless, 3-sigma events are extremely unlikely and 5-sigma events have almost certainly never occurred.

Chapter 1

Introduction

A 4°C world by the end of the century remains a real risk. The updated United Nations Environment Programme (UNEP) Emissions Gap Report, released at the Climate Convention Conference in Doha in December 2012, found that present emission trends and pledges are consistent with emission pathways that reach warming in the range of 3.5°C to 5°C by 2100 (UNEP 2012) (Box 1.1). This outlook is higher than that of *Turn Down the Heat: Why a 4°C Warmer World Must be Avoided,*[6] which estimated that current pledges, if fully implemented, would likely lead to warming exceeding 3°C before 2100. Several lines of evidence indicate that emissions are likely to be higher than those that would result from present pledges, as estimated in *Turn Down the Heat* in 2012. Apart from the 2012 UNEP Gap report, the Turn Down The Heat report includes recent estimates derived from a large set of energy sector economic models. Estimates of present trends and policies come from the International Energy Agency (IEA) *World Energy Outlook 2012* report. Based on the IEA current policy scenario, in the absence of further mitigation action, a 4°C warming above pre-industrial levels within this century is a real possibility with a 40 percent chance of warming exceeding 4°C by 2100 and a 10 percent chance of it exceeding 5°C (International Energy Agency 2012).[7]

One of the key conclusions of *Turn Down the Heat* was that the impacts of climate change would not be evenly distributed (Box 1.2). In a 4°C world, climate change is expected to affect societies across the globe. As is illustrated in Figure 1.1, temperatures do not increase uniformly relative to present-day conditions and sea levels do not rise evenly. Impacts are both distributed and felt disproportionately toward the tropics and among the poor.

This report provides a better understanding of the distribution of impacts in a 4°C world by looking at how different regions—Sub-Saharan Africa, South East Asia, and South Asia—are projected to experience climate change. While such climate events as heat waves are expected to occur across the globe, geographic and socioeconomic conditions produce particular vulnerabilities in different regions. Vulnerability here is broadly understood as a function of exposure to climate change and its impacts and the extent to which populations are able to cope with these impacts.[8]

Specific climate impacts form the basis of each regional assessment:

- Sub-Saharan Africa heavily relies on agriculture as a source of food and income. Ninety-seven percent of agricultural production is currently rainfed. This leaves the region highly vulnerable to the consequences of changes in precipitation patterns, temperature, and atmospheric CO_2 concentration for agricultural production.
- South East Asia, with its archipelagic landscape and a large proportion of the population living in low-lying deltaic and coastal regions (where a number of large cities are located), is particularly vulnerable to the impacts of sea-level rise. South East Asia is also home to highly bio-diverse marine wildlife and many coastal livelihoods depend on the goods

6 Hereafter referred to as *Turn Down the Heat*.

7 This report analyzes a range of scenarios that includes a recent IEA analysis, as well as current and planned national climate policies, and makes projections of warming that are quantified in Chapter 2. In contrast, the previous report (World Bank 2012) used an illustrative "policy" scenario that has relatively ambitious proposed reductions by individual countries for 2020, as well as for 2050, and thus suggests that there is only a 20 percent likelihood of exceeding 4°C by 2100.

8 IPCC (2007) defines vulnerability as "the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change".

Box 1.1 Definition of Warming Levels and Base Period in this Report

This report and the previous *Turn Down the Heat* report referenced future global-warming levels against the pre-industrial period. A "2°C World" and a "4°C World" is defined as the increase in global-mean near-surface air temperature above pre-industrial climate by the end of the 21st century. This approach is customary in the international policy debate, including the UNFCCC, as well as in scientific assessments closely related to this debate, such as those produced by the IEA (World Energy Outlooks) and UNEP (UNEP Emissions Gap Reports). By contrast, IPCC's Fourth Assessment Report expressed warming projections relative to an increase in the mean over the period 1980–1999, while the upcoming Fifth Assessment Report (AR5) uses 1986–2005 as a base period. Given observed warming from pre-industrial levels to 1986–2005 of about 0.7°C, all projections in AR5 would thus be around 0.7°C "lower" than those shown in this report for the same emission scenarios and impact levels. In other words a "4°C world" scenario in 2100 in this report would be a world 3.3°C warmer than 1986–2005 in the AR5. See further details in Appendix 1.

In addition, while projections in this report often refer to projections around the year 2100, it is also common to refer to averages for the 20 years around 2090, as is often done in many impact assessments and in the IPCC. In this case a 4°C scenario in 2100 would be about a 3.5°C scenario above pre-industrial for the 2080–2099 period, given the projected rate of warming in such scenarios of 0.5°C/decade by the end of the century. This scenario would thus be only 2.8°C warmer than the 1986–2005 base period by the 2080–2099 period yet it would be identical with the "4°C world" scenario in this report. While different base and averaging periods are used to describe the climate changes resulting from the same underlying emissions scenarios, it is important to realize that the concentration of carbon dioxide and other greenhouse gases and aerosols in a given year or period are not changed, nor is the nature of the impacts described.

Box 1.2 Extreme Events 2012–2013

During the last year, extreme events have been witnessed across the globe. A particular high-temperature event at a particular place cannot be attributed one-on-one to anthropogenic climate change, but the likelihood of such events is projected to increase, in particular in the tropics where local year-to-year variations are smaller. Although below-average temperatures were recorded over Alaska and northern and eastern Australia, high temperatures occurred over North America, southern Europe, most of Asia, and parts of northern Africa. Across the United States, the number of broken temperature records in 2012 doubled compared to the August 2011 heat wave. Extremes in other climate variables can occur in tandem with heat events, such as the extreme drought accompanying this year's heat wave in the US, which extended into northern Mexico. The drought in northern Brazil was the worst in 50 years.

By contrast, countries in Africa, including Tanzania, Nigeria, Niger, and Chad, experienced severe flooding because of an unusually active African monsoon season. Devastating floods impacted Pakistan as well, with more than 5 million people and 400,000 hectares of crops estimated to have been affected. Even in some areas of above-average warming, early in the year several unusually cold spells were accompanied by heavy snowfall, including in northeast China and Mongolia. 2012 saw a record loss of Arctic sea ice.

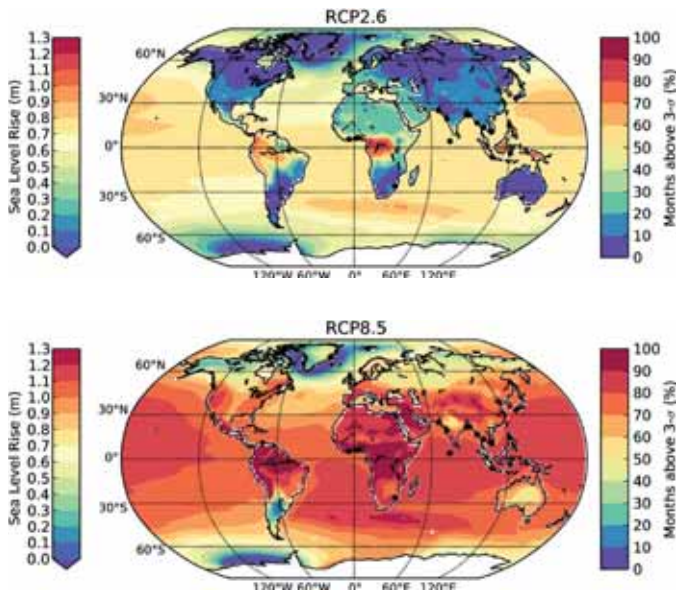
The year 2012 was also an active year for tropical cyclones, with Hurricane Sandy the most noteworthy because of the high number of lives lost and infrastructure damaged in the Caribbean and in the United States. Typhoon Sanba in East Asia was the strongest cyclone globally in 2012; it affected thousands of people in the Philippines, Japan, and the korean Peninsula.

Australia saw a severe heat wave during the Australian summer, with record temperatures and associated severe bush fires followed by extreme rainfall and flooding. Records were continuously broken, with the hottest summer on record and the hottest seven consecutive days ever recorded in Australia. A recent report by the Australian Climate Commission (Australian Climate Comission 2013) attributes the severity and intensity of recorded temperatures and extreme events to anthropogenic climate change. However, no studies have been published attributing the other extreme events listed above to anthropogenic climate change.

and services offered by these ecosystems. The impacts of sea-level rise and changes in marine conditions, therefore, are the focus for South East Asia, with the Philippines and Vietnam serving as examples for maritime and mainland regions respectively.

- In South Asia, populations rely on seasonal monsoon rainfall to meet a variety of needs, including human consumption and irrigation. Agricultural production, an income source for approximately 70 percent of the population, in most part depends on groundwater resources being replenished by monsoon rains. Snow and glacial melt in the mountain ranges are the primary source of upstream freshwater for many river basins and play an important role in providing freshwater for the region. The variability of monsoon rainfall is expected to increase and the supply of water from melting mountain glaciers is expected to decline in the long term. South Asia is, therefore, particularly vulnerable to impacts on freshwater resources and their consequences.

Figure 1.1: Projected sea-level rise and northern-hemisphere summer heat events over land in a 2°C World (upper panel) and a 4°C World (lower panel)[a]



Unusual heat extremes (3-σ, or sigma) refer to temperatures exceeding the historical ("normal") mean recorded in the respective area by 3 standard deviations. Such heat extremes are highly unlikely in a stable climate: In a normal distribution based on climate conditions from 1951–80, events warmer than 3-sigma from the mean occur on average once in 740 years. Monthly temperature data do not necessarily follow a normal distribution (for example, the distribution can have "long" tails, making warm events more likely) and the return times can be different from the ones expected in a normal distribution. Nevertheless, 3-sigma heat extremes are extremely unlikely without climate change. The US heat wave 2012 and the Russian heat wave 2010 classify as unusual heat extremes, that is, 3-sigma events. However, extreme heat events are more likely in future under climate change as the normal distribution shifts: for example, a value of 50 percent in Figure 1.1 indicates that heat extremes of 3-sigma or greater have a probability of occurring once every two months.

[a] Following (Hansen, Sato, & Ruedy, 2012), the period 1951–80 is defined as a baseline for changes in heat extremes. This baseline has the advantage of having been a period of relatively stable global temperature, prior to rapid global warming, and of providing sufficient observational measurements such that the climatology is well defined. The baseline for sea-level rise projections is the period 1986–2005.

This new report builds on the scientific background of the earlier report and zooms in on the three focus regions to examine how they are impacted by warming up to and including an increase in global mean temperature of 4°C above pre-industrial levels in the 21st century. The projections on changes in temperature, heat extremes, precipitation, and aridity are based on original analysis of Coupled Model Intercomparison Project Phase 5 (CMIP5) Global Circulation Model (GCM) output and those of sea-level rise on CMIP5 GCMs, semi-empirical modeling, and the "simple climate model," the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC; see also Appendix 1 for details) (Box 1.3). The sectoral analysis for the three regions is based on existing literature.

The report is structured as follows. Chapter 2 explores the probability of warming reaching 4°C above pre-industrial levels and discusses the possibility of significantly limiting global mean warming to below 2°C. It further provides an update on global climate impact projections for different levels of global warming. The updated analysis of the risks at the global level further complements the 2012 report and provides a framework for the regional case studies. Chapters 3 to 5 present analysis of climate impacts for the three regions: Sub-Saharan Africa, South East Asia, and South Asia.

The focus of the regional chapters is the nature of the impacts and the associated risks posed to the populations of the regions. The possibility of adaptation and its capacity to minimize the vulnerability to the risks accompanying climate change is not assessed in this report. Rather, this report sets out to provide an overview of the challenges that human populations are expected to face under future projected climate change due to impacts in selected sectors. Some dimensions of vulnerability of populations are not covered here, such as gender and the ways in which climate change impacts may be felt differently by men and women. Finally, while many of the findings presented in this report may prove relevant to development policy in these regions, this report is not intended to be prescriptive; rather, it is intended to paint a picture of some of the challenges looming in a 4°C world.

In this report, as in the previous one, "a 4°C world" is used as shorthand for warming reaching 4°C above pre-industrial levels by the end of the century. It is important to note that this does not imply a stabilization of temperatures nor that the magnitude of impacts is expected to peak at this level. Because of the slow response of the climate system, the greenhouse gas emissions and concentrations that would lead to warming of 4°C by 2100 and associated higher risk of thresholds in the climate system being crossed, would actually commit the world to much higher warming, exceeding 6°C or more in the long term with several meters of sea-level rise ultimately associated with this warming (Rogelj et al. 2012; International Energy Agency 2012; Schaeffer and van Vuuren 2012). For a 2°C warming above pre-industrial levels, stabilization at this level by 2100 and beyond is assumed in the projections, although climate impacts would persist for decades, if not centuries to come: sea-level rise, for example, would likely reach 2.7 meters above 2000 levels by 2300 (Schaeffer, Hare, Rahmstorf, and Vermeer 2012).

Populations across the world are already experiencing the first of these challenges at the present level of warming of 0.8°C above pre-industrial levels. As this report shows, further major challenges are expected long before the end of the century in both 2°C and a 4°C warming scenarios. Urgent action is thus needed to prevent those impacts that are still avoidable and to adapt to those that are already being felt and will continue to be felt for decades to

come. For many systems, climate change exacerbates other non-climatic stressors such as land degradation or marine pollution. Even without climate change, human support systems are likely to be placed under further pressure as populations grow.

Box 1.3 Climate Change Projections, Impacts, and Uncertainty

In this report the projections of future climate change and its plausible consequences are based, necessarily, on modeling exercises. The results discussed take into account the inherent uncertainties of model projections. The analysis of temperature and precipitation changes, as well as heat extremes and aridity, is based on state-of-the-art Coupled Model Intercomparison Project Phase 5 (CMIP5) climate models. Precipitation data was bias-corrected, such that it reproduces the historical mean and variation in precipitation. Results are reported as the mean of the CMIP5 models and where relevant a measure of agreement/disagreement of models on the sign of changes is indicated. The projections might therefore provide more robust and consistent trends than a random selection of model results, even at regional scales. Results reported from the literature are, in most cases, based on climate impact models and are likewise faced with issues about uncertainty. As with the case for climate projections, there are limitations on the precision with which conclusions can be drawn. For this reason, conclusions are drawn where possible, from multiple lines of evidence across a range of methods, models and data sources including the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) and the Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX).

Chapter 2

The Global Picture

Global projections of temperature, heat extremes, and precipitation changes, as well as projections of sea-level rise, are presented in this chapter. Drawing on the latest data from the first inter-sectoral impact model intercomparison project (ISI-MIP), a number of sectoral impacts are updated. These include the risk of biome shifts and diminished water availability. The final section of this chapter presents an initial evaluation of hotspots where impacts in multiple sectors occur and places this evaluation in the context of the most recent literature for each sector.

In this report, the low-emissions scenario RCP2.6, a scenario which is representative of the literature on mitigation scenarios aiming to limit the increase of global mean temperature to 2°C (Van Vuuren et al. 2011), is used as a proxy for a 2°C world. The high-emissions scenario RCP8.5 is used as proxy for a 4°C world. These emissions paths are used by many studies that are being assessed for the Fifth Assessment Report (AR5) of the IPCC. These are the underlying projections of temperature and precipitation changes, as well as those on heat extremes and sea-level rise in this chapter and the regional parts of this report.

Observed Changes and Climate Sensitivity

Observations show that warming during the last decade has been slower than earlier decades (Figure 2.1). This is likely the result of a temporary slowdown or "hiatus" in global warming and a natural phenomenon (Easterling and Wehner 2009; Meehl et al. 2011). Slower and faster decades of warming occur regularly superimposed on an overall warming trend (Foster and Rahmstorf 2011). Evaluating all major influences that determine global mean temperature changes, Foster and Rahmstorf (2011) show that over the past decade the underlying trend in warming continued unabated, if one filters out the effects of ENSO, solar variations, and volcanic activity.[9]

One of the basic tests of a model is whether it is able to reproduce observed changes: recent analysis shows clearly that in both the IPCC's Third and Fourth Assessment Reports climate model warming projections match observations very well. (Figure 2.2) (Foster and Rahmstorf (2011).

The recent slower warming has led to media attention that suggests the sensitivity of the climate system to anthropogenic emissions might be smaller than estimated previously.[10] However, an overall review of climate sensitivity that takes into account multiple lines of evidence, including methodologies that result in low climate sensitivity estimates and other studies that show instead a larger estimate of sensitivity (Knutti and Hegerl 2008), results in values for climate sensitivity consistent with IPCC's AR4: "most likely" around 3°C, a 90 percent probability of larger than 1.5°C, "very likely" in the range of 2–4.5°C; values substantially higher than 4.5°C cannot be ruled out.

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9 This can be explained by natural external forcings, like those of solar and volcanic origin, and physical mechanisms within the climate system itself, with a large role played by the El Niño/La Niña-Southern-Oscillation (ENSO), a pattern of natural fluctuations in heat transfer between the ocean's surface and deeper layers. If such fluctuations are filtered out of the observations, a robust continued warming signal emerges over the past three decades. It is this signal that should be compared to the average warming of climate models, because the latter exhibit the same upswings and downswings of warming as the observational signal, but at different times, due to the natural chaotic nature of the climate system. Taking an average from many models filters out these random variations; hence, this must also be done with observational data sets before comparing with model results.

10 Recently, one such study that resulted in a value around 2°C, much like other studies using comparable methods and included in IPCC's meta-analysis, received media attention (see Box 2.1). http://www.forskningsradet.no/en/Newsarticle/Global_warming_less_extreme_than_feared/1253983344535/p1177315753918.

Box 2.1 Climate Sensitivity

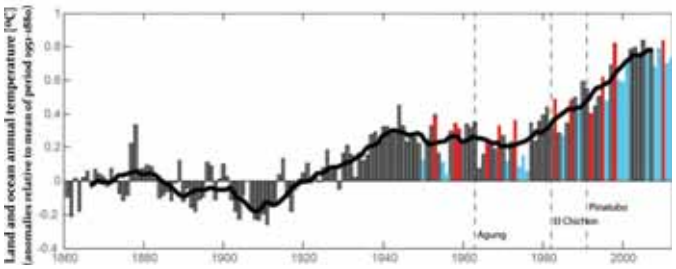
Climate sensitivity (more specifically equilibrium climate sensitivity [ECS]) is defined as the change in global mean surface temperature at equilibrium following a doubling of atmospheric carbon dioxide (CO_2) concentrations. It is a measure of the long-term response of the climate system to a sustained increase in radiative[a] forcing.

Research efforts are continuing to better constrain ECS. Recent studies indicate that both the high end (Fasullo and Trenberth 2012) and the low end (Amundsen and Lie 2012) cannot be excluded, while the current range of results for the most advanced climate models (Andrews et al. 2012) and reconstructions of climatic records over the last 65 million years (E. J. Rohling et al. 2012) confirm the "likely" range given in the AR4 assessment.

The probabilistic global mean climate projections in this section consider the AR4 assessment as still being representative of our current understanding of the ECS and use an intermediate (that is, neither the most optimistic nor the most conservative) interpretation of it (Rogelj et al. 2012b). Note that in projections from more complex models (such as the CMIP5 models analyzed for temperature, precipitation, and aridity projections in this report), climate sensitivity is not a predefined model parameter but is emerging from all the feedback processes included in the model.

[a] In the context of climate change, the IPCC AR4 defines this as "a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism."

Figure 2.1: Time series from the instrumental measurement record of global-mean annual-mean surface-air temperature anomalies relative to a 1851–80 reference period



Solid black lines represent the 11-year running mean. Vertical dashed lines indicate three of the largest recent volcanic eruptions. Coloring of annual-mean temperature bars from 1950 onward indicate "neutral years" (grey), as opposed to warming El Niño (red) and cooling La Niña ENSO events (blue).

Sources: Jones et al. (2012); Morice et al. (2012) for temperature record, ENSO years from NOAA (adapted from NOAA - http://www.ncdc.noaa.gov/sotc/global/2012/13).

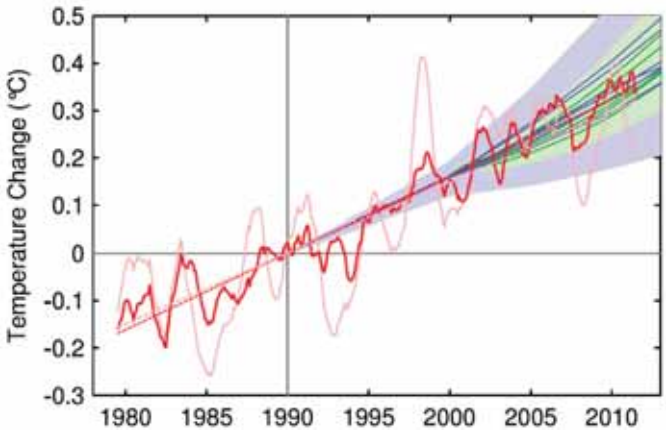
Unlike global warming, for sea-level rise, the models consistently underestimate the accelerating rise in sea levels compared to observations (Figure 2.3). Along with observations, Figure 2.3 shows projections for sea-level rise by ice-sheet and ocean models reported in the IPCC's Third and Fourth Assessment Reports. Remarkably, the models are not able to keep pace with observed sea-level rise, which rises 60-percent faster compared to the best estimates from models. This mismatch initiated the development of "semi-empirical" models (e.g., Rahmstorf 2007; Kemp et al. 2011) that constrain model parameters by centuries to millennia of observations.[11] Based on these parameters, such models project changes that by 2100 are generally higher than the process-based models by around 30–50 percent (see World Bank 2012 for more background).

How Likely is a 4°C World?

The previous *Turn Down the Heat* report estimated that current emission reductions pledges by countries worldwide, if fully implemented, would likely lead to warming exceeding 3°C before 2100.

New assessments of business-as-usual emissions in the absence of strong climate mitigation policies (Riahi et al. 2013; Kriegler et al. 2013; Schaeffer et al. 2013), as well as recent reevaluations of the likely emission consequences of pledges and targets adopted

Figure 2.2: Global-mean surface-air temperature time series unadjusted (thin pink line) and adjusted for short-term variability (red line)

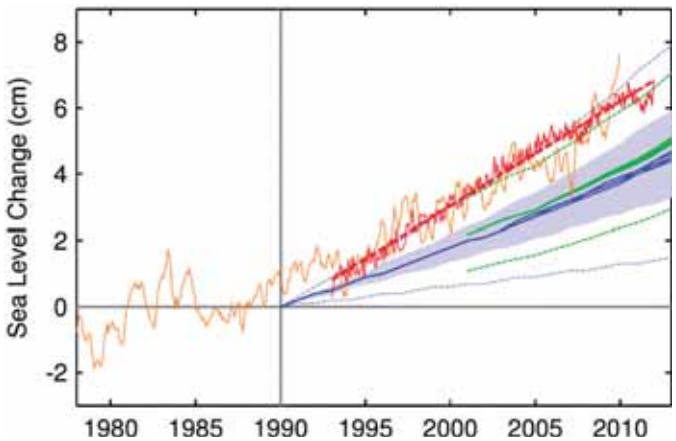


The blue range represents model results from IPCC Third Assessment Report and the green range from IPCC AR4.

Source: Adapted from Rahmstorf et al. (2012).

[11] Data dating back more than about 150 years is generally from reconstructions of past climatic circumstance obtained by proxy data, i.e. observational evidence from which past climate changes can be derived.

Figure 2.3: Sea-level rise from observations (orange: tide gauges, red: satellites) and models (blue: projections from IPCC TAR starting in 1990, green: projections from IPCC AR4 starting in 2000)



Models do not include a sea-level decline due to dam building estimated for 1961–2003 that is part of the observed time series. Including this in the models would widen the gap with observations further, although this is likely fully compensated by increased groundwater extraction during the last 2 decades

Source: Adapted from Rahmstorf et al. (2012).

by countries, point to a considerable likelihood of warming reaching 4°C above pre-industrial levels within this century. The latest research supports both of these findings (see Appendix 1):

The most recent generation of energy-economic models estimates emissions in the absence of further substantial policy action (business as usual), with the median projections reaching a warming of 4.7°C above pre-industrial levels by 2100, with a 40 percent chance of exceeding 5°C (Schaeffer et al. 2013). Newly published assessments of the recent trends in the world's energy system by the International Energy Agency in its World Energy Outlook 2012 indicate global-mean warming above pre-industrial levels would approach 3.8°C by 2100. In this assessment, there is a 40 percent chance of warming exceeding 4°C by 2100 and a 10 percent chance of it exceeding 5°C.

In relation to the effects of pledges, the updated UNEP Emissions Gap Assessment 2012, found that present emission trends and pledges are consistent with emission pathways that reach warming in the range of 3 to 5°C by 2100, with global emissions estimated for 2020 closest to levels consistent with a pathway leading to 3.5–4°C warming by 2100.[12]

The high emissions scenario underlying novel assessments, RCP8.5, reaches a global-mean warming level of about 4°C above pre-industrial levels by the 2080s and gives a median warming of about 5°C by 2100.[13]

According to new analysis (see Appendix 1), there is a 66-percent likelihood that emissions consistent with RCP8.5 will lead to a warming of 4.2 to 6.5°C, and a remaining 33-percent chance that warming would be either lower than 4.2°C or higher than 6.5°C by 2100.[14] On average, the most recent business-as-usual scenarios lead to warming projections close to those of RCP8.5 and there is a medium chance that end-of-century temperature rise exceeds 4°C. Approximately 30 percent of the most recent business-as-usual scenarios reach a warming higher than that associated with RCP8.5 by 2100 (see Figure 2.4, right-hand panel).

Can Warming be Held Below 2°C?

State-of-the-art climate models show that, if emissions are reduced substantially, there is a high probability that global mean temperatures can be held to below 2°C relative to pre-industrial levels. Climate policy has to date not succeeded in curbing global greenhouse gas emissions, and emissions are steadily rising (Peters et al. 2013). However, recent high emission trends do not imply high emissions forever (van Vuuren and Riahi 2008). Several studies show that effective climate policies can substantially influence the trend and bring emissions onto a feasible path in line with a high probability of limiting warming to below 2°C, even with limited emissions reductions in the short term (for example, OECD 2012; Rogelj et al. 2012a; UNEP 2012; van Vliet et al. 2012; Rogelj et al. 2013). The available scientific literature makes a strong case that achieving deep emissions reductions over the long term is feasible; reducing total global emissions to below 50 percent of 2000 levels by 2050 (Clarke et al. 2009; Fischedick et al. 2011; Riahi et al. 2012). Recent studies also show the possibility, together with the consequences of delaying action (den Elzen et al. 2010; OECD 2012; Rogelj et al. 2012a, 2013; van Vliet et al. 2012).

Patterns of Climate Change

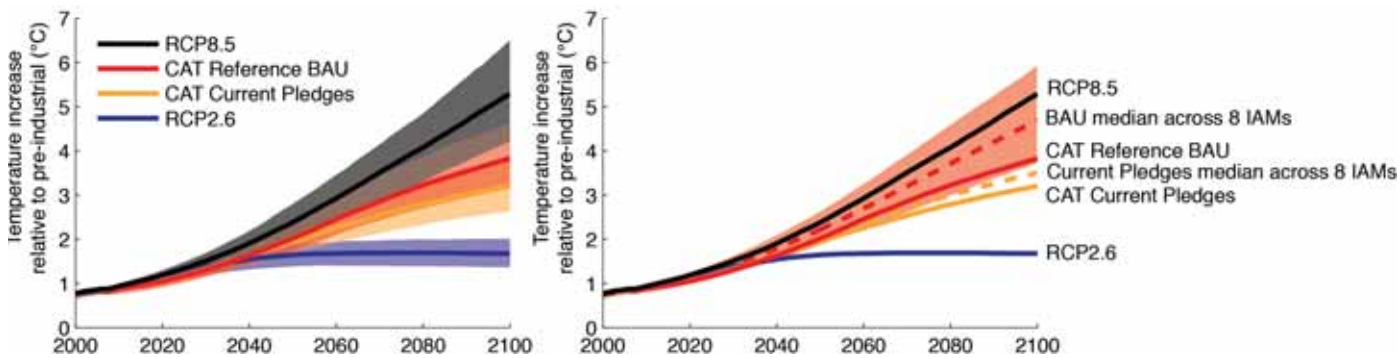
This report presents projections of global and regional temperature and precipitation conditions, as well as expected changes in aridity and in the frequency of severe heat extremes. These analyses are based on the ISI-MIP database (Warszawski et al., in preparation), consisting of a subset of the state-of-the-art climate model projections of the Coupled Model Intercomparison Project phase 5 (CMIP5; K. E. Taylor, Stouffer, and Meehl, 2011) that were bias-corrected against late twentieth century meteorological observations (Hempel, Frieler,

[12] This applies for the "unconditional pledges, strict rules" case.

[13] RCP refers to "Representative Concentrations Pathway," which underlies the IPCC´s Fifth Assessment Report. RCPs are consistent sets of projections for only the components of radiative forcing (the change in the balance between incoming and outgoing radiation to the atmosphere caused primarily by changes in atmospheric composition) that are meant to serve as inputs for climate modeling. See also Box 1, "What are Emission Scenarios?" on page 22 of the previous report.

[14] A probability of > 66 percent is labeled "likely" in IPCC's uncertainty guidelines adopted here.

Figure 2.4: Projections for surface-air temperature increase



The left-hand panel shows probabilistic projections by the Simple Climate Model (SCM; see Appendix 1). Lines show "best-estimate" (median) projections for each emission scenario, while shaded areas indicate the 66 percent uncertainty range. The shaded ranges represent the uncertainties in how emissions are translated into atmospheric concentrations (carbon cycle uncertainty) and how the climate system responds to these increased concentrations (climate system uncertainty). The right-hand panel shows projections of temperature increase for the scenarios assessed in this report in the context of business-as-usual (BAU) projections from the recent Integrated Assessment Model (IAM) literature discussed in the Appendix. The light-red shaded area indicates the 66 percent uncertainty range around the median (red dashed line) of BAU projections from 10 IAMs.

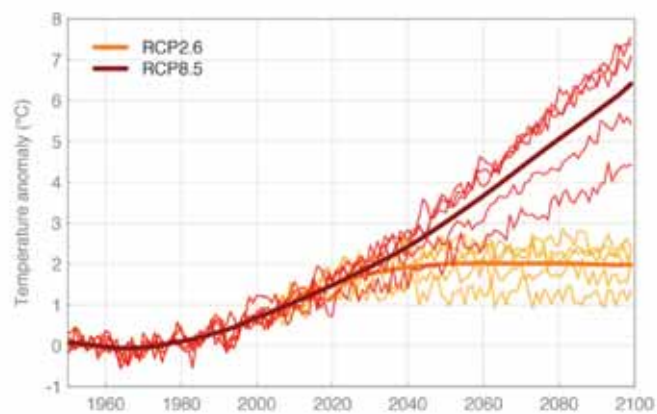
Warszawski, Schewe and Piontek 2013; see also Appendix 2). The latter refers to a method of letting the models provide more accurate future projections on a global, as well as on a regional (subcontinental) scale. The patterns of change in this subset of models are shown to be consistent with published CMIP5 multi-model mean changes for temperature, precipitation, and heat extremes. Following Hansen, Sato, and Ruedy (2012), the period 1951–80 is defined as a baseline for changes in heat extremes. This baseline has the advantage of having been a period of relatively stable global temperature, prior to rapid global warming, and of providing sufficient observational measurements such that the climatology is well defined. The baseline for sea-level rise projections is the period 1986–2005.

This chapter discusses the results from a global perspective; the following three chapters look at three selected regions: Sub-Saharan Africa, South East Asia, and South Asia. The focus is on changes expected during the summer, as this is the season when climate change is expected to have the greatest impact on human populations in many regions (Hansen, Sato, and Ruedy 2012).

Projected Temperature Changes

Under scenario RCP2.6, global average land surface temperatures for the months June, July, August peak at approximately 2°C above the 1951–80 baseline by 2050 and remain at this level until the end of the century (Figure 2.5). The high emissions scenario RCP8.5 follows a temperature trajectory similar to that of RCP2.6 until 2020, but starts to deviate upwards strongly after 2030. Warming continues to increase until the end of the century with global-mean land surface temperature for the northern hemisphere summer reaching nearly 6.5°C above the 1951–80 baseline by 2100. Note that these values are higher than the associated global mean temperature anomalies since warming is more pronounced over land than ocean.

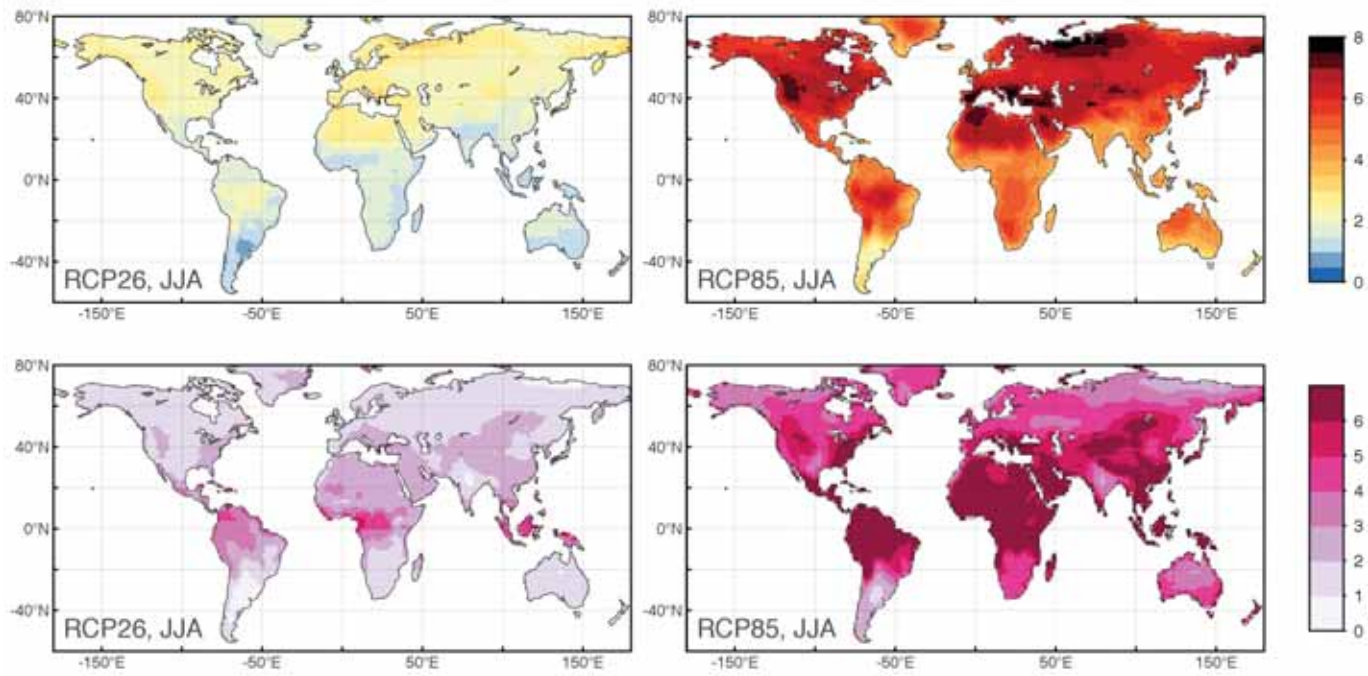
Figure 2.5: Temperature projections for global land area



Temperature projections for global land area, for the multi-model mean (thick lines), and individual models (thin lines), under scenarios RCP2.6 and RCP8.5 for the months of June, July, and August (JJA). The multi-model mean has been smoothed to give the climatological trend.

Warming is generally stronger in the Northern Hemisphere, a pattern which is found for both emissions scenarios and for both the summer and winter seasons (see Figure 2.6 for JJA). This is a well-documented feature of global warming. Thus, Northern Hemisphere summers are expected to typically warm by 2–3°C under RCP2.6 and by 6.5–8°C under RCP8.5. As shown in the previous report, regions that see especially strong absolute warming include the Mediterranean, the western United States, and northern Russia.

Figure 2.6: Multi-model mean temperature anomaly for RCP2.6 (left) and RCP8.5 (right) for the months of JJA



Temperature anomalies in degrees Celsius (top row) are averaged over the time period 2071–99 relative to 1951–80, and normalized by the local standard deviation (bottom row).

A good way to gain appreciation of the warming is to compare it to the historically observed natural year-to-year temperature variability (Hansen et al. 2012). The absolute warming is thus divided (normalized) by the local standard deviation (sigma), which represents the normal year-to-year changes in monthly temperature because of natural variability (see the box 2.2). A normalized warming of 5-sigma, therefore, means that the average change in the climate is five times larger than the current normal year-to-year variability. In the tropics, natural variability is small (with typical standard deviations of less than 1°C), so the normalized warming peaks in the tropics (Figure 2.6), although the absolute warming is generally larger in the Northern Hemisphere extra-tropics. Under a high-emissions scenario (RCP8.5), the expected 21st century warming in tropical regions in Africa, South America, and Asia shifts the temperature distribution by more than six standard deviations (Fig. 2.2.1.2). A similarly large shift is projected for some localized extra-tropical regions, including the eastern Mediterranean, the eastern United States, Mexico, and parts of central Asia. Such a large normalized warming implies a totally new climatic regime in these regions by the end of the 21st century, with the coldest months substantially warmer than the hottest months experienced during 1951–80. The extent of the land area projected to shift into a new climatic regime (that is, a warming by six standard deviations or more) is dramatically reduced when emissions are limited to the RCP2.6 scenario. Under such a low-emissions scenario, only localized regions in eastern tropical Africa and South East Asia are projected to see substantial normalized warming up to about four standard deviations. In some regions, non-linear climate feedbacks seem to play a role in causing warming under RCP8.5 to be much larger than under RCP2.6. The eastern Mediterranean region illustrates this situation. It warms by ~3°C (or ~2 sigma) under the low-emissions scenario compared to ~8°C (or ~6 sigma) under the high-emissions scenario.

Projected Changes in Heat Extremes

A thorough assessment of extreme events by the IPCC (2012) concludes that it is very likely that the length, frequency, and intensity of heat waves will increase over most land areas under future climate warming, with more warming resulting in more extremes. The following quantifies how much a low emission scenario (RCP2.6) would limit the increase in frequency and intensity of future heat waves as compared to RCP8.5.

Several studies have documented the expected increase in heat extremes under a business-as-usual (BAU) emissions scenario

or in simulations with a doubling of CO_2 (typically resulting in ~3°C global mean warming). Without exception, these show that heat extremes, whether on daily or seasonal time scales, greatly increase under high-emissions scenarios. The intensity of extremely hot days, with a return time of 20 years,[15] is expected to increase between 5°C and 10°C over continents, with the larger values over North and South America and Eurasia related to substantial decreases in regional soil moisture there (Zwiers and Kharin 1998). The frequency of days exceeding the present-day 99th percentile could increase by a factor of 20 (D. N. Barnett, Brown, Murphy, Sexton, and Webb 2005). Moreover, the intensity, duration, and frequency of three-day heat events is projected to significantly increase—by up to 3°C in the Mediterranean and the western and southern United States (G. A. Meehl and Tebaldi 2004). Studying the 2003 European heat wave, Schär et al. (2004) project that toward the end of the century approximately every second European summer is likely to be warmer than the 2003 event. On a global scale, extremely hot summers are also robustly predicted to become much more common (D. N. Barnett, Brown, Murphy, Sexton, and Webb 2005b). Therefore, the intensity, duration, and frequency of summer heat waves are expected to be substantially greater over all continents, with the largest increases over Europe, North and South America, and East Asia (Clark, Brown, and Murphy 2006).

In this and in the previous report, threshold-exceeding heat extremes are analyzed with the threshold defined by the historical observed variability (see Box 2.2). For this definition of extremes, regions that are characterized by high levels of warming combined with low levels of historical variability tend to see the strongest increase in extremes (Sillmann and Kharin 2013a). The approach is useful because ecosystems and humans are adapted to local climatic conditions and infrastructure is designed with local climatic conditions and its historic variations in mind. Thus even a relatively small change in temperature in the tropics can have relatively large impacts, for example if coral reefs experience temperatures exceeding their sensitivity thresholds (see, for example, Chapter 4 on "Projected Impacts on Coral Reefs").

An alternative approach would be to study extremes exceeding an absolute threshold, independent of the past variability. This is mostly relevant when studying impacts on specific sectors where the exceedance of some specific threshold is known to cause severe impacts. For example, wheat growth in India has been shown to be very sensitive to temperatures greater than 34°C (Lobell, Sibley, & Ortiz-Monasterio, 2012). As this report is concerned with impacts across multiple sectors, thresholds defined by the local climate variability are considered to be the most relevant index.

This report analyzes the timing of the increase in monthly heat extremes and their patterns by the end of the 21st century for both the low-emission (RCP2.6 or a 2°C world) and high-emission (RCP8.5 or a 4°C world) scenarios. In a 2°C world, the bulk of

[15] This means that there is a 0.5 probability of this event occurring in any given year.

Box 2.2 Heat Extremes

In sections assessing extremes, this report defines two types of extremes using thresholds based on the historical variability of the current local climate (similar to Hansen et al. 2012). The absolute level of the threshold thus depends on the natural year-to-year variability in the base period (1951–1980), which is captured by the standard deviation (sigma).

3-sigma Events – Three Standard Deviations Outside the Normal

- Highly unusual at present
- Extreme monthly heat
- Projected to become the norm over most continental areas by the end of the 21st century

5-sigma Events – Five Standard Deviations Outside the Normal

- Essentially absent at present
- Unprecedented monthly heat: new class of monthly heat extremes
- Projected to become common, especially in the tropics and in the Northern Hemisphere (NH) mid-latitudes during summertime

For a normal distribution, 3-sigma events have a return time of 740 years. The 2012 U.S. heat wave and the 2010 Russian heat wave classify as 3-sigma events (Coumou & Robinson, submitted). 5-sigma events have a return time of several million years. Monthly temperature data do not necessarily follow a normal distribution (for example, the distribution can have "long" tails, making warm events more likely) and the return times can be different from the ones expected in a normal distribution. Nevertheless, 3-sigma events are extremely unlikely and 5-sigma events have almost certainly never occurred over the lifetime of key ecosystems and human infrastructure.[a]

[a] Note that the analysis performed here does not make assumptions about the underlying probability distribution.

the increase in monthly extremes, as projected for a 4°C world by the end of the century, would be avoided. Although unusual heat extremes (beyond 3-sigma) would still become substantially more common over extended regions, unprecedented extremes (beyond the 5-sigma threshold) would remain essentially absent over most continents. The patterns of change are similar to those described for a 4°C world, but the frequency of threshold-exceeding extremes is strongly reduced. It is only in some localized tropical regions that a strong increase in frequency compared to the present day is expected (see the regional chapters). In these regions, specifically in western tropical Africa (see Chapter 3 on "Regional Patterns of Climate Change") and South East Asia (see Chapter 5 on "Regional Patterns of Climate Change"), summer months with unusual temperatures become dominant, occurring in about 60–80 percent of years, and extremes of unprecedented temperatures become regular (about 20–30 percent of years) by the end of the century.

In parallel with the increase in global mean temperature, in a 2°C world the percentage of land area with unusual temperatures steadily increases until 2050; it then plateaus at around 20 percent, as shown in Figure 2.7. On a global scale, the land area affected by northern hemisphere summer months with unprecedented temperatures remains relatively small (at less than 5 percent). This implies that, in the near term, extremes would increase manifold compared to today even under the low-emissions scenario. In a 4°C world, the land area experiencing extreme heat would continue to increase until the end of the century. This results in unprecedented monthly heat covering approximately 60 percent of the global land area by 2100. Although these analyses are based on a new set of climate models (that is, those used in ISI-MIP—see Appendix 2), the projections for a 4°C world are quantitatively consistent with the results published in the previous report.

Under RCP8.5 (or a 4°C world), the annual frequency of warm nights beyond the 90th percentile increases to between 50–95 percent, depending on region, by the end of the century (Sillmann and Kharin 2013a). Under RCP2.6 (or a 2°C world), the frequency of warm nights remains limited to between 20–60 percent, with the highest increases in tropical South East Asia and the Amazon region (Sillmann and Kharin 2013a). Extremes, expressed as an exceedance of a particular percentile threshold derived from natural variability in the base period, show the highest increase in tropical regions, where interannual temperature variability is relatively small. Under RCP8.5, the duration of warm spells, defined as the number of consecutive days beyond the 90th percentile (Sillmann and Kharin 2013b), increases in tropical regions to more than 300, occurring essentially year round (Sillmann and Kharin 2013a).

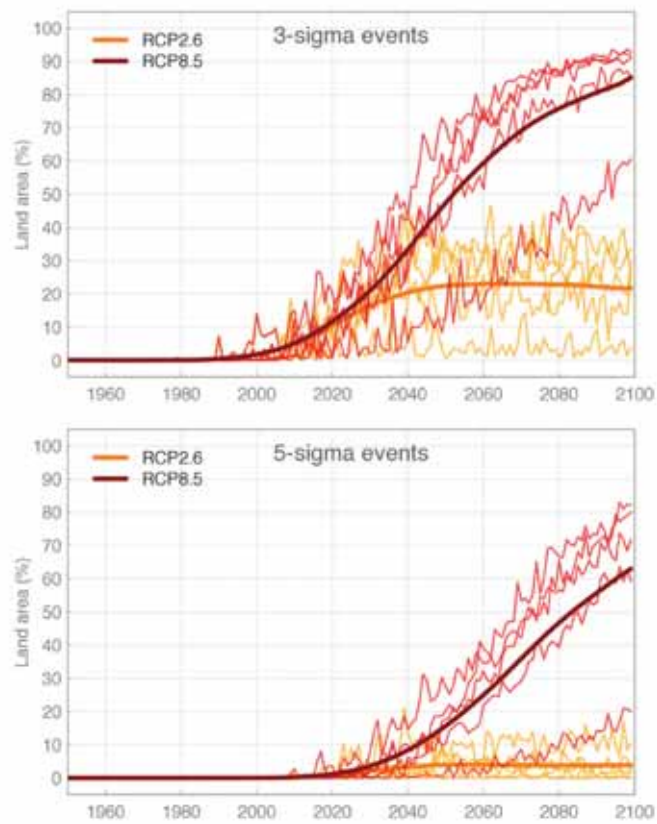
Precipitation Projections

On a global scale, warming of the lower atmosphere strengthens the hydrological cycle, mainly because warmer air can hold more water vapor (Coumou and Rahmstorf 2012). This strengthening causes dry regions to become drier and wet regions to become wetter (Trenberth 2010). There are other important mechanisms, however, such as changes in circulation patterns and aerosol forcing, which may lead to strong deviations from this general picture. Increased atmospheric water vapor can also amplify extreme precipitation (Sillmann and Kharin 2013a).

Although modest improvements have been reported in the precipitation patterns simulated by the state-of-the-art CMIP5 models (Kelley, Ting, Seager, and Kushnir 2012; Jia & DelSole 2012; Zhang and Jin 2012) as compared to the previous generation (CMIP3), substantial uncertainty remains. This report therefore only provides changes in precipitation patterns on annual and seasonal timescales. The ISI-MIP models used were bias-corrected such that they reproduce the observed historical mean and variation in precipitation. The projections might therefore also provide more robust and consistent trends on regional scales.

The expected change in annual mean precipitation by 2071–99 relative to 1951–80 is shown in Figure 2.8 for RCP2.6 (a 2°C

Figure 2.7: Multi-model mean (thick line) and individual models (thin lines) of the percentage of global land area warmer than 3-sigma (top) and 5-sigma (bottom) during boreal summer months (JJA) for scenarios RCP2.6 and RCP8.5



world) and RCP8.5 (a 4°C world). Across the globe, most dry areas get drier and most wet areas get wetter. The patterns of change in precipitation are geographically similar under the low and high emissions scenarios, but the magnitude is much larger in the latter. Under the weak climatic forcing in a 2°C world, precipitation changes are relatively small compared to natural variability, and the models disagree in the direction of change over extended regions. As the climatic signal in a 4°C world becomes stronger, the models converge in their predictions showing much less inter-model disagreement in the direction of change. Uncertainty remains mostly in those regions at the boundary between areas getting wetter and areas getting drier in the multi-model mean.

There are important exceptions to the dry-get-drier and wet-get-wetter patterns. Firstly, arid regions in the southern Sahara and in eastern China are expected to see more rainfall. Although the percentage change can be greater than 50 percent, absolute changes are still very small because of the current exceptionally dry conditions in these regions. Secondly, in the eastern part of the Amazon tropical rainforest, annual rainfall is likely to decrease. A clearly highly impacted region is the Mediterranean/North African region, which is expected to see up to 50 percent less annual rainfall under the high-emission scenario associated with a 4°C world.

In some regions, changes in extreme precipitation are expected to be more relevant from the point of view of impact than changes in the annual mean. Inter-model disagreement, however, tends to be larger for more extreme precipitation events, limiting robust projections (Sillmann and Kharin 2013b). Still on a global scale, total wet day precipitation and maximum five-day precipitation are robustly projected to increase by 10 percent and 20 percent, respectively, under RCP8.5 (Sillmann and Kharin 2013a). Regionally, the number of consecutive dry days is expected to increase in subtropical regions and decrease in tropical and near-arctic regions (Sillmann and Kharin 2013a). In agreement with Figures 2.6 and 2.8, extreme indices for both temperature and precipitation (notably consecutive dry days) stand out in the Mediterranean, indicating a strong intensification of heat and water stress.

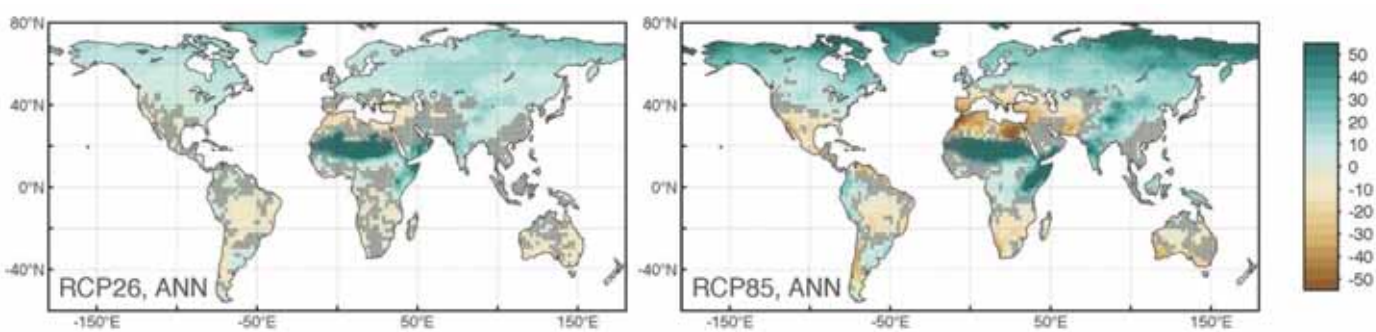
Sea-level Rise

Projecting sea-level rise as a consequence of climate change is a highly difficult, complex, and controversial scientific problem, as was discussed in the previous report. This section focuses on briefly recapping projections at a global level and providing an update on new findings, thus providing the global context for the regional sea-level rise projections in Chapters 3–5.

Process-based approaches dominate sea-level rise projections. They refer to the use of numeric models that represent the physical processes at play, such as the CMIP5 models discussed in Chapter 2 on "Patterns of Climate Change" that form the basis for much of the work on projected climate impacts presented in this report. Key contributions of observed and future sea-level rise are the thermal expansion of the ocean and the melting of mountain glaciers ice caps, and the large ice sheets of Greenland and Antarctica. In the case of the Greenland and Antarctic ice sheets, uncertainties in the scientific understanding of the response to global warming lead to less confidence in the application of ice-sheet models to sea-level rise projections for the current century (e.g., Rahmstorf 2007).

A second approach to projecting global sea-level rise is to take into account the observed relationship between past sea-level rise and global mean temperature over the past millennium to project future sea-level rise (Kemp et al. 2011; Schaeffer et al. 2012). This "semi-empirical" approach generally leads to higher projections, with median sea-level rise by 2081–2100 of 100 cm for RCP8.5, with a 66 percent uncertainty range of 81–118 cm and a 90 percent range of 70–130 cm. The low-carbon pathway RCP2.6 leads

Figure 2.8: Multi-model mean of the percentage change in annual mean precipitation for RCP2.6 (left) and RCP8.5 (right) by 2071–99 relative to 1951–80



Hatched areas indicate uncertainty regions with two out of five models disagreeing on the direction of change compared to the remaining three models.

to 67 cm of SLR by that time, with a 66 percent range of 57–77 cm and a 90 percent range of 54–98 cm. According to this analysis, a 50 cm sea-level rise by the 2050s may be locked in whatever action is taken now; limiting warming to 2°C may limit sea-level rise to about 70 cm by 2100, but in a 4°C world over 100cm can be expected, with the sea-level rise in the tropics 10–15 percent higher than the global average. All three regions studied here have extensive coastlines within the tropics with high concentrations of vulnerability.

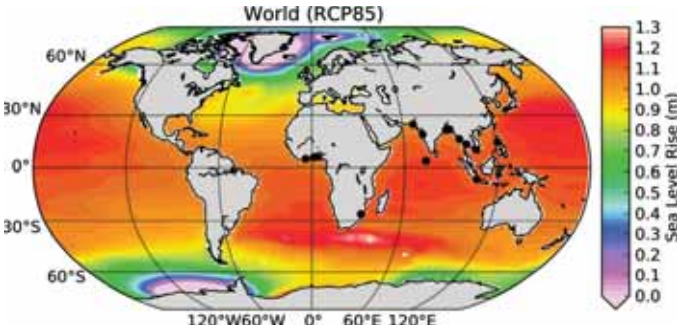
Although semi-empirical approaches have their own limitations and challenges (for example, Lowe and Gregory 2010; Rahmstorf et al. 2012), in this report these higher projections were adopted as the default, noting that uncertainties are large and this report primarily looks at the literature from a risk perspective.

Most impacts studies looking at sea-level rise focus on the level reached by a certain time. The *rate* of sea-level rise is another key indicator for risk, as well as for the long-term resilience of ecosystems and small-island developing states (Figure 2.9). The difference between high- and low-emissions scenarios is especially large for this indicator by 2100 compared to sea-level rise *per se*.[16]

As explained in the previous report, sea-level rises unevenly across the globe. A clear feature of regional projections (see Figure 2.10) is the relatively high sea-level rise at low latitudes (in the tropics) and below-average sea-level rise at higher latitudes (Perrette, Landerer, Riva, Frieler, and Meinshausen 2013). This is primarily because of the polar location of ice masses, the gravitational pull of which decreases because of the gradual melting process and accentuates the rise in the tropics, far away from the ice sheets. Close to the main ice-melt sources (Greenland, Arctic Canada, Alaska, Patagonia, and Antarctica), crustal uplift and reduced attraction cause a below-average rise, and even a sea-level fall in the very near-field of a mass source.

Ocean dynamics, such as ocean currents and wind patterns, shape the pattern of projected sea level. In particular, an above-average contribution from ocean dynamics is projected along the

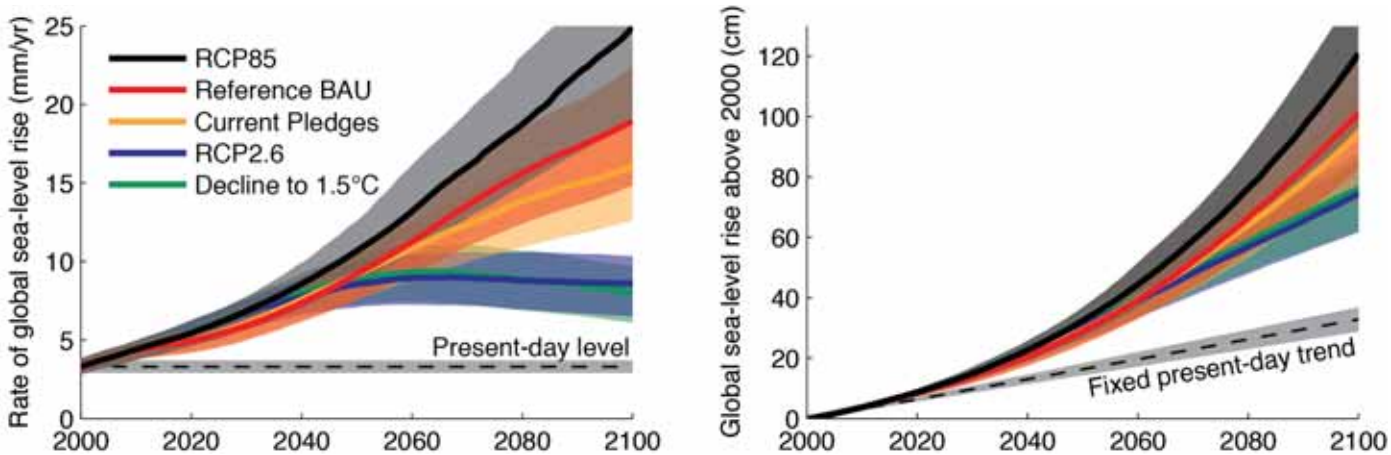
Figure 2.10: Sea-level rise in the period 2081–2100 relative to 1986–2005 for the high-emission scenario RCP8.5



Cities in the focus regions of this report are indicated in both this and Figure 2.11 and labeled in the lower panel of the latter.

[16] In addition, a high rate of sea-level rise by 2100 will set the stage for several centuries of further sea-level rise, given the slow response of oceans and ice sheets, amounting to multiple meters of SLR for the highest scenarios. Indeed, even in the low *Decline to 1.5°C* scenario extended model runs (not shown) analogous to those in Schaeffer et al. (2013) show that even with emissions fixed at year-2100 levels, the rate of SLR is projected to drop well below present-day observed rates by 2300, but not yet to zero.

Figure 2.9: Projections of the rate of global sea-level rise (left panel) and global sea-level rise (right panel)

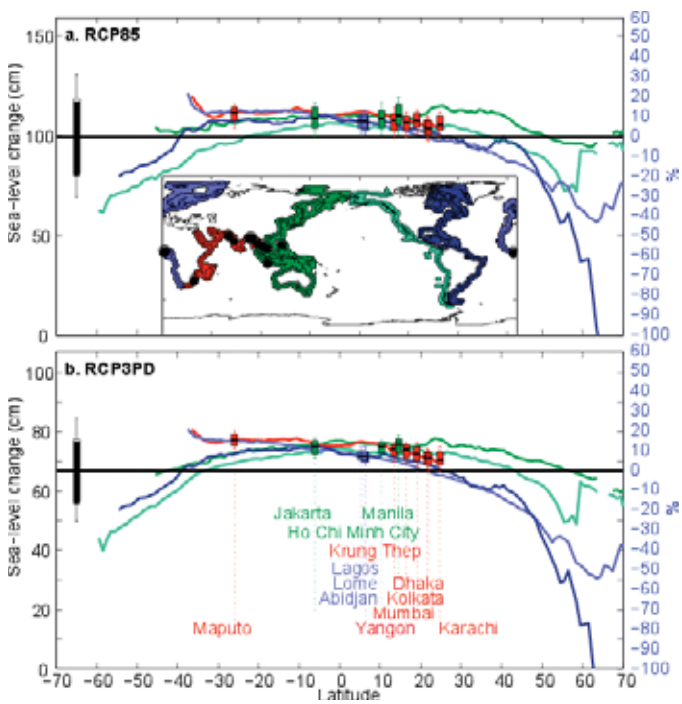


Lines show "best-estimate" (median) projections for each emission scenario, while shaded areas indicate the 66 percent uncertainty range.

Source: Present-day rate from Mayssignac and Cazenave (2012).

northeastern North American and eastern Asian coasts, as well as in the Indian Ocean. On the northeastern North American coast, gravitational forces counteract dynamic effects because of the nearby location of Greenland. Along the eastern Asian coast and in the Indian Ocean, which are far from melting glaciers, both gravitational forces and ocean dynamics act to enhance sea-level rise, which can be up to 20 percent higher than the global mean. Highlighting the coastlines, Figure 2.11 shows sea-level rise along a latitudinal gradient, with specified locations relevant for the regional climate impacts sections presented later.

Figure 2.11: Sea-level rise in the period 2081–2100 relative to 1986–2005 along the world's coastlines, from south to north



Each color line indicates an average over a particular coast as shown in the inlet map in the upper panel. The scale on the right-hand side represents the ratio of regional sea-level compared to global-mean sea level (units of percent), and the vertical bars represent the uncertainty thereof, showing 50 percent, 68 percent, and 80 percent ranges. The top panel shows results for the RCP8.5 emission pathway, the lower panel the low emission pathway RCP2.6. Cities in the focus regions of this report are indicated in both panels and labeled in the lower panel.

Other local circumstances can modify the regional pattern significantly through local vertical movement of land caused by natural factors, such as the post-glacial rebound of land still underway at high latitudes; anthropogenic influences other than climate change, such as compaction of soil following extraction of natural resources or large-scale infrastructure development, can also modify the regional pattern It is beyond the scope of this report to explore such particular local circumstances.

Ocean Warming and Acidification

The world's oceans are expected to see further changes related to climate change. The previous report presented projections of ocean acidification, which occurs when the oceans absorb CO_2 as atmospheric concentrations: The scenarios of 4°C warming or more by 2100 correspond to a carbon dioxide concentration of above 800 ppm and lead to a further decrease of pH by another 0.3, equivalent to a 150-percent acidity increase since pre-industrial levels. The degree and rate of observed ocean acidification due to anthropogenic CO_2 emissions appears to be greater than during any of the ocean acidification events identified in the geological past and is expected to have wide-ranging and adverse consequences for coral reefs and marine production. Some of the impacts of ocean acidification are presented in Chapter 4 under "Impacts on Agricultural and Aquaculture Production in Deltaic and Coastal Regions".

The world´s oceans have, in addition, been taking up approximately 93 percent of the additional heat caused by anthropogenic climate change (Levitus et al. 2012). This has been observed for depths up to 2,000 meters. Since the late 1990s, the contribution of waters below 700 meters increases and the overall heat uptake has been reported to have been higher during the last decade (1.19 ± 0.11 W m^{-2}) than the preceding record (Balmaseda, Trenberth, and Källén 2013). Ocean warming exerts a large influence on the continents: 80 to 90 percent of warming over land has been estimated to be indirectly driven by ocean warming (Dommenget 2009). This implies a time lag and commitment to further global warming following even large emission decreases. Furthermore, recent research suggests that warming further enhances the negative effect of acidification on growth, development, and survival across many different calcifying species (Kroeker et al. 2013).

Chapter 3

Sub-Saharan Africa: Food Production at Risk

REGIONAL SUMMARY

Sub-Saharan Africa is a rapidly developing region of over 800 million people, with 49 countries[17], and great ecological, climatic, and cultural diversity. By 2050, its population is projected to approach 1.5–1.9 billion people. With a 4°C global warming by the end of the century, sea level is projected to rise up to 100 cm, droughts are expected to become increasingly likely in central and southern Africa, and never-before-experienced heat extremes are projected to affect increasing proportions of the region. Projections also show an increased likelihood of increased annual precipitation in the Horn of Africa and parts of East Africa that is likely to be concentrated in bursts and, thereby, increase the risk of flooding. Increased atmospheric concentrations of CO_2 are likely to facilitate a shift from grass to woodland savanna and thereby negatively impact pastoral livelihoods if grass-based forage is reduced. Climate change is expected to have adverse impacts and pose severe risks, particularly on agricultural crop production, pastoral and livestock systems, and capture fisheries. It may also significantly increase the challenges of ensuring food security and eradicating poverty.

Sub-Saharan Africa is particularly vulnerable to impacts on agriculture. Most of the region´s agricultural crop production is rainfed and therefore highly susceptible to shifts in precipitation and temperature. A net expansion of the overall area classified as arid or hyper-arid is projected for the region as a whole, with likely adverse consequences for crop and livestock production. Since the 1950s, much of the region has experienced increased drought and the population´s vulnerability is high: The 2011 drought in the Horn of Africa, for example, affected 13 million people and led to extremely high rates of malnutrition, particularly among children. Under future climate change, droughts are projected to become increasingly likely in central and southern Africa, with a 40-percent decrease in precipitation in southern Africa if global temperatures reach 4°C above pre-industrial levels by the 2080s (2071–2099 relative to 1951–1980).

[17] This report defines Sub-Saharan Africa as the region south of the Sahara. For the projections on changes in temperature, precipitation, aridity, heat extremes, and sea-level rise, the area corresponds broadly to regions 15, 16, and 17 in the IPCC´s special report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX).

Pastoral systems are also at risk from climate impacts, as livestock is affected by extreme heat, water stress, an increased prevalence of diseases, and reduced fodder availability. Marine fish stocks migrate toward higher latitudes as waters warm and potential catches may be diminished locally, adding to the already large pressure placed on ecosystems by overfishing.

Heat extremes are projected to affect increasing proportions of the region, with adverse consequences for food production systems, ecosystems and human health. Direct and indirect impacts on human health are also expected, and an acceleration of the urbanization trend in response to additional pressures caused by climate change is likely to compound vulnerability.

Current Climate Trends and Projected Climate Change to 2100

Climate change exerts pressure on ecosystems and key sectors in Sub-Saharan Africa, with repercussions for the human populations dependent on them.

Rainfall

In terms of precipitation, the region is characterized by significant inter-annual and inter-decadal variability, and long-term trends are uncertain and inconsistent on the sub-regional scale: For example, while West Africa has experienced declines in mean annual precipitation over the past century, an increase in the Sahel has been observed over the last decade. In southern Africa and the tropical rainforest zone, no long-term trend has been observed. Inter-annual variability has increased, however, with more intense droughts and rainfall events reported in parts of southern Africa. Eastern Africa has seen increasing rainfall in some parts over the past decades, which is a reversal of a drying trend over most parts of the region during the past century.

Under 2°C warming, the existing differences in water availability across the region are likely to become more pronounced. For example, average annual rainfall is projected to increase mainly in the Horn of Africa (with both positive and negative impacts), while parts of Southern and West Africa may see decreases in rainfall and groundwater recharge rates of 50–70 percent. Under 4°C warming, annual precipitation in Southern Africa may decrease by up to 30 percent, while East Africa is projected by many models to be wetter than today, leading to an overall decrease in the risk of drought. Some important caveats are in order however, on precipitation projections. First, there is a significant degree of uncertainty, particularly for east and west Africa. Second, even if, on an annual average, precipitation does increase, it is likely to be concentrated in bursts rather than evenly distributed over the year.[18] In addition, droughts are projected to become increasingly likely over southern and central Africa. A "likely" event is defined as a >66 percent chance of occurring, using the modeling approaches adopted in this report.

Temperature

Since the 1960s, measurements show that there has been a warming trend that has continued to the present, with an increase in the number of warm spells over southern and western Africa. Recent work has found a detectable human-induced warming over Africa as a whole, with warm extremes in South Africa since 1961. A summer warming trend is projected to be mostly uniformly distributed throughout the region. In a 4°C world and relative to a 30-year baseline period (1951–80), monthly summer temperature increases over Sub-Saharan Africa are projected to reach 5°C above the baseline temperature by 2100. In a 2°C world, increases in African summer temperatures are projected to peak at about 1.5°C above the baseline temperature by 2050.

As global mean temperatures rise, unusual and unprecedented heat extremes[19] are projected to occur with greater frequency during summer months. By the time global warming reaches 1.5°C in the 2030s, heat extremes that are unusual or virtually absent today are projected to cover over one-fifth of land areas in the Southern Hemisphere summer months. Unprecedented monthly heat extremes, could cover up to 5 percent of land areas in this timeframe. Under 2°C warming, monthly heat extremes that are unusual or virtually absent in today´s regional climate are projected to cover nearly 45 percent of land areas by the 2050s, and unprecedented heat extremes are expected to cover up to 15 percent of land area in the summer. With global warming reaching about 4°C by the end of the century, unusual summertime heat extremes are projected to cover most of the land areas (85 percent), with unprecedented heat extremes covering more than 50 percent.

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[18] Uncertainty is particularly large for East Africa due to concerns about whether the GCM models adequately capture the dynamics of the rainy seasons in that region and because higher resolution regional climate models do not seem to reproduce, but rather contradict, the increase in precipitation seen in the projections of most global models. Drought risk results from periods of anomalously low precipitation or high warming or both, but this risk is also influenced by other climate variables like wind speed and incoming radiation. Climate-model projections of warming generally have lower uncertainty, while uncertainties in precipitation projections differ between regions. Uncertainties in drought projections are smallest for Southern Africa (primarily driven by warming), somewhat larger for Central Africa (because of smaller signals of change), and largest for West Africa (for which there is large disagreement across models on precipitation changes, both in sign and in amplitude).

[19] In this report, unusual and unprecedented heat extremes are defined using thresholds based on the historical variability of the current local climate. The absolute level of the threshold thus depends on the natural year-to-year variability in the base period (1951–1980), which is captured by the standard deviation (sigma). Unusual heat extremes are defined as 3-sigma events. For a normal distribution, 3-sigma events have a return time of 740 years. The 2012 U.S. heat wave and the 2010 Russian heat wave classify as 3-sigma events. Unprecedented heat extremes are defined as 5-sigma events. They have a return time of several million years. Monthly temperature data do not necessarily follow a normal distribution (for example, the distribution can have "long" tails, making warm events more likely) and the return times can be different from the ones expected in a normal distribution. Nevertheless, 3-sigma events are extremely unlikely and 5-sigma events have almost certainly never occurred.

Likely Physical and Biophysical Impacts of Projected Climate Change

The projected changes in rainfall, temperature, and extreme event frequency and/or intensity will have both direct and indirect impacts on sea-level rise, aridity, crop yields, and agro-pastoral systems that would affect populations.

Projected Aridity Trends

Patterns of aridity[20] are projected to shift and expand within the total area classified as such due to changes in temperature and precipitation. Arid regions are projected to spread, most notably in Southern Africa but also in parts of West Africa. Total hyper-arid and arid areas are projected to expand by 10 percent compared to the 1986–2005 period. Where aridity increases, crop yields are likely to decline as the growing season shortens. Decreased aridity is projected in East Africa; the change in area, however, does not compensate for increases elsewhere.

Sea-level Rise

Sea level is projected to rise more than the global average in the tropics and sub-tropics. Under a warming of 1.5°C, sea-level is projected to rise by 50 cm along Sub-Saharan Africa's tropical coasts by 2060, with further rises possible under high-end projections. In the 2°C warming scenario, sea-level rise is projected to reach 70 cm by the 2080s, with levels higher toward the south. The 4°C warming scenario is projected to result in a rise of 100 cm of sea-level by the 2090s. The difference in rate and magnitude of sea-level rise between the 4°C warming scenario and the 2°C warming scenario by 2100 becomes pronounced due to the continuing rate of sea-level rise in the higher warming scenario relative to the stabilized level under 2°C. The projected sea-level under 4°C would increase the share of the population at risk of flooding in Guinea-Bissau and Mozambique to around 15 percent by 2100, compared to around 10 percent in projections without sea-level rise; in The Gambia, the share of the population at risk of flooding would increase many fold to 10 percent of the population by 2070.

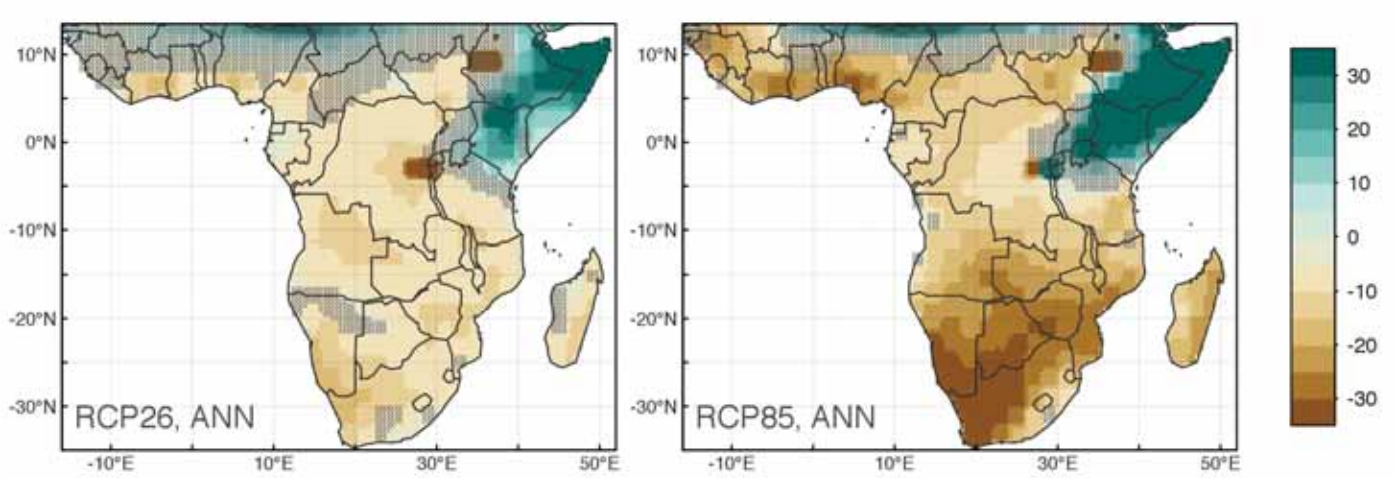
Sector-based and Thematic Impacts

Ecosystems

Savanna grasslands may be reduced in area, with potential impacts on livelihoods and pastoral systems. By the time 3°C global warming is reached, savannas are projected to decrease from about a quarter at present to approximately one-seventh of total land area, reducing the availability of food for grazing animals. Both changes in climatic conditions and increasing atmospheric CO_2 concentration are projected to play a role in bringing about regime shifts in African ecosystems, thereby altering the composition of species. Due to

[20] Aridity is characterized by a structural precipitation deficit-meaning a lack of necessary rainfall amounts for vegetation and/or crop growth-and is potentially driven by a positive feedback mechanism. In regions where the soil dries out due to a lack of precipitation, no more heat can be converted into latent heat and all heat results in increased surface temperatures. This additional heating of the land increases evaporative demand of crops and amplifies the precipitation deficit.

Figure 3.1: Sub-Saharan Africa – Multi-model mean of the percentage change in the Aridity Index in a 2°C world (left) and a 4°C world (right) for Sub-Saharan Africa by 2071–2099 relative to 1951–1980



In non-hatched areas, at least 4/5 (80 percent) of models agree. In hatched areas, 2/5 of the models disagree. Note that a negative change corresponds to a shift to more arid conditions. Particular uncertainty remains for East Africa, where regional climate model projections tend to show an increase in precipitation, which would be associated with a decrease in the Aridity Index (see also footnote 2). A decrease in aridity does not necessarily imply more favorable conditions for agriculture or livestock, as it may be associated with increased flood risks.

Table 3.1: Summary of climate impacts and risks in Sub-Saharan Africa[a]

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C[b,c] (≈2030s[d])	Around 2°C (≈2040s)	Around 3°C (≈2060s)	Around 4°C (≈2080s)
Heat extreme[e] (in the Southern Hemisphere summer)	Unusual heat extremes	Virtually absent	20–25 percent of land	45 percent of land	70 percent of land	>85 percent of land
	Unprecedented heat extremes	Absent	<5 percent of land	15 percent of land	35 percent of land	>55 percent of land
Drought		Increasing drought trends observed since 1950	Increasing drought risk in southern, central, and West Africa, decrease in East Africa, but West and East African projections are uncertain	Likely risk of severe drought in southern and central Africa, increased risk in West Africa, decrease in east Africa but west and East African projections are uncertain	Likely risk of extreme drought in southern Africa and severe drought in central Africa, increased risk in West Africa, decrease in East Africa, but West and East African projections are uncertain	Likely risk of extreme drought in southern Africa and severe drought in central Africa, increased risk in West Africa, decrease in East Africa, but West and East African projections are uncertain
Aridity		Increased drying	Little change expected	Area of hyper-arid and arid regions grows by 3 percent		Area of hyper-arid and arid regions grows by 10 percent. Total arid and semi-arid area increases by 5 percent
Sea-level rise above present (1985–2005)		About 21 cm to 2009[f]	30cm[g]-2040s 50cm-2070 70cm by 2080–2100	30cm-2040s 50cm-2070 70cm by 2080–2100	30cm-2040s 50cm-2060 90cm by 2080–2100	30cm-2040s 50cm-2060 105cm by 2080–2100

[a] A more comprehensive table of impacts and risks for SSA is presented at the end of Chapter 3.
[b] Refers to the global mean increase above pre-industrial temperatures.
[c] Years indicate the decade during which warming levels are exceeded in a business-as-usual scenario exceeding 4°C by the 2080s.
[d] Years indicate the decade during which warming levels are exceeded with a 50 percent or greater change (generally at the start of the decade) in a business-as-usual scenario (RCP8.5 scenario). Exceedance with a likely chance (>66 percent) generally occurs in the second half of the decade cited.
[e] Mean heat extremes across climate model projections are given. Illustrative uncertainty range across the models (minimum to maximum) for 4°C warming are 70–100 percent for unusual extremes, and 30–100 percent for unprecedented extremes. The maximum frequency of heat extreme occurrence in both cases is close to 100 percent, as indicator values saturate at this level.
[f] Above 1880 estimated global mean sea level.
[g] Add 20 cm to get an approximate estimate above the pre-industrial sea level.

CO_2 fertilization, trees may be able to outcompete shade-intolerant grasses in savannas, leading to a reduction in grassland area and declines in food availability for livestock and other animals. It is not yet clear if the negative effects of increased drought on trees in the region would limit such forest expansion. In response to changes in temperature and rainfall variability, a 20-percent decline in tree density in the western Sahel has been observed since the 1950s.

Agricultural Production

Several lines of evidence indicate a likely substantial risk to crop yields and food production adversely affecting food security by 1.5–2°C warming, with growing risks at higher levels of warming.

- **High temperature sensitivity** thresholds for some important crops, such as maize, wheat, and sorghum, have been observed, with large yield reductions once the threshold is exceeded. For example, the photosynthesis rate (key factor in growth and yield) of crops such as wheat and rice is at a maximum for temperatures from about 20–32°C. The IPCC AR4 report (IPCC 2007) stated that even moderate increases (1–2°C) are likely to have a negative effect on yields for major cereals like wheat, maize, and rice; further warming will have increasingly negative effects, showing decreases in wheat yield in low latitude regions of approximately 50 percent for an increase in mean local temperature of about 5°C. As these temperature thresholds are exceeded more frequently with 2°C and 4°C warming, significant production shocks are likely.
- **Loss or change of suitable areas.** A 1.5°–2°C warming by the 2030s–2040s could lead to about 40–80 percent reductions in present maize, millet, and sorghum cropping areas for current cultivars. By 3°C warming, this reduction could grow to more than 90 percent.
- **Significant yield decreases** are expected in the near term under relatively modest levels of warming. Under 1.5–2°C warming, median yield losses of around 5 percent are projected, increasing to median estimates of around –15 percent (range –5 percent to –27 percent for 2–2.5°C warming).[21] Under 3–4°C warming there are indications that yields may

[21] The range is given across the following crops: millet, sorghum, wheat, cassava, and groundnuts.

decrease by around 15–20 percent across all crops and regions, although the availability of studies estimating potential yield impacts is limited.

- **Per capita crop production** at warming of about 1.8°C (by the 2050s) is projected to be reduced by 10 percent compared to a case without climate change. With larger yield reductions projected for higher levels of warming, this risk could grow; however, this has yet to be quantified. **Livestock production** is also expected to suffer due to climate impacts on forage availability and heat stress.
- **Diversification options for agro-pastoral systems** (e.g., switching to silvopastoral systems, irrigated forage production, and mixed crop-livestock systems) are likely to dwindle as climate change reduces the carrying capacity of the land and livestock productivity. The livestock sector has been vulnerable to drought in the past. For example, pastoralists in southern Ethiopia lost nearly 50 percent of their cattle and about 40 percent of their sheep and goats to droughts between 1995–97.
- **The CO_2 fertilization** effect remains uncertain. A strong positive response of crops to increasing atmospheric CO_2 concentrations would help to dampen the impacts related to changes in temperature and precipitation. However, important crops, including maize, sorghum, and pearl millet—among the dominant crops in Africa—are not very sensitive to atmospheric CO_2 concentrations. Furthermore, the magnitude of these effects remains uncertain when compared with the results from the free-air CO_2 enrichment (FACE)[22] experiments, because the fertilization effects used in various models appear to be overestimated. Under sustained CO_2 fertilization, the nutritional value of grain per unit of mass has been observed to decrease.

Fisheries

Livelihoods dependent on fisheries and other ecosystem services are projected to be threatened in some regions, with critical species possibly ceasing to be locally available. Potential fish catches off the coast of West Africa, where fish accounts for as much as 50 percent of the animal protein consumed, is likely to be reduced by as much as 50 percent by the 2050s (compared to 2000 levels). In other regions, such as the eastern and southeastern coasts of Sub-Saharan Africa, yield potential has been projected to increase.

Health

Malnutrition can have major secondary health implications by causing childhood stunting or by increasing susceptibility to other diseases. Under warming of 1.2–1.9°C, undernourishment levels are expected to be in the range of 15–65 percent, depending on the sub-region, due to crop yield and nutritional quality declines. Moderate stunting of children under age five is expected to occur at a rate of 16–22 percent, and severe stunting at a rate of 12–20 percent. Without climate change, however, moderate stunting rates are projected to remain close to present levels (21–30 percent across the region), and severe stunting is projected to decrease by 40 percent.

Integrated Synthesis of Climate Change Impacts in Sub-Saharan Africa

Sub-Saharan Africa is confronted with a range of climate risks that could have far-reaching repercussions for the region´s societies and economies. Even in a situation in which warming is limited below 2°C, there are very substantial risks that would continue to grow as warming approaches 4°C.

Climate Change Projected to Increase Poverty and Risks from Disease

Poverty in the region may grow even further due to climate impacts, as poor households with climate sensitive sources of income are often disproportionately affected by climate change and large parts of the population still depend on the agricultural sector as their primary source of food security and income. Below 2°C warming, large regional risks to food production and security emerge; these risks would become stronger if adaptation measures were inadequate and the CO_2 fertilization effect is weak. Poverty has been estimated to increase by up to one percent following severe food production shocks in Malawi, Uganda, and Zambia. As warming approaches 4°C, the impacts across sectors increase.

Malnutrition as a consequence of impacts on food production further increases susceptibility to diseases, compounding the overall health risks in the region. Childhood stunting resulting from malnutrition is associated with reductions in both cognitive ability and school performance. Projected crop yield losses and adverse effects on food production that result in lower real incomes would exacerbate poor health conditions and malnutrition; with malaria and other diseases expected to worsen under climate change, adverse effects on childhood educational performance may be expected.

The **diseases** that pose a threat in Sub-Saharan Africa as a consequence of climate change include vector- and water-borne diseases such as malaria, Rift Valley fever, and cholera. The risk of these diseases is expected to rise as changes in temperature and precipitation patterns increase the extent of areas with conditions conducive to vectors and pathogens. Other impacts expected to accompany climate change include mortality and morbidity due to such extreme events as flooding and more intense and hotter heat waves.

[22] FACE experiments measure the effect of elevated CO_2 concentrations in the open air, thereby excluding factors in a traditional laboratory setting that may influence experimental results.

Climate Change Expected to Challenge Urban Development, Infrastructure, and Education

The existing **urbanization** trend in Sub-Saharan Africa could be accelerated by the stresses that climate change is expected to place on rural populations. These pressures are expected to arise partly through impacts on agricultural production, which currently provides livelihoods to 60 percent of the labor force in the region. Migration to urban areas may provide new livelihood opportunities, but it also exposes migrants to new risks. Conditions that characterize poor urban areas, including overcrowding and inadequate access to water, drainage, and sanitation facilities, aid the transmission of vector- and water-borne diseases. As many cities are located in coastal areas, they are exposed to coastal flooding because of sea-level rise. The poorest urban dwellers tend to be located in vulnerable areas, such as floodplains and steep slopes, further placing them at risk of extreme weather events. Impacts occurring even far-removed from urban areas can be felt in these communities. For example, food price increases following agricultural production shocks have the most damaging consequences within cities.

Impacts on infrastructure caused by sea-level rise can have effects on human and economic development, including impacts on human health, port infrastructure, and tourism. For example, floods in 2009 in the Tana Delta in Kenya cut off medical services to approximately 100,000 residents; sea-level rise of 70cm by 2070 would cause damages to port infrastructure in Dar es Salaam, Tanzania—a hub for international trade—exposing assets of US$10 billion, or more than 10 percent of the city's GDP (Kebede and Nicholls 2011). Such damage to the Dar es Salaam port would have would have larger economic consequences since it serves as the seaport for several of its landlocked neighbours.

There are indications that climate change could impact the ability to meet the educational needs of children in particularly vulnerable regions. Projected crop yield losses and adverse effects on food production would exacerbate poor health conditions and malnutrition; with malaria and other diseases expected to worsen under climate change, adverse effects on childhood educational performance may be expected. Childhood stunting resulting from malnutrition is associated with reduced cognitive ability and school performance. The projected increase in extreme monthly temperatures within the next few decades may also have an adverse effect on learning conditions for students and teachers.

Overall, populations in Sub-Saharan Africa are expected to face mounting pressures on food production systems and risks associated with rising temperature and heat extremes, drought, changing precipitation patterns, sea-level rise, and other extreme events. Health impacts are likely to increase and be exacerbated by high rates of malnutrition, with possible far-reaching and long-term consequences for human development. Significant crop yield reductions at warming levels as low as 2°C warming are expected to have strong repercussions on food security for vulnerable populations, including in many growing urban areas. These and other impacts on infrastructure, in combination, may negatively impact economic growth and poverty reduction in the region. A warming of 4°C is projected to bring large reductions in crop yield, with highly adverse effects on food security, major increases in drought severity and heat extremes, reductions in water availability, and disruption and transformation of important ecosystems. These impacts may cause large adverse consequences for human populations and livelihoods and are likely to be highly deleterious to the development of the region.

Introduction

This report defines Sub-Saharan Africa as the region south of the Sahara. For the projections on changes in temperature, precipitation, aridity, heat extremes, and sea-level rise, the area corresponds broadly to regions 15, 16, and 17 in the IPCC´s special report on *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX).

The region´s development prospects have been improving as it has experienced above-average growth. The picture that emerges from the scientific evidence of climate impacts, however, is that global warming poses escalating risks which could undermine promising trends, even at relatively low levels of warming.

The most prominent physical risk factors identified for the region are:

- Increases in temperatures and extremes of heat
- Adverse changes to precipitation patterns in some regions
- Increased incidences of extreme weather events
- Sea-level rise
- Increased aridity

This analysis reviews these physical impacts[23] and their effects on specific sectors, including agriculture, water resources, and human health.[24]

Sub-Saharan Africa is characterized by a large diversity of cultural, social, and economic conditions. This diversity shapes

[23] Not all physical risks are covered in this section; tropical cyclones, for example, are dealt with in the South East Asia section.

[24] This section does not cover all sectors affected by climate change. Risks to the energy sector, for example, are dealt with in the South Asian section.

the vulnerability of populations to these physical impacts. A number of geographic factors also influence the nature and extent of the physical impacts of climate change. For example, more than one in five people in Sub-Saharan Africa live on degraded land, which is more prone to losses in agricultural production and water availability.

The focus of this regional analysis is on food production systems. The IPCC AR4 in 2007 found that Africa is particularly vulnerable to the impacts of climate change, with a substantial risk that agricultural production and access to food in many African countries could be severely compromised—which could adversely affect food security and malnutrition. Recent literature on agriculture and ecosystems confirms this finding, and is presented in Chapter 3, under "Projected Ecosystem Changes" and "Human Impacts."

Regional Patterns of Climate Change

A warming trend since the 1960s to the present has been observed in Sub-Saharan Africa (Blunden & Arndt, 2012). Between 1961 and 2000, for example, there was an increase in the number of warm spells over southern and western Africa. More recent work finds a detectable human-induced warming over Africa as a whole, with warm extremes in South Africa since 1961(Knutson, Zeng, and Wittenberg 2013). In terms of precipitation, the region is characterized by significant inter-annual and inter-decadal variability, but trends are inconsistent on the sub-regional scale: West Africa and the tropical rainforest zone have experienced declines in mean annual precipitation while no long-term trend has been observed in southern Africa even though inter-annual variability has increased with more intense droughts and rainfall events have been reported. Eastern Africa, meanwhile, has seen increasing rainfall in the northern part of the region and decreasing rainfall in the southern part.

In the IPCC AR4, Giannini, Biasutti, Held, and Sobel (2008) analyze temperature and precipitation changes in the CMIP3 climate model ensemble under the SRES AIB scenario relative to pre-industrial levels. Two continental-scale patterns dominate African climate variability: (1) a drying pattern related to ocean warming and enhanced warming of the southern tropics compared to the northern tropics, and (2) the effects of the El Niño Southern Oscillation (ENSO), which is more dominant in East Africa and South Africa (Giannini, Biasutti, Held, and Sobel 2008).

The CMIP3 model-spread is considerable, however, with uncertainty even in the direction of change for precipitation in some regions. For eastern tropical Africa and southern Africa, there is generally stronger consensus between models than for western Africa. A clear percentage-increase in rainfall is projected in eastern tropical Africa and a smaller percentage-decrease is projected in southern Africa.

Box 3.1 Observed Vulnerability

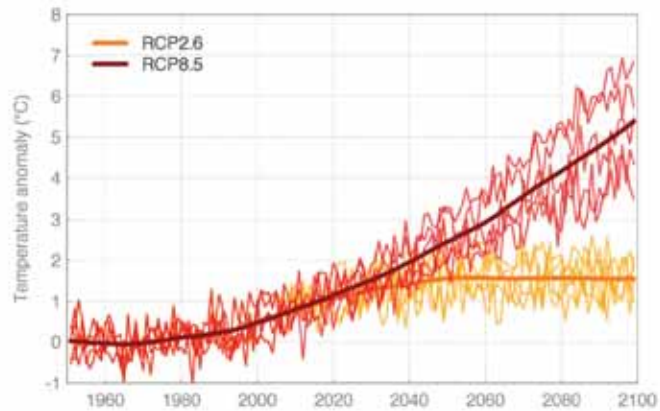
Sub-Saharan African populations are vulnerable to extreme weather events. A number of natural disasters have severely affected populations across the region in the past. Although no studies attributing these events to climate change were found in the course of this research, these events show the region's existing vulnerability. Throughout Sub-Saharan Africa, droughts have increased over the past half century. The consistency across this region between analyses, as well as model projections, suggest the observed trend toward more severe drying would continue under further global warming (Aiguo Dai 2011; Sheffield, Wood, and Roderick 2012; Van der Schrier, Barichivich, Briffa, and Jone 2013). An example of regional vulnerability is the 2011 drought in the Horn of Africa, which affected large numbers of people across Somalia, Ethiopia, Djibouti, and Kenya. As a result, more than 13 million people across the region required life-saving assistance (Karumba 2013). The situation led to extremely high rates of malnutrition, particularly among children (leading to the famine being described as a "children's famine"), accompanied by high rates of infectious diseases, such as cholera, measles, malaria, and meningitis (Zaracostas 2011). The drought particularly exacerbated an existing complex emergency characterized by conflict and insecurity in Somalia (USAID 2012) and caused large numbers of Somalis to become internally displaced or to flee to Ethiopia and Kenya, where they entered overcrowded refugee camps and were faced with further health risks because of inadequate facilities (McMichael, Barnett, and McMichael 2012).

Flooding in early 2013 in river valleys in southern Africa, which most severely affected Mozambique, is another recent example of significant exposure to extreme weather events. The flooding caused over 100 direct flood-caused deaths, such as drowning and electrocution from damaged power lines. Furthermore, indirect mortalities are likely to far exceed those of direct flood caused deaths, for instance through steep increases in the prevalence of diaroheal disease and malaria. The flooding also caused livestock and crop losses, and widespread temporary displacement with a total of 240,827 people affected in Mozambique (UNRCO 2013). A subsequent cholera epidemic with 1,352 reported cases in the northern province of Cabo Delgado has been linked to the disaster. Floodwaters also damaged health clinics (UNRCO 2013). The country has also seen other flooding and cyclones in recent years, notably in 2000, when one-third of crops were destroyed and hundreds of people lost their lives (Fleshman 2007).

These examples from the Horn of Africa and Mozambique highlight the ramifications for exposed populations arising from the extreme events that may become more frequent and intense with climate change.

Some modest improvements in representing precipitation patterns by CMIP5 models have been reported, though not specifically for Sub-Saharan Africa (Kelley et al. 2012; Li, Waliser, Chen, and Guan 2012; Zhang and Jin 2012). Uncertainty in future precipitation projections remains large. Moreover, recent decadal fluctuations in Africa´s climate, especially droughts in the Sahel region, have been notoriously hard to reproduce in coupled climate models (Giannini, Biasutti, Held, and Sobel 2008; Mohino, Janicot, and Bader 2010). The analyses presented here are based on ISI-MIP models, which are bias-corrected to reproduce the observed historical mean and variation in both temperature and precipitation. This way, future projections might provide more robust and consistent trends. Nevertheless, given the uncertainty in the underlying climate models, only large-scale changes in precipitation patterns over those regions where the models agree can be considered robust. Warming patterns, however, are much more robust.

Figure 3.2: Temperature projections for Sub-Saharan land area

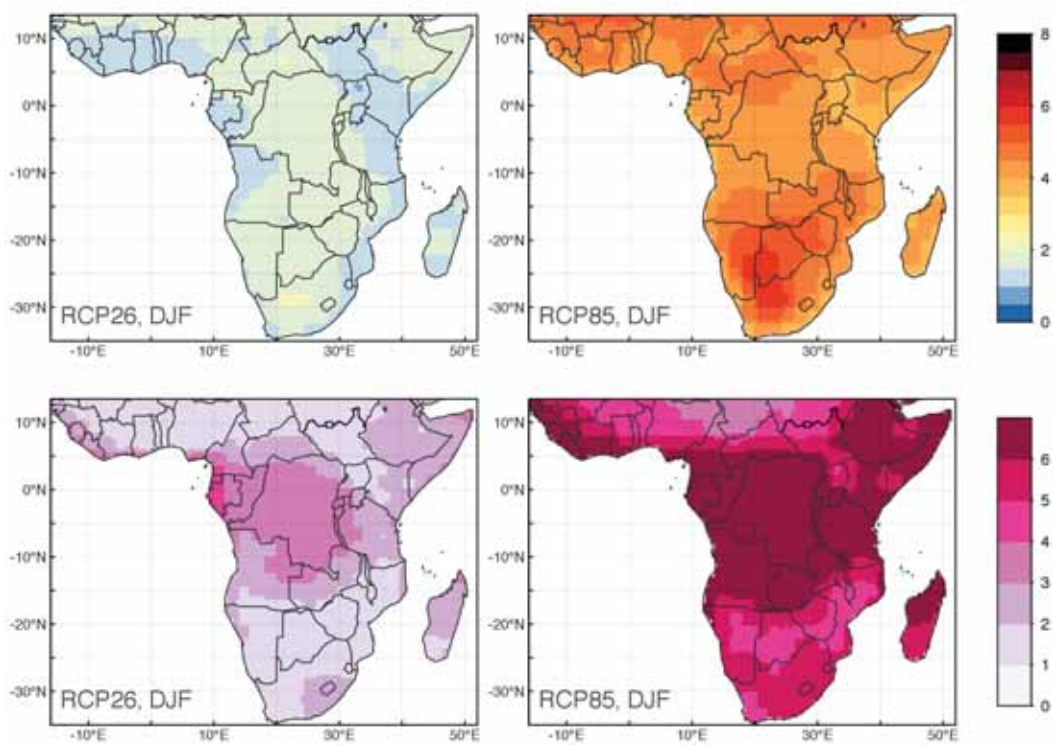


Multi-model mean (thick line) and individual models (thin lines) under RCP2.6 (2°C world) and RCP8.5 (4°C world) for the months of DJF. The multi-model mean has been smoothed to give the climatological trend.

Projected Temperature Changes

The projected austral summer (December, January, and February, or DJF) warming of the Sub-Saharan land mass for low- and high-emission scenarios is shown in Figure 3.2. Warming is slightly less strong than for that of the global land area, which is a general feature of the Southern Hemisphere (see Figure 2.7). In a 2°C

Figure 3.3: Multi-model mean temperature anomaly for RCP2.6 (left) and RCP8.5 (right) for the months of DJF for Sub-Saharan Africa



Temperature anomalies in degrees Celsius (top row) are averaged over the time period 2071–99 relative to 1951–80, and normalized by the local standard deviation (bottom row).

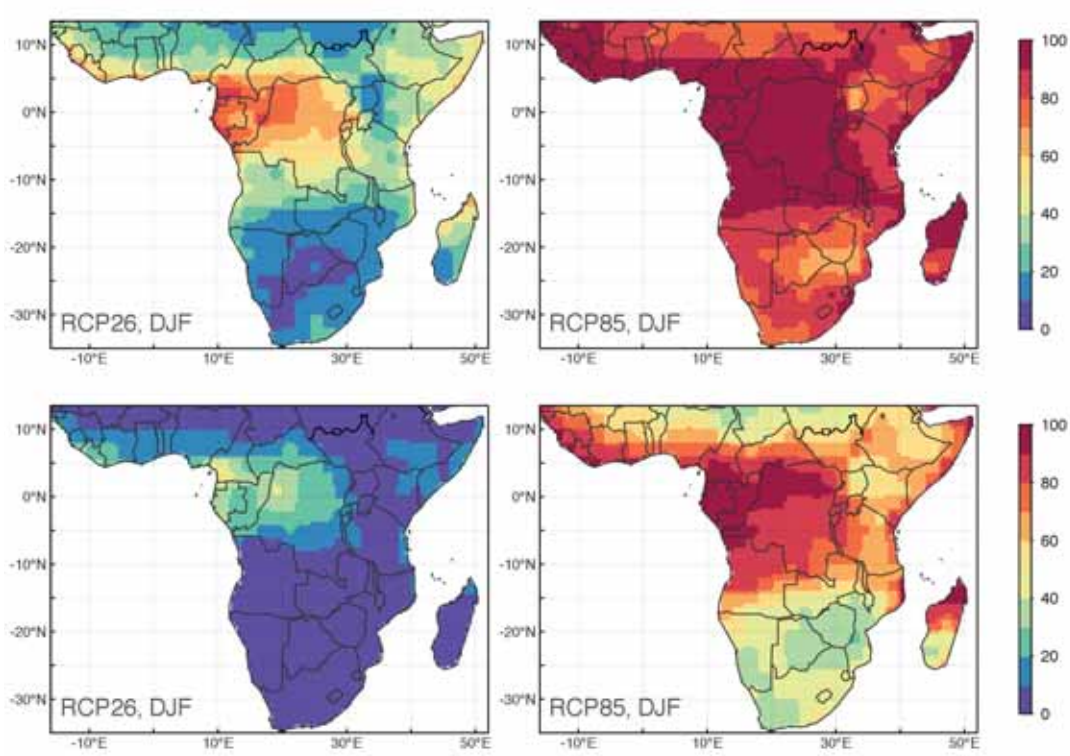
world, African summer temperatures peak by 2050 at about 1.5°C above the 1951–80 baseline and remain at this level until the end of the century. In a 4°C world, warming continues to increase until the end of the century, with monthly summer temperatures over Sub-Saharan Africa reaching 5°C above the 1951–80 baseline by 2100. Geographically, this warming is rather uniformly distributed, although in-land regions in the subtropics warm the most (see Figure 3.3). In subtropical southern Africa, the difference in warming between RCP2.6 and RCP8.5 is especially large. This is likely because of a positive feedback with precipitation: the models project a large decrease in precipitation here (see Figure 3.6), limiting the effectiveness of evaporative cooling of the soil.

The normalized warming (that is, the warming expressed in terms of the local year-to-year natural variability) shows a particularly strong trend in the tropics (Figure 3.3). The normalized warming is a useful diagnostic as it indicates how unusual the warming is compared to fluctuations experienced in the past. The monthly temperature distribution in tropical Africa shifts by more than six standard deviations under a high-emission scenario (RCP8.5), moving this region to a new climatic regime by the end of the 21st century. Under a low-emission scenario (RCP2.6), only localized regions in eastern tropical Africa will witness substantial normalized warming up to about four standard deviations.

Projected Changes in Heat Extremes

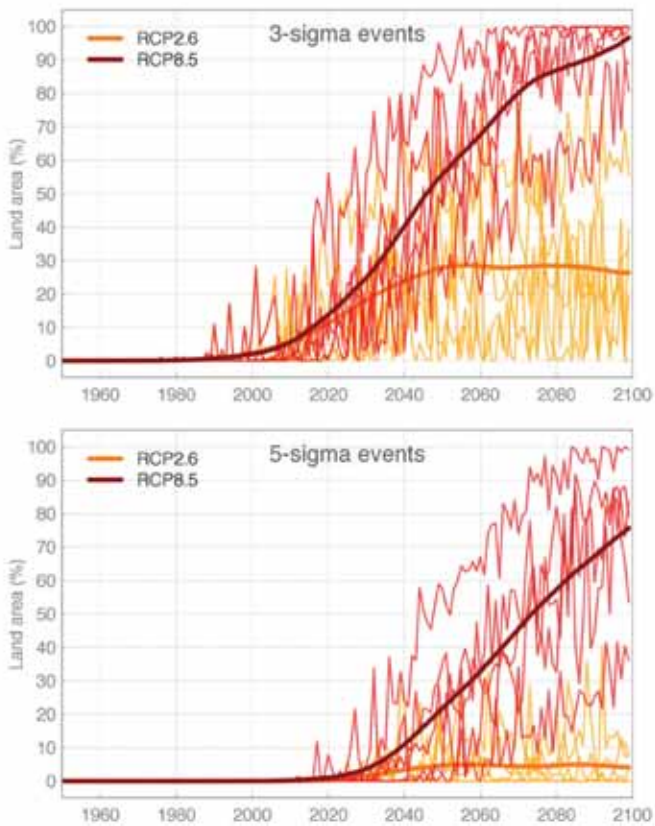
The frequency of austral summer months (DJF) hotter than 5-sigma, characterized by unprecedented temperatures (see the Chapter 2 on "Projected Temperature Changes"), increases over Sub-Saharan Africa under the high-emission scenario (Figure 3.4 and 3.5). By 2100, the multi-model mean of RCP8.5 projects that 75 percent of summer months would be hotter than 5-sigma (Figure 3.5) and substantially higher than the global average (see Chapter 2 on "Projected Changes in Heat Extremes"). The model uncertainty in the exact timing of the increase in frequency of extremely hot months is larger for Sub-Saharan Africa compared to the global mean uncertainty as averaging is performed over a smaller surface area. During the 2071–99 period, more than half (~60 percent) of Sub-Saharan African summer months are projected to be hotter than 5-sigma, with tropical West Africa in particular being highly impacted (~90 percent). Over this period, almost all summer months across Sub-Saharan Africa will be hotter than 3-sigma, with temperatures considered unusual or virtually absent in today's

Figure 3.4: Multi-model mean of the percentage of austral summer months in the time period 2071–99



Temperatures greater than 3-sigma (top row) and 5-sigma (bottom row) for scenario RCP2.6 (left) and RCP8.5 (right) over Sub-Saharan Africa.

Figure 3.5: Multi-model mean (thick line) and individual models (thin lines) of the percentage of Sub-Saharan African land area warmer than 3-sigma (top) and 5-sigma (bottom) during austral summer months (DJF) for scenarios RCP2.6 and RCP8.5



Multi-model mean (thick line) and individual models (thin lines) under RCP2.6 (2°C world) and RCP8.5 (4°C world) for the months of DJF. The multi-model mean has been smoothed to give the climatological trend.

climate (Figure 3.4). Under RCP8.5, all African regions, especially the tropics, would migrate to a new climatic regime. The precise timing of this shift depends on the exact regional definition and the model used.

Under the low-emission scenario, the bulk of the high-impact heat extremes expected in Sub-Saharan Africa under RCP8.5 would be avoided. Extremes beyond 5-sigma are projected to cover a minor, although non-negligible, share of the surface land area (~5 percent), concentrated over western tropical Africa (Figure 3.4). Over most subtropical regions, 5-sigma events would still be rare. In contrast, the less extreme months, beyond 3-sigma, would increase substantially to about 30 percent of the Sub-Saharan land area (Figure 3.5). Thus, even under a low-emission scenario, a substantial increase in heat extremes in the near term is anticipated.

Consistent with these findings, CMIP5 models project that the frequency of warm nights (beyond the 90th percentile) and the duration of warm spells increases most in tropical Africa (Sillmann and Kharin 2013a). Under RCP8.5, by the end of the century warm nights are expected to occur about 95 percent of the time in tropical west and east Africa and about 85 percent of the time in southern Africa, with only limited inter-model spread. Limiting greenhouse gas emissions to a RCP2.6 scenario reduces these numbers to ~50 percent and ~30 percent respectively.

Precipitation Projections

Consistent with CMIP3 projections (Giannini, Biasutti, Held, and Sobel 2008a), the ISI-MIP models' projected change in annual mean precipitation shows a clear pattern of tropical East Africa (Horn of Africa) getting wetter and southern Africa getting drier. Note that for Somalia and eastern Ethiopia the projections show a large relative change over a region that is very dry. Western tropical Africa only shows a weak (<10 percent) increase in annual precipitation, although model uncertainty is large and there is limited agreement among models on the size of changes. The dipole pattern of wetting in tropical East Africa and drying in southern Africa is observed in both seasons and in both emission scenarios. Under the low-emission scenario, the magnitudes of change are smaller, and the models disagree on the direction of change over larger areas. Under the high-emission scenario, the magnitude of change becomes stronger everywhere and the models converge in the direction of change. For this stronger signal of change, model disagreement between areas getting wetter and areas getting drier (in the multi-model mean) is limited to regions at the boundary and some regions in tropical western Africa.

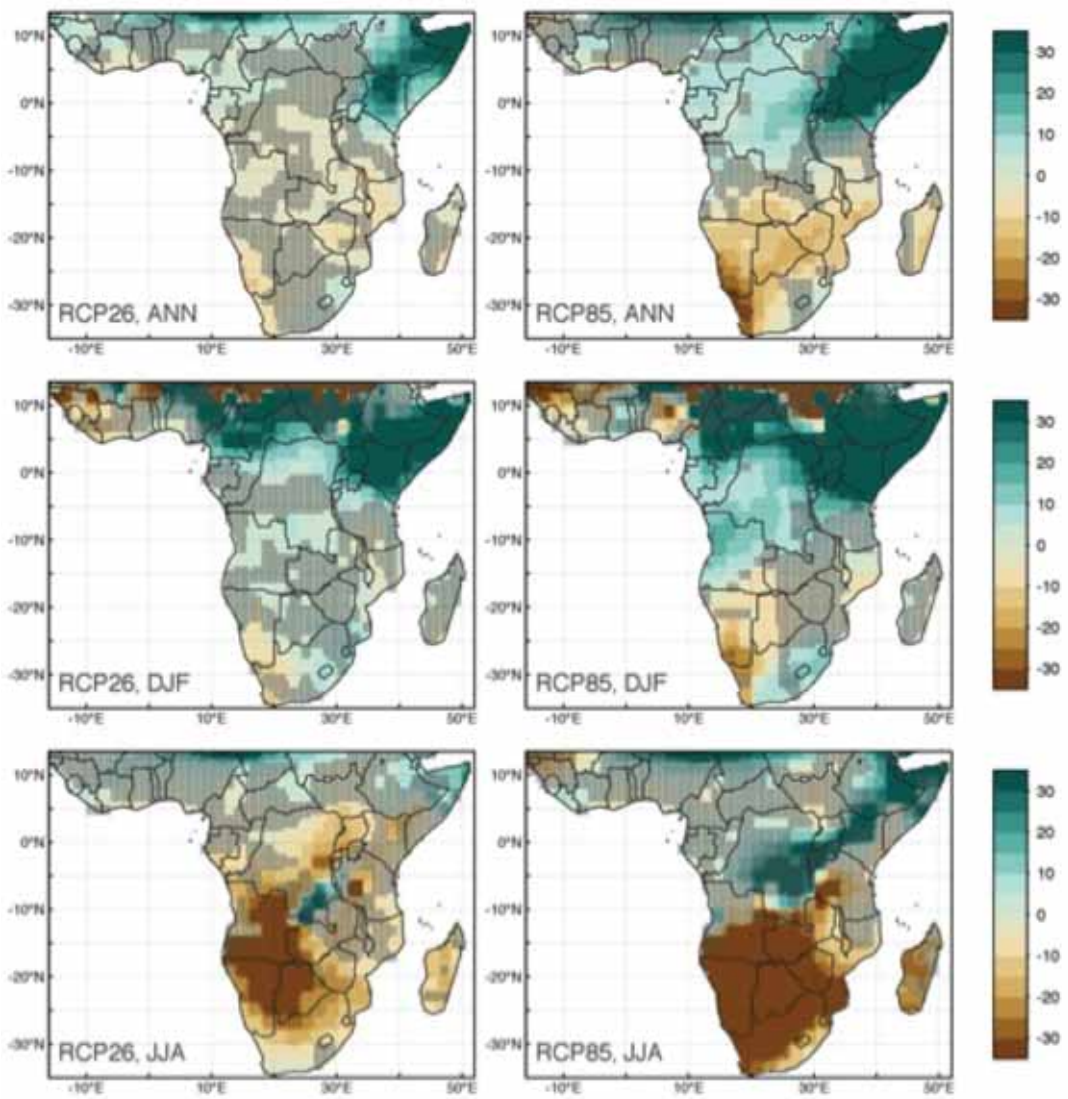
Subtropical southern Africa could see a decrease of annual precipitation by up to 30 percent, contributing to an increase in aridity in this region (see Chapter 3 on "Aridity"), although it must be noted that this is a large relative change in a region with very low rainfall.

The wetting of tropical East-Africa occurs predominantly during the austral summer (DJF), whereas the drying of southern Africa occurs predominantly during the austral winter (JJA), the driest season, so that the annual pattern is primarily determined by the smaller relative changes during the wetter season (DJF).

However, the agreement between global models on increased precipitation in East Africa and the Horn of Africa in particular does not necessarily imply high confidence in these results. Although global climate models are needed to project interactions between global circulation patterns of atmosphere and ocean, regional models offer a higher spatial resolution and provide a way to take into account complex regional geography and reproduce local climate generally better than global models. Regional models use boundary conditions prescribed by global models, so that their large-scale forcings, for example due to anthropogenic influences, are consistent with GCMs.

Regional climate models do not reproduce the increase in precipitation projected by global models for East Africa as a whole. On

Figure 3.6: Multi-model mean of the percentage change in annual (top), austral summer (DJF-middle) and austral winter (JJA-bottom) precipitation for RCP2.6 (left) and RCP8.5 (right) for Sub-Saharan Africa by 2071–99 relative to 1951–80



Hatched areas indicate uncertainty regions with two out of five models disagreeing on the direction of change compared to the remaining three models.

a sub-regional scale, these models show areas of strongly reduced precipitation by mid-century for a roughly 2°C global warming, for example in Uganda and Ethiopia (Patricola and Cook 2010; Cook and Vizy 2013; Laprise et al. 2013). Cook and Vizy (2012) showed how the strong decrease of the long rains in regional climate models, combined with warming, would lead to a drastically shorter growing season in East Africa, partly compensated by a modest increase in short-rains season length.

Using global-model projections in precipitation, (Dai, 2012) estimated for a global-mean warming of 3°C by the end of the 21st century that drought risk expressed by the Palmer Drought Severity Index[25] (PDSI) reaches a permanent state of severe to extreme droughts in terms of present-day conditions over southern Africa, as well as increased drought risk over Central Africa. Dai (2012) showed that projected changes in soil-moisture content are generally consistent with the pattern of PDSI over Sub-Saharan Africa. Taylor et al. (2012) confirmed that the projected

[25] Drought indicators like PDSI include a time-dependent water balance calculation that includes monthly precipitation, temperature, wind speed, incoming radiation, and takes account of present-day local climate so that drought risk is presented relative to existing conditions.

increased drought risk over southern Africa is consistent across other drought indicators, but added West Africa as an area where projections consistently show an increased drought risk. However, Figure 3.6 shows that precipitation changes are highly uncertain in the latter region, which Taylor et al (2012) might not have been taken into account fully.

According to Giannini, Biasutti, Held, and Sobel (2008a), the uncertainties in western tropical Africa are mainly because of competing mechanisms affecting rainfall. On the one hand, the onset of convection and subsequent rainfall is mainly affected by temperature at the surface and higher levels in the atmosphere. On the other hand, the amount of moisture supply is primarily affected by changes in atmospheric circulation, which can be induced by the temperature contrast between land and ocean. The effect of El Niño events mainly act via the first mechanism, with warming of the whole tropical troposphere stabilizing the atmospheric column and thereby inhibiting strong convection (Giannini, Biasutti, Held, and Sobel 2008a).

Sillmann and Kharin (2013a) studied precipitation extremes for 2081–2100 in the CMIP5 climate model ensemble under the low emission high emission scenario. Under the high-emission scenario, the total amount of annual precipitation on days with at least 1 mm of precipitation (total wet-day precipitation) increases in tropical eastern Africa by 5 to 75 percent, with the highest increase in the Horn of Africa, although the latter represents a strong relative change over a very dry area. In contrast to global models, regional climate models project no change, or even a drying for East Africa, especially during the long rains. Consistently, one recent regional climate model study projects an increase in the number of dry days over East Africa (Vizy and Cook 2012b). Changes in extreme wet rainfall intensity were found to be highly regional and projected to increase over the Ethiopian highlands.

Sillmann and Kharin (2013a) further projected changes of +5 to –15 percent in total wet-day precipitation for tropical western Africa with large uncertainties, especially at the monsoon-dependent Guinea coast. Very wet days (that is, the top 5 percent) show even stronger increases: by 50 to 100 percent in eastern tropical Africa and by 30 to 70 percent in western tropical Africa. Finally in southern Africa, total wet day precipitation is projected to decrease by 15 to 45 percent, and very-wet day precipitation to increase by around 20 to 30 percent over parts of the region. However, some localized areas along the west coast of southern Africa are expected to see decreases in very wet days (up to 30 percent). Here, increases in consecutive dry days coincide with decreases in heavy precipitation days and maximum consecutive five-day precipitation, indicating an intensification of dry conditions. The percentile changes in total wet-day precipitation, as well as in very wet days, are much less pronounced in the low emission scenario RCP2.6.

Aridity

The availability of water for ecosystems and society is a function of both demand and supply. The long-term balance between demand and supply is a fundamental determinant of the ecosystems and agricultural systems able to thrive in a certain area. This section assesses projected changes in Aridity Index (AI), an indicator designed for identifying "arid" regions, that is regions with a structural precipitation deficit (UNEP 1997; Zomer 2008). AI is defined as total annual precipitation divided by potential evapotranspiration; the latter is a standardized measure of water demand representing the amount of water a representative crop type would need over a year to grow (see Appendix 2). Potential evapotranspiration is to a large extent governed by (changes in) temperature, although other meteorological variables play a role as well.

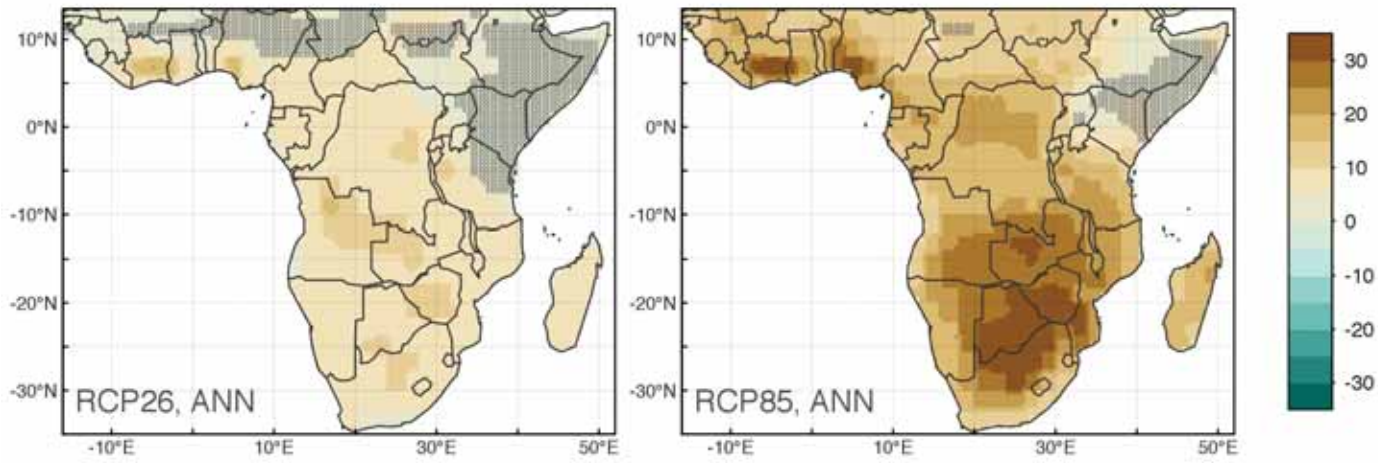
A smaller AI value indicates a larger water deficit (i.e., more arid condition), with areas classified as hyper-arid, arid, semi-arid, and sub-humid as specified in Table 3.2. In the absence of an increase in rainfall, an increase in potential evapotranspiration translates into a lower AI value and a shift toward more structurally arid conditions.

Analysis by the authors shows that, in general, the annual mean of monthly potential evapotranspiration increases under global warming (see Appendix 2). This is observed over all of Sub-Saharan Africa with strong model agreement, except for regions projected to see a strong increase in precipitation. In Eastern Africa and the Sahel region, the multi-model mean shows a small reduction in potential evapotranspiration—but the models disagree. Thus regions that are getting wetter in terms of increased rainfall see either only a limited increase or even a decrease in potential evapotranspiration. By contrast, a more unambiguous signal emerges for regions projected to get less rainfall (notably southern Africa), where the projections show an enhanced increase in potential evapotranspiration. This is likely because of the feedback between precipitation and evaporation via temperature. In regions receiving more rainfall there is enough water available for evaporative cooling; this limits the warming of the surface. In regions where the soil dries out because of a lack of precipitation, however, no more heat can be converted into latent heat and all heat results in increased surface temperatures.

Table 3.2: Climatic classification of regions according to Aridity Index (AI)

	Minimum AI Value	Maximum AI Value
Hyper-arid	0	0.05
Arid	0.05	0.2
Semi-arid	0.2	0.5
Sub-humid	0.5	0.65

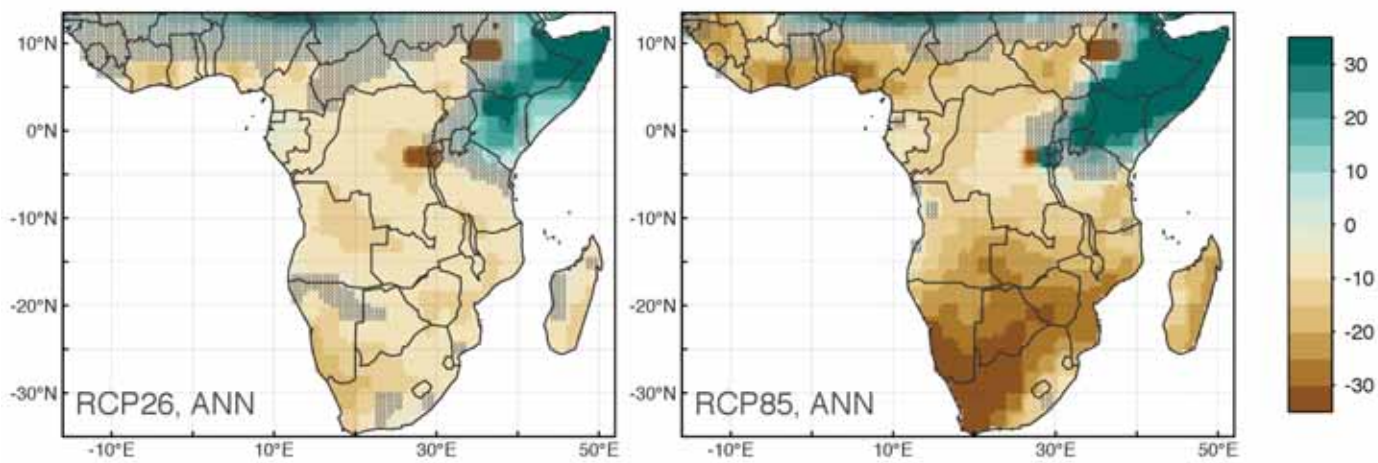
Figure 3.7: Multi-model mean of the percentage change in the annual-mean of monthly potential evapotranspiration for RCP2.6 (left) and RCP8.5 (right) for Sub-Saharan Africa by 2071–99 relative to 1951–80



In non-hatched areas, at least 4/5 (80 percent) of models agree. In hatched areas, at least 2/5 (20 percent) disagree.

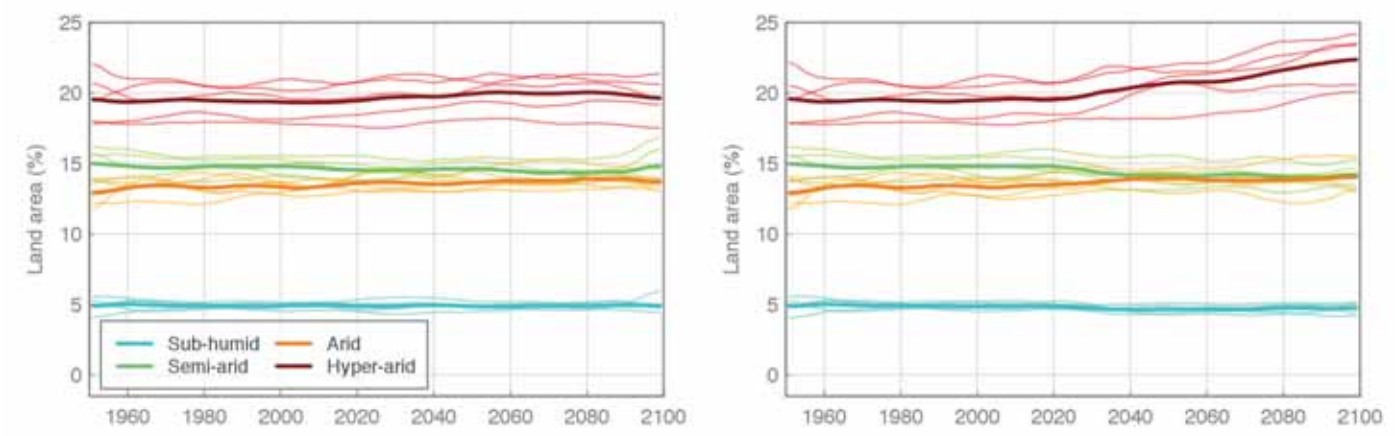
In general, a local warming, amplified by dry conditions, leads to an increase in potential evaporation. In other words, were a standard crop-type to grow there, it would need to release more heat in the form of evapotranspiration to survive the local conditions. This shortens the growing season, if moisture is the main factor constraining the length of the growing season, which is generally the case in sub-humid and drier regions. A shorter growing season implies lower crop yields, a higher risk of crop failure, or a need to shift to different crop types (adaptation). In the absence of an increase in rainfall (supply), an increase in potential evapotranspiration (demand) translates into a lower AI value and a shift toward more structurally arid conditions. There is a close match between the shift in potential evapotranspiration in Figure 3.7 and the shift in AI, which is shown in Figure 3.8, with the strongest deterioration toward more arid conditions in Southern Africa. A notable exception is southwestern Africa, where

Figure 3.8: Multi-model mean of the percentage change in the aridity index in a 2°C world (left) and a 4°C world (right) for Sub-Saharan Africa by 2071–99 relative to 1951–80



In non-hatched areas, at least 4/5 (80 percent) of models agree. In hatched areas, at least 2/5 (20 percent) disagree. Note that a negative change corresponds to a shift to more arid conditions and vice versa.

Figure 3.9: Multi-model mean (thick line) and individual models (thin lines) of the percentage of Sub-Saharan African land area under sub-humid, semi-arid, arid, and hyper-arid conditions for scenarios RCP2.6 (left) and RCP8.5 (right)



the evapotranspiration-driven shift in AI is amplified by a decline in rainfall (see Figure 3.6). By contrast, the improved (higher) aridity index in East Africa is correlated with higher rainfall projected by global climate models, a characteristic that is uncertain and not reproduced by higher-resolution regional climate models (see Chapter 3 on "Precipitation Projections"). In addition, note that for Somalia and eastern Ethiopia the shift implies a large relative shift imposed on a very low aridity index value, which results in AI values still classified as arid or semi-arid.

The shift in AI in Figure 3.8 translates into a shift of categorization of areas into aridity classes. Figure 3.9 shows that although there is little change in net dry areas in a 2°C world, a 4°C world leads to a shift of total area classification toward arid and hyper-arid. The overall area of hyper-arid and arid regions is projected to grow by 10 percent in a 4°C world (from about 20 percent to 23 percent of the total sub-Saharan land area), and by 3 percent in a 2°C world by 2080–2100 relative to 1986–2005. As semi-arid area shrinks, total arid area increases by 5 percent in a 4°C world and 1 percent in a 2°C world. The results for a 4°C world are consistent with Fischer et al. (2007), who used a previous generation of GCMs and a more sophisticated classification method based on growing period length to estimate a 5–8 percent increase in arid area in Africa by 2070–2100.

Regional Sea-level Rise

The difference in regional sea-level rise in Sub-Saharan Africa between a 2°C and a 4°C world is about 35 cm by 2100 using the semi-empirical model employed in this report. As explained in Chapter 2, current sea levels and projections of future sea-level rise are not uniform across the world. Sub-Saharan Africa as defined in this report stretches from 15° north to 35° south. Closer to the equator, but not necessarily symmetrically north and south, projections of local sea-level rise show a stronger increase compared to mid-latitudes. Sub-Saharan Africa experienced sea-level rise of 21 cm by 2010 (Church and White 2011). For the African coastlines, sea-level rise projected by the end of the 21st century relative to 1986–2005 is generally around 10-percent higher than the global mean, but higher than this for southern Africa (for example, Maputo) and lower for West Africa (for example, Lomé). Figure 3.10 shows the regional sea-level rise projections under the high emission scenario RCP8.5 for 2081–2100. Note that these projections include only the effects of human-induced global climate change, not those of local land subsidence resulting from natural or human influences.

Figure 3.10: Regional sea-level rise in 2081–2100 (relative to 1986–2005) for the Sub-Saharan coastline under RCP8.5

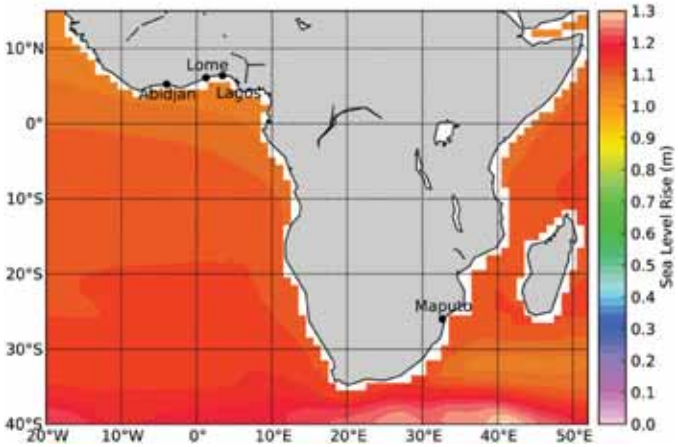
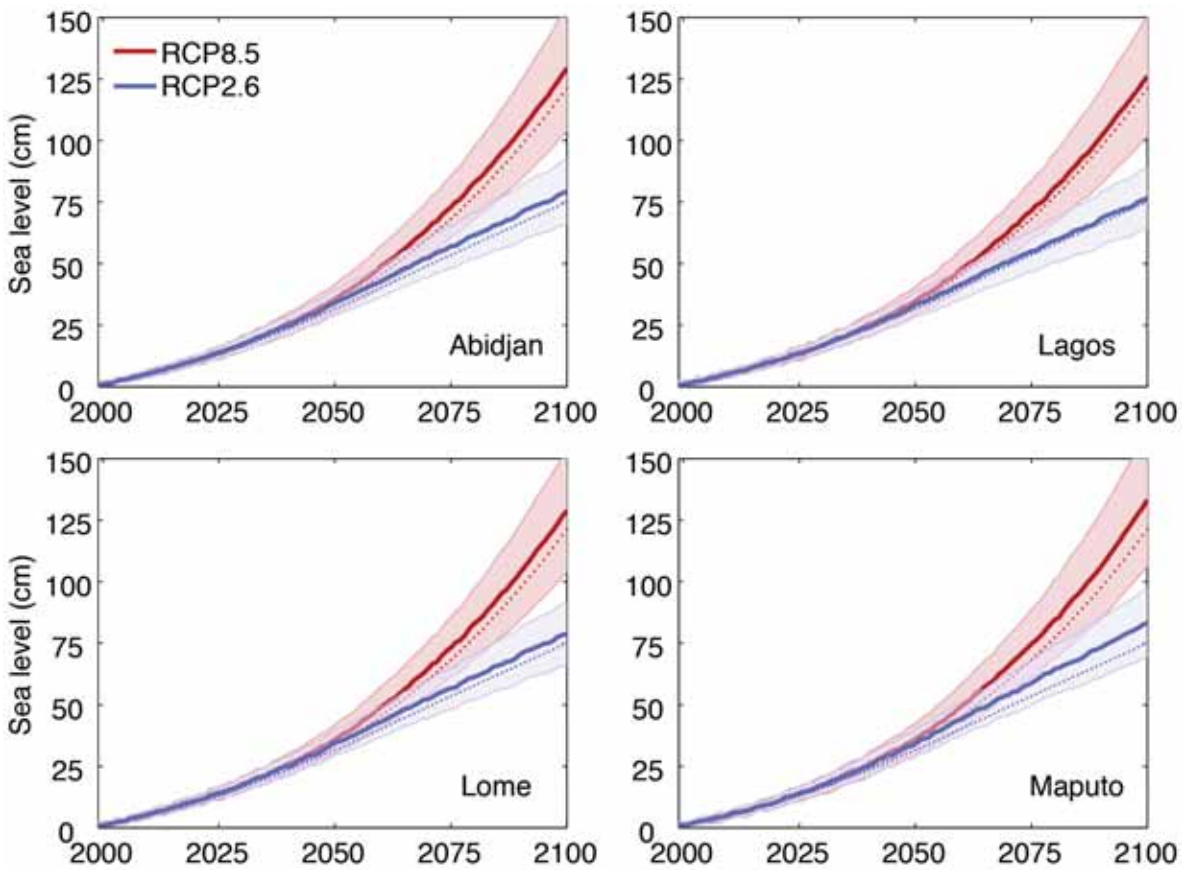


Figure 3.11: Local sea-level rise above 1986–2005 mean as a result of global climate change (excluding local change because of land subsidence by natural or human causes)



Shaded areas indicate 66 percent uncertainty range and dashed lines global-mean sea-level rise for comparison.

The time series of sea-level rise in a selection of locations in Sub-Saharan Africa is shown in Figure 3.11. Locations in West Africa are very close in terms of latitude and are projected to face comparable sea-level rise in a 4°C world, that is around 105 (85 to 125) cm by 2080–2100 (a common time period in impact studies assessed in the following sections). In a 2°C world, the rise is significantly lower but still considerable, at 70 (60 to 80) cm. Near Maputo in southern Africa, regional sea-level rise is some 5 cm higher by that time. For these locations, the likely regional sea-level rise (>66 percent chance) exceeds 50 cm above 1986–2005 by the 2060s in a 4°C warming scenario and 100 cm by the 2090s, both about 10 years before the global mean exceeds these levels.

In a 2°C warming scenario, 0.5 m is likely exceeded by the 2070s, only 10 years after exceeding this level in a 4°C warming scenario. By the 2070s, the rate of sea-level rise in a 2°C warming scenario peaks and remains constant, while that in the 4°C warming scenario continues to increase. As a result, one meter of sea-level rise is reached in a 4°C warming scenario by 2090; this level is not likely to be exceeded until well into the 22nd century in a 2°C warming scenario.

The Vulnerability of Coastal Populations and Infrastructure

Sea-level rise would have repercussions for populations and infrastructure located in coastal areas. Using the DIVA model, Hinkel et al. (2011) investigate the future impacts of sea-level rise in Sub-Saharan Africa on population and assets in Sub-Saharan Africa, with and without adaptation measures, under four different sea-level rise scenarios[26] and a no sea-level rise scenario. The applied adaptation measures are dikes building, maintenance, and upgrades and beach nourishment.

[26] Forty-two cm, 64 cm, 104 cm, and 126 cm above 1995 sea level for a range of mitigation and non-mitigation scenarios.

Projected Number of People Flooded and Displaced

Hinkel et al. (2011) estimate the number of people flooded[27] every year and the number of people forced to migrate because of the impacts of coastal erosion induced by sea-level rise. Under the high sea-level rise scenario (126 cm by 2100), the authors estimate that there would be approximately 18 million[28] people flooded in Sub-Saharan Africa per year. Under a sea-level rise scenario (64 cm by 2100), there would be close to 11 million people flooded every year. In the no sea-level rise scenario, only accounting for delta subsidence and increased population, up to 9 million people would be affected.

Mozambique and Nigeria are projected to be the most affected African countries, with 5 and 3 million people respectively being flooded by 2100 under the high sea-level rise scenario. However, Guinea-Bissau, Mozambique, and The Gambia would suffer the highest percentage of population affected, with up to 10 percent of their total projected population affected by flooding.

As a consequence of land loss because of coastal erosion induced by sea-level rise, the authors project that by 2100 between 12,000[29] (low business-as-usual sea-level rise scenario) and 33,000 people[30] (high business-as-usual sea-level rise scenario) could be forced to migrate.

Projected Damage to Economic Assets

Infrastructure in coastal zones is particularly vulnerable to both sea-level rise and to such weather extremes as cyclones. Damage to port infrastructure in Dar es Salaam, Tanzania, for example, would have serious economic consequences. The seaport handles approximately 95 percent of Tanzania's international trade and serves landlocked countries further inland (Kebede and Nicholls 2011). Most of the tourism facilities of Mombasa, Kenya, are located in coastal zones, which are under threat of sea-level rise in addition to a higher frequency of flooding and other extreme weather events that already cause damage almost every year (Kebede, Nicholls, Hanson, and Mokrech 2012). Damage to seafront hotel infrastructure has also already been reported in Cotonou, Benin—with this also considered a risk with rising sea levels elsewhere (Hope 2009). While to date there are few projections of the effects on gross domestic product (GDP) from impacts on the tourism sector, the agglomeration of tourism infrastructure in coastal areas may place this sector at severe risk of the impacts of sea-level rise.

Hinkel et al. (2011) estimate the damage costs resulting from sea-level rise in Sub-Saharan Africa, defining damage costs as the projected cost of economic damage induced by coastal flooding, forced migration, salinity intrusion, and loss of dry land. The authors estimate damage costs using a 1995 dollar undiscounted value.[31] In a no-adaption scenario, the sea-level rise would incur approximately $3.3 billion[32] in damages in Sub-Saharan Africa under the 126 cm sea-level rise scenario. Under a lower emission scenario leading to a 2°C temperature increase by the end of the century, damages due to sea-level rise may be up to half a billion dollars lower. Mozambique and Guinea Bissau are expected to be the most affected African countries, with a loss of over 0.15 percent of their national GDPs.

Water Availability

The impact of climate change on temperature and precipitation is expected to bring about major changes in the terrestrial water cycle. This affects the availability of water resources and, consequently, the societies that rely on them (Bates, Kundzewicz, Wu, and Palutikof 2008).

Different forms of water availability are distinguishable. Blue water refers to water in rivers, streams, lakes, reservoirs, or aquifers that is available for irrigation, municipal, industrial, and other uses. Green water refers to the precipitation that infiltrates the soil, which rainfed agriculture and natural ecosystems depend on. Because of the different exposure to climate change, the fraction of blue water in aquifers will be discussed separately as groundwater. Blue water resulting from river runoff and surface water and green water are directly affected by temperature and precipitation changes; whereas, groundwater, a component of blue

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27 This is the "expected number of people subject to annual flooding taking into account coastal topography, population and defenses" as well the effects of sea-level rise (Hinkel et al. 2011).

28 Hinkel, Vuuren, Nicholls, and Klein (2012)the number of people flooded reaches 168 million per year in 2100. Mitigation reduces this number by factor 1.4, adaptation by factor 461 and both options together by factor 540. The global annual flood cost (including dike upgrade cost, maintenance cost and residual damage cost project 27 million people flooded in 2100 under this sea-level rise scenario in Africa. The 18 million people figure for Sub-Saharan Africa was obtained by subtracting the number of people flooded in Egypt (about 8 million), Tunisia (0.5 million), and Morocco (0.5 million).

29 About 15,000 people are projected to be forced to migrate in 2100 under this sea-level rise scenario in the whole of Africa. The figure of 12,000 people for Sub-Saharan Africa was obtained by subtracting the number of people forced to migrate in Egypt (about 2,000) and in Morocco (about 1,000).

30 About 40,000 people are projected to be forced to migrate in 2100 under this sea-level rise scenario in the whole of Africa. The figure of 33,000 people for Sub-Saharan Africa was obtained by subtracting the number of people forced to migrate in Egypt (about 5,000) and in Morocco (about 2,000).

31 Note that using an undiscounted 1995 dollar may contribute to an overestimation of future damage costs.

32 Hinkel et al. (2012)the number of people flooded reaches 168 million per year in 2100. Mitigation reduces this number by factor 1.4, adaptation by factor 461 and both options together by factor 540. The global annual flood cost (including dike upgrade cost, maintenance cost and residual damage cost project $8.9 billion in damages in 2100 under this sea-level rise scenario in Africa. The $3.3 billion damage figure for Sub-Saharan Africa was obtained by subtracting the damage cost in Egypt (about $5 billion), Tunisia, Morocco ($0.5 billion), and in Libya ($0.1 billion).

water, is relatively more resilient to climate variability as long as it is sufficiently[33] recharged from precipitation (Kundzewicz and Döll 2009; Taylor et al. 2012).

The Sub-Saharan African region's vulnerability to changes in water availability is particularly high because of its dependence on rainfed agriculture (Calzadilla, Zhu, Rehdanz, Tol, and Ringler 2009; Salvador Barrios, Outtara, Strobl, and Ouattara 2008) and its lack of water-related infrastructure (Brown and Lall 2006).

Present Threats to Water Availability

Because of a lack of investment in water-related infrastructure that could alleviate stressors, Sub-Saharan Africa is among the regions in the world most seriously threatened by an absence of water security (Vörösmarty et al. 2010). Vörösmarty et al. (2010) find that large parts of Sub-Saharan Africa have medium to high threats[34] arising from semi-aridity and highly seasonally variable water availability, compounded by pollution and human and agricultural water stresses.

Threats are especially high along the Guinea coast and East Africa. This contrasts to regions, such as Europe, where even higher levels of water availability threats are circumvented because of massive investments in water-related infrastructure. According to Vörösmarty et al. (2010), even to alleviate present-day vulnerabilities, a central challenge for Sub-Saharan Africa lies in improving water security by investing in water resource development without undermining riverine biodiversity, as has happened in developed regions similar to Europe.

The index assessed in Vörösmarty et al. (2010) refers to the threat of scarcity in access to clean blue water; green water security seems presently less at risk. Rockström et al. (2009) found that many of the areas classified as blue water scarce (that is, with less than 1,000 m^3 per capita per year as is the case for Burkina Faso, Nigeria, Sudan, Uganda, Kenya, Somalia, Rwanda, Burundi, parts of Zimbabwe, and South Africa) can at present provide an adequate overall supply of green water required for producing a standard diet (1,300 m^3 per capita per year). Since these indicators refer to water availability per capita, one way to interpret these findings is that there is a better match between population density and available green water (for agricultural production) than between population and available blue water.

Groundwater often is the sole source of safe drinking water in rural areas of Sub-Saharan Africa (MacDonald et al. 2009). Unlike the major aquifer systems in northern Africa, most of Sub-Saharan Africa has generally low permeability and minor aquifers, with some larger aquifer systems located only in the Democratic Republic of" before Congo, parts of Angola, and southern Nigeria (MacDonald et al. 2012). A lack of assessments of both groundwater resources and water quality are among the large uncertainties in assessing the yield of African aquifers (MacDonald et al. 2012). Given that groundwater can act as a buffer for projected climate change, the main challenge will be to quantify whether projected recharge rates would balance with increasing demand-driven exploitation (Taylor et al. 2012).

Projected Impacts on Water Availability

The future impacts of climate change on water availability and stress for Sub-Saharan Africa have been studied for many years. A critical uncertainty is projecting changes in regional precipitation (see Chapter 3 on "Precipitation Projections"). One of the important messages from these projections is that large regions of uncertainty remain, particularly in West Africa and East Africa, but that the uncertainties are reduced with increasing levels of warming. In other words, model projections tend to converge when there is a stronger climate change signal. Projected future population levels and the scale of economic activity have a major impact on indices of water scarcity and availability: a larger population reduces water availability per person, all other circumstances being equal.

Gerten et al. (2011) investigate the changes in water availability per capita. Considering the impacts of climate change alone,[35] they drive a hydrological model with a large ensemble of CMIP3, or earlier generation, climate models. For the 2080s (with a global-mean warming of 3.5°C above pre-industrial levels), they found decreases in green water availability of about 20 percent relative to 1971–2000 over most of Africa[36] and increases of about 20 percent for parts of East Africa (Somalia, Ethiopia, and Kenya). Although green water availability and the Aridity Index assessed in Chapter 3 under "Aridity" are driven by different measures of demand, the analysis undertaken for this report found a strong consistency between the patterns of decreased green water availability and increased aridity across Africa. Gerten et al. (2011) further assessed changes in blue water availability, indicating a 10–20 percent increase in East Africa, Central Africa, and parts of West Africa. The latter is not fully consistent with the more recent multi-model studies discussed below and in Chapter 3 under "Crops", which found a decrease of blue water availability over virtually all of West Africa (Schewe et al. 2013). Taken together and assuming a constant population, most of East Africa and Central Africa

[33] Kundzewicz and Döll 2009 define renewable groundwater resources as those where the extraction is equal to the long-term average groundwater recharge. If the recharge equals or exceeds use, it can be said to be sufficient.

[34] The threats are defined using expert assessment of stressor impacts on human water security and biodiversity, using two distinctly weighted sets of 23 geospatial drivers organized under four themes (catchment disturbance, pollution, water resource development, and biotic factors). The threat scale is defined with respect to the percentiles of the resulting threat distribution (e.g., moderate threat level (0.5), very high threat (0.75)).

[35] In this scenario, population is held constant at the year 2000 level under the SRESA2 scenario (arriving at 4.1°C by the end of the century).

[36] South Africa is excluded because changes were found to be insignificant.

show an increase of total green and blue water availability, while Southern Africa and most of West Africa is expected to experience reductions of up to 50 percent. If projected population increases are taken into account, these results indicate with high consensus among models that there is at least a 10-percent reduction in total water availability per capita for all of Sub-Saharan Africa.

A scarcity index can be defined by relating the total green and blue water availability to the amount needed to produce a standard diet and taking into account population growth. For East Africa, Angola, the Democratic Republic of Congo, and most of West Africa, the scarcity index indicates that these countries are very likely to become water scarce; most of Southern Africa is still unlikely to be water scarce.[37] In the latter case, this is mainly because of much lower projections of population growth than for the other parts of the region, with at most a twofold increase (compared to a fourfold increase for the Sub-Saharan African average). It should be noted that the study by Gerten et al. assumes that the CO_2 fertilization effect reduces the amount of water needed to produce a standard diet. The CO_2 fertilization effect, however, and therefore the extent to which the effect of potential water shortages might be offset by the CO_2 fertilization effect, remain very uncertain. Without CO_2 fertilization, Gerten et al. (2011) note that water scarcity deepens, including in South Africa and Sudan, and adds countries like Mauritania, the Democratic Republic of Congo, Zimbabwe, and Madagascar to the list of African countries very likely to be water scarce.

For many countries, the estimate of water availability at the country level may imply that a large portion of its population could still suffer from water shortages because of a lack of sufficient water-related infrastructure among other reasons (Rockström et al. 2009).

In a more recent study of water availability, Schewe et al. (2013) use a large ensemble of the most recent CMIP5 generation of climate models combined with nine hydrological models. They investigate the annual discharge (that is, runoff accumulated along the river network) for different levels of warming during the 21st century under the high warming scenario (RCP8.5 ~3.5°C above pre-industrial levels by 2060–80).[38]

Under 2.7°C warming above pre-industrial levels within regions with a strong level of model agreement (60–80 percent)—Ghana, Côte d'Ivoire, and southern Nigeria—decreases in annual runoff of 30–50 percent are projected. For southern Africa, where there is much greater consensus among impact models, decreases of 30–50 percent are found, especially in Namibia, east Angola, and western South Africa (all of which feature arid climates), Madagascar, and Zambia; there are also local increases. Large uncertainties remain for many regions (e.g., along the coast of Namibia, Angola and in the central Democratic Republic of Congo). With over 80-percent model consensus, there is a projected increase of annual discharge of about 50 percent in East Africa (especially southern Somalia, Kenya, and southern Ethiopia).

This multi-model study found that the largest source of uncertainty in West Africa and East Africa results from the variance across climate models, while in Southern Africa both climate and hydrological models contribute to uncertainty. Uncertainty in hydrological models dominates in western South Africa and in the western Democratic Republic of Congo.

These projected regional changes are enhanced by up to a factor of two for a warming of ~3.5°C above pre-industrial levels, compared to 2.7°C warming above pre-industrial levels, and there is more consensus across the models. These findings are consistent with the changes in aridity previously discussed.

While these broad patterns are consistent with earlier studies, there are important differences. For example, Fung, Lopez, and New (2011) and Arnell et al. (2011) found even more pronounced decreases in Southern Africa of up to 80 percent for a warming of 4°C above 1961–90 levels (which corresponds to ~4.4°C above pre-industrial levels). Gosling et al. (2010) use one hydrological model with a large ensemble of climate models for a range of prescribed temperature increases. The projections for 4°C warming relative to 1961–90 (which corresponds to ~4.4°C above pre-industrial levels) are largely consistent with the findings of Schewe et al. (2013), albeit with some regional differences (e.g., more rather than less runoff in Tanzania and northern Somalia).

In general, effects are found to be amplified in a 4°C world toward the end of the 21st century and, with population growth scenarios projecting steady increases in the region, large parts of Sub-Saharan Africa are projected to face water scarcity (Fung et al. 2011). To help alleviate vulnerability to changes in surface water, the more resilient groundwater resources can act as a buffer—if used sustainably under population growth. However, Sub-Saharan Africa has mostly small discontinuous aquifers; because of a lack of geologic assessments as well as projected increased future land use, large uncertainties about their yields remain. Furthermore, with regions such as South Africa facing a strong decrease in groundwater recharges (Kundzewicz and Döll 2009), the opportunities to balance the effects of more variable surface water flows by groundwater are severely restricted.

The Role of Groundwater

As noted before, groundwater can provide a buffer against climate change impacts on water resources, because it is relatively more resilient to moderate levels of climate change in comparison to surface

[37] Large parts of Sub-Sahara Africa (except for Senegal, The Gambia, Burkina Faso, Eritrea, Ethiopia, Uganda, Rwanda, Burundi, and Malawi) are projected to be very unlikely to be water scarce by 2100 in the A2 scenario, for a constant population, due to climate change alone.

[38] Note that Schewe et al. (2013) only discuss annual discharges; the distribution of discharges across the season can have severe impacts.

water resources (Kundzewicz and Döll 2009). Döll (2009) studies groundwater recharge for 2041–79 compared to the 1961–90 average using two climate models for the SRES A2 and B2 scenarios (global-mean warming 2.3°C and 2.1°C respectively above pre-industrial levels). For both scenarios, Döll finds a decrease in recharge rates of 50–70 percent in western Southern Africa and southern West Africa, while the recharge rate would increase in some parts of eastern Southern Africa and East Africa by around +30 percent. Note that these increases might be overestimated, as the increased occurrence of heavy rains, which are likely in East Africa (Sillmann, Kharin, Zwiers, Zhang, and Bronaugh, 2013), lowers actual groundwater recharge because of infiltration limits which are not considered in this study. MacDonald et al. (2009) also note that increased rainfall, especially heavy rainfall—as is projected for East Africa—is likely to lead to contamination of shallow groundwater as water tables rise and latrines flood, or as pollutants are washed into wells.

Döll (2009) determine the affected regions in western Southern Africa and southern West Africa as highly vulnerable when defining vulnerability as the product of a decrease in groundwater recharge and a measure of sensitivity to water scarcity. The sensitivity index is composed of a water scarcity indicator as an indicator of dependence of water supply on groundwater and the Human Development Index.

The prospects of alleviating surface water scarcity by using groundwater are severely restricted for those areas where not only surface water availability but also groundwater recharge is reduced because of climate change (as is the case for western Southern Africa and southern West Africa) (Kundzewicz and Döll 2009).

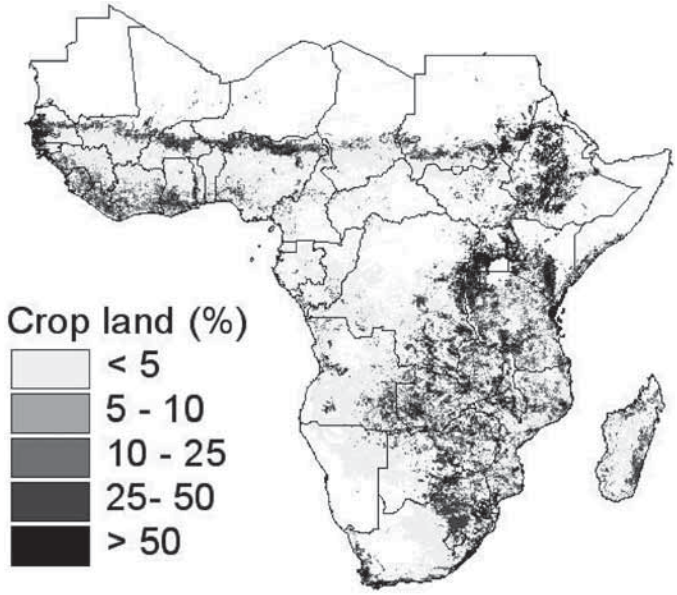
Apart from uncertainty in precipitation projections in Döll (2009), which only used two climate models as drivers, sources of uncertainty lie in the hydrological model used and the lack of knowledge about groundwater aquifers (MacDonald et al. 2009). A further uncertainty relates to changes in land use because of agriculture, which responds differently to changes in precipitation compared to natural ecosystems (R G Taylor et al. 2012). There is more certainty about rises in groundwater extraction in absolute terms resulting from population growth, which threatens to overexploit groundwater resources, particularly in semiarid regions where projected increases of droughts, as well as the projected expansion of irrigated land, is expected to intensify groundwater demand (Taylor et al. 2012).

Agricultural Production

Agriculture is often seen as the most weather dependent and climate-sensitive human activity. It is particularly exposed to weather conditions in Sub-Saharan Africa, where 97 percent of total crop land is rainfed (Calzadilla et al. 2009). Given that 60 percent of the labor force is involved in the agricultural sector, livelihoods are also exposed (Collier, Conway, and Venables 2008).

It is widely accepted that agricultural production in Sub-Saharan Africa is particularly vulnerable to the effects of climate change because of a number of environmental characteristics (Barrios, Outtara, and Strobl 2008). Sub-Saharan Africa is characterized by large differences in water availability because of the diversity of geographical conditions. While the tropics are humid throughout the year, rainfall in the subtropics is limited to the wet season(s). Further poleward, the semiarid regions rely on the wet seasons for water and, together with the arid regions, receive little runoff from permanent water sources. This is exacerbated by high temperatures and dry soils, which absorb more moisture. Average runoff is therefore about 15-percent lower in Sub-Saharan Africa than in any other continent (Barrios et al. 2008). As the tropical regions are not suitable for crop production, crop production in Sub-Saharan Africa is typically located in semiarid regions. The same holds for livestock production, which for animals other than pigs, is not practiced in humid regions because of susceptibility of diseases and low digestibility of associated grasses (Barrios et al. 2008; see Figure 3.12). This, taken together with the fact that less than 4 percent of cultivated area in Sub-Saharan Africa is irrigated (You et al. 2010), makes food production systems highly reliant on rainfall and thus vulnerable to climatic changes, particularly to changes in precipitation and the occurrence of drought.

Figure 3.12: Crop land in Sub-Saharan Africa in year 2000



Source: You, Wood, and Wood-Sichra (2009).

Reprinted from Agricultural Systems, 99, You, Wood, and Wood-Sichra, Generating plausible crop distribution maps for Sub-Saharan Africa using a spatially disaggregated data fusion and optimization approach, 126–140, Copyright (2009), with permission from Elsevier. Further permission required for reuse.

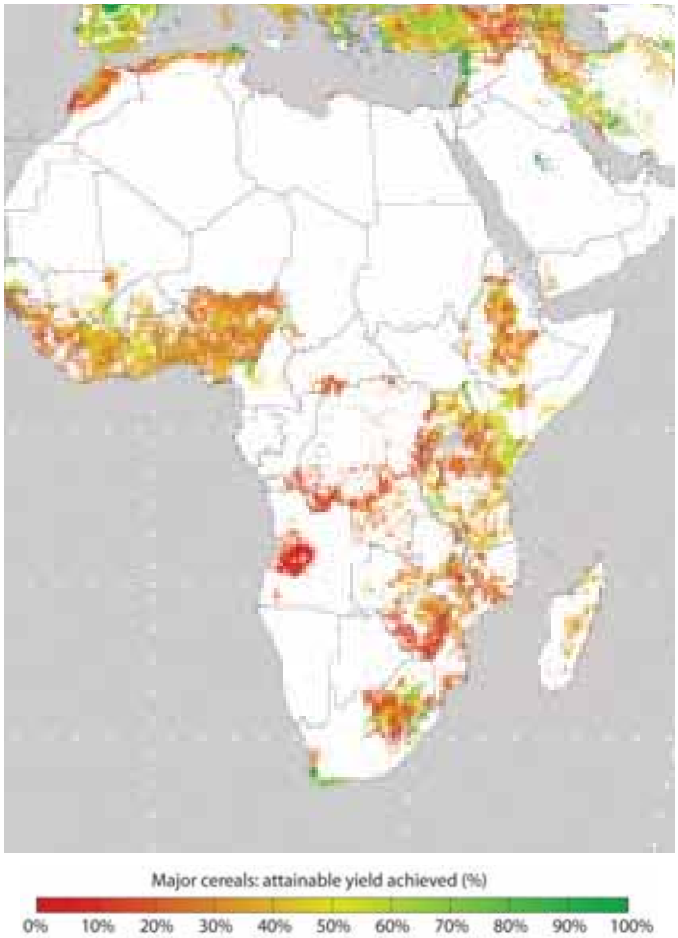
The following render agricultural productivity critically vulnerable to climate change: high dependence on precipitation combined with observed crop sensitivities to maximum temperatures during the growing season (Asseng et al. 2011; David B Lobell, Schlenker, and Costa-Roberts 2011a; Schlenker and Roberts 2009); varying and often uncertain responses to factors such as increasing CO_2 concentration; and low adaptive capacities (Müller 2013). As a consequence, climate change is expected to affect agriculture by reducing the area suitable for agriculture, altering the growing season length, and reducing the yield potential (Kotir 2011; Thornton, Jones, Ericksen, and Challinor 2011a). The impacts of extreme events are as yet uncertain but are expected to be significant (Rötter, Carter, Olesen, and Porter 2011).

Africa has already seen declines in per capita agricultural output in recent decades, especially for staple foods; the most important staple foods are cassava, rice, soybean, wheat, maize, pearl millet, and sorghum (Adesina 2010; Liu et al. 2008). Important factors include high levels of population growth, volatile weather, and climatic conditions that have seen droughts or flooding destroy or limit harvests. A number of other factors have also contributed, including use of low-productivity technologies and limited and costly access to modern inputs (Adesina 2010). Levels of malnutrition[39] are high, partly as a result of this limited productivity and the high dependence on domestic production. The prevalence of malnutrition among children under five exceeds 21 percent (2011 data; World Bank 2013n) and one in three people in Sub-Saharan Africa is chronically hungry (Schlenker and Lobell 2010). The prevalence of undernutrition in Sub-Saharan Africa has decreased only slightly since the 1990s, from 32.8 percent (1990–92) to 26.8 percent (projections for 2010–12; Food and Agriculture Organization of the United Nations 2012a).

An important factor remains: the yield potential of arable land in Sub-Saharan Africa is significantly higher than actually achieved (see Figure 3.13). Factors that limit yield differ across regions and crops. For example, nutrient availability is the limiting factor for maize in Western Africa, while water availability is an important co-limiting factor in East Africa (Mueller et al. 2012).

The agricultural areas in Sub-Saharan Africa that have been identified as the most vulnerable to the exposure of changes in climatic conditions are the mixed semiarid systems in the Sahel, arid and semiarid rangeland in parts of eastern Africa, the systems in the Great Lakes region of eastern Africa, the coastal regions of eastern Africa, and many of the drier zones of southern Africa (Thornton et al. 2006). Faures and Santini (2008) state that relative poverty, which limits adaptive capacities of the local population and thus increases vulnerability, is generally highest in highland temperate, pastoral, and agro-pastoral areas. Those areas classified in the study as highland temperate areas include, for example, Lesotho and the highlands of Ethiopia and Angola; the pastoral zones include much of Namibia, Botswana, and the Horn of Africa; and the agro-pastoral zones include parts of the Sahel region and of Angola, Namibia, Botswana, Zimbabwe, Zambia, Kenya, and Somalia.

Figure 3.13: Average "yield gap" (difference between potential and achieved yields) for maize, wheat, and rice for the year 2000



Source: Adapted from Mueller et al. (2012).

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Although (changes in) rainfall patterns are crucial for the Sahel region and a drying since the 1960s is well documented (Box 3.2), climate model projections of precipitation in this region diverge widely even in the sign of future change, not just for the generation of models at the time of IPCC's AR4 but also for the latest CMIP5 generation of models used for AR5 (Roehrig et al. 2012). Sahel rainfall is closely linked to sea-surface temperatures in the

[39] Defined as a physical condition that is caused by the interaction of an inadequate diet and infection, and of which under-nutrition or insufficient food energy intake is one form (Liu et al. 2008; Roudier et al. 2011).

Box 3.2: The Sahel Region

The Sahel, often cited in the literature as a highly vulnerable area, is a belt of land located between the Sahara desert to the north and tropical forests to the south, with the landscape shifting between semiarid grassland and savanna (Sissoko, Van Keulen, Verhagen, Tekken, and Battaglini 2011). Water is scarce and the soil quality is poor, in part because of human-induced degradation. While the exact nature and cause of observed changes in patterns of rainfall in this region is debatable, there appears to have been an overall shift toward increased temperatures and lower annual average rainfall since the 1960s in the semiarid regions of West Africa (Kotir 2011). These conditions have undermined agricultural production in the region since the 1970s (Barrios et al. 2008). The high levels of climatic risk and relative scarcity of natural resources makes livelihoods in areas such as the Sahel particularly precarious. The repercussions of a climatic disruption to agriculture for affected populations may be more severe here, where people are living nearer the margins of subsistence, than in areas with more abundant resources (Roncoli, Ingram, and Kirshen 2001).

equatorial Atlantic, which are set to increase under global warming (Roehrig et al. 2012), with local rainfall changes amplified by land-surface feedbacks, including vegetation patterns (Giannini et al. 2008). Anthropogenic aerosols over the North Atlantic, however, may have contributed to historic Sahel drying (Rotstayn and Lohmann 2002; Ackerley et al. 2011; Booth et al. 2012), so that drying might be alleviated as aerosol emissions in the Northern Hemisphere are reduced due to air-quality policy or low-carbon development. Total rainfall has recovered somewhat from the 1980s, although there are indications that precipitation frequency has remained at a low level while individual rainfall events have become more intense (Giannini et al. 2008). This is consistent with a basic understanding of a warming world that increases the moisture capacity of the atmosphere and leads to more intense precipitation events.

Crops

Climate change is expected to affect crop yields through a range of factors.

Climatic Risk Factors

One risk factor to which the region is exposed is increasing temperature. High temperature sensitivity thresholds for important crops such as maize, wheat, and sorghum have been observed, with large yield reductions once the threshold is exceeded (Luo 2011). Maize, which is one of the most common crops in Sub-Saharan Africa, has been found to have a particularly high sensitivity to temperatures above 30°C within the growing season. Each day in the growing season spent at a temperature above 30°C reduces yields by one percent compared to optimal, drought-free rainfed conditions (David B Lobell, Schlenker et al. 2011). The optimal temperature of wheat, another common crop, is generally between 15 and 20°C, depending on the varieties of wheat. The annual average temperature across Sub-Saharan Africa is already above the optimal temperature for wheat during the growing season (Liu et al. 2008), and it is expected to increase further. Increases in temperature may translate into non-linear changes in crop yields when high temperature thresholds are crossed. Long-term impacts (toward the end of the 21st century) could be more than twice those in the shorter term to 2050 (Berg, De Noblet-Ducoudré, Sultan, Lengaigne, and Guimberteau 2012).

Drought represents a continuing threat to agriculture, and Africa might be the region most affected by drought-caused yield reductions in the future (Müller, Cramer, Hare, and Lotze-Campen 2011). Recent projections by Dai (2012) indicate that the Sahel and southern Africa are likely to experience substantially increased drought risk in future decades. Rainfall variability on intra-seasonal, inter-annual, and inter-decadal scales may also be a critical source of risk (Mishra et al. 2008). Some studies find that in Sub-Saharan Africa the temporal distribution of rainfall is more significant than the total amount (for example, Wheeler et al. 2005, cited in Laux, Jäckel, Tingem, and Kunstmann 2010).

Another factor that could play a role for future agricultural productivity is plant disease. Climate extremes can alter the ecology of plant pathogens, and higher soil temperatures can promote fungal growth that kills seedlings (Patz, Olson, Uejo, and Gibbs 2008).

One of the major sources of discrepancy between projections of crop yields lies in the disagreement over the relative significance of temperature and precipitation (see Lobell and Burke 2008 on this debate). Assessing the relative role of temperature and rainfall is difficult as the two variables are closely linked and interact (Douville, Salaa-Melia, and Tyteca 2006). The significance of each may vary according to geographical area. For example, Berg et al. (2012) find that yield changes in arid zones appear to be mainly driven by rainfall changes; in contrast, yield appears proportional to temperature in equatorial and temperate zones. Similarly, Batisane and Yarnal (2010) find that rainfall variability is the most important factor limiting dryland agriculture; this may not be so elsewhere. Levels of rainfall variability that would be considered low in some climate regions, such as 50 mm, can mean the difference between a good harvest and crop failure in semi-arid regions with rainfed agriculture.

CO_2 Fertilization Effect Uncertainty

Whether the CO_2 fertilization effect is taken into account in crop models also influences outcomes, with the studies that include it generally more optimistic than those that do not. The CO_2 fertilization effect may increase the rate of photosynthesis and water use efficiency, thereby producing increases in grain mass and number; this may offset to some extent the negative impacts of climate change (see Laux et al. 2010 and Liu et al. 2008). Crop yield and total production projections differ quite significantly depending on whether the potential CO_2 fertilization effect is strong, weak, or absent. See Chapter 3 on "Agricultural Production" for further discussion of the CO_2 fertilization effect.

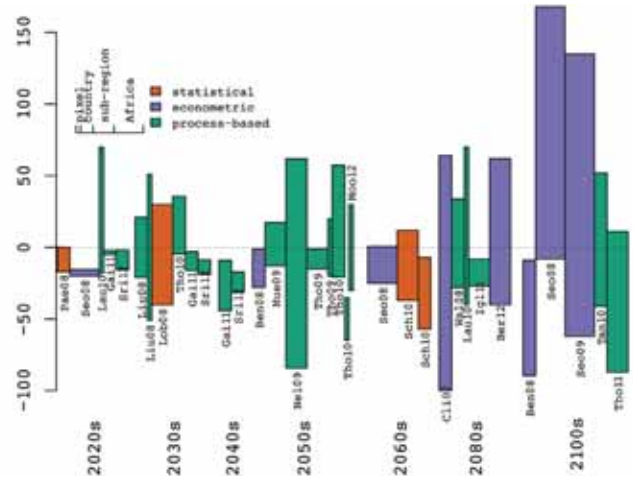
Projected Changes in Crop Yields

Many recent studies examining one or more climatic risk factors predict project significant damage to agricultural yields in Sub-Saharan Africa. These include Knox, Hess, Daccache, and Ortola (2011), Ericksen et al. (2011), Thornton, Jones, Ericksen, and Challinor (2011), and Schlenker and Lobell (2010). However, crop modeling suggests that there can be positive as well as negative impacts on agriculture in Africa, and impacts are expected to vary according to farm type and crop type (Müller et al. 2011) and depending on whether or not adaptation is assumed (Müller 2013). Müller (2013), in a literature review of African crop productivity under climate change, points out that uncertainty in projections increases with the level of detail in space and time. Despite uncertainties, Müller (2013) emphasizes that there is a very substantial risk based on projections of a substantial reduction in yield in Africa. According to Müller (2013), yield reductions in the near term, while often not as severe as in the long term, are particularly alarming as they leave only little time to adapt.

A substantial risk of large negative impacts on crop yields in the West African region, with a median 11-percent reduction by the 2080s, is found in recent meta-analysis of 16 different studies (Roudier et al. 2011). The West African region presently holds over 40 percent of Sub-Saharan Africa's population and over half of the area for cereal, root, and tuber crops. Rainfall in West Africa depends on the West African monsoon, for which climate change projections differ widely. Some project a drier climate and some a wetter climate, which is reflected in the broad range of yield projections.

Larger impacts are found in the northern parts of West Africa, with a median 18-percent reduction in yield projected, compared to the southern West African region, with 13-percent reductions. Dry cereal production in Niger, Mali, Burkina Faso, Senegal, and The Gambia is expected to be more severely affected than those in Benin, Togo, Nigeria, Ghana, Liberia, Sierra Leone, Cameroon, Guinea, Guinea-Bissau, and Côte d'Ivoire, with relative changes of –18 percent and –13 percent respectively. This difference can be explained by a greater warming over continental Africa, the Sahel, and the Sahara in particular, compared to the western parts of the region (where temperatures are expected to increase more slowly).

Figure 3.14: Climate change impacts on African agriculture as projected in recent literature after approval and publication of the IPCC Fourth Assessment Report (AR4)



Impacts are expressed as percent changes relative to current conditions; bar width represents spatial scale of the assessment, colors denote the model type employed (statistical in orange, econometric in purple, and process-based in green). Seo08 refers to the livestock sector only; Tho10 reports pixel-based results only for a random selection of strongly impacted pixels; Sch10 shows country data only for maize; Wal08 employs stylized scenarios that are representative for the climate in 2070–2100; Tan10 refers to NE Ghana only; Gai11 and Sri12 refer to Upper Ouémé basin in the Republic of Benin only.

Source: Müller (2013). The reference information for the studies included in this graph can be found in Appendix 4.

From Müller C. (2013). African lessons on climate change risks for agriculture. Annual Reviews of Nutrition, 33, 1-35. ANNUAL REVIEW OF NUTRITION by Darby, William J. ; Broquist, Harry P. ; Olson, Robert E. Reproduced with permission of ANNUAL REVIEWS in the format Republish in a book via Copyright Clearance Center. Further permission required for reuse." after "... Copyright Clearance Center.

Consistent with other work, this review finds that negative impacts on production are intensified with higher levels of warming (Roudier et al. 2011). It finds close to zero or small negative changes for the 2020s for most scenarios (1.1–1.3°C above pre-industrial levels globally); median losses in the order of –5 percent by the 2050s (1.6–2.2°C above pre-industrial levels globally); and, for the 2080s, a range of reductions of around –5 percent to –20 percent, with the median reduction being greater than 10 percent (2.4–4.3°C above pre-industrial levels globally).

The smallest reductions or largest increases are with the CO_2 fertilization effect taken into account and the greatest reductions are all without it. Analyzing the subset of studies, which also account for CO_2 fertilization, Roudier et al. (2011) find that the CO_2 fertilization effect, which is particularly strong in high emission scenarios and for such C3 crops as soybean and groundnut, leads to significant differences in projections. It may even reverse the direction of impacts. However, major crops in West Africa are C4 crops, such as maize, millet, and sorghum, for which the CO_2 fertilization effect is less pronounced, so that the positive effect may be overestimated (Roudier et al. 2011).

Schlenker and Lobell (2010) estimated the impacts of climate change on five key African crops, which are among the most important calorie, protein, and fat providers in Sub-Saharan Africa: maize, sorghum, millet, groundnuts, and cassava (rice and wheat are excluded from the study as they are usually irrigated). They estimated country-level yields for the 2050s (2046–65) by obtaining future temperature and precipitation changes from 16 GCMs for the A1B SRES scenario and by applying these future changes to two historical weather data series (1961 to 2000 and 2002, respectively) with regression analysis. In this study, for a 2050s global-mean warming of about 2.2°C above pre-industrial levels the median impacts across Sub-Saharan Africa on the yield of maize, sorghum, millet, groundnut, and cassava[40] are projected to be negative, resulting in aggregate changes of –22 percent, –17 percent, –17 percent, –18 percent, and –8 percent. This important work also estimates the probability of yield reductions, which is useful for risk assessments looking at the tales of the probability distribution of likely future changes. It finds a 95-percent probability that the yield change will be greater than –7 percent for maize, sorghum, millet, and groundnut, with a 5-percent probability that damages will exceed 27 percent for these crops.[41] The results further indicate that the changes in temperature appear likely to have a much stronger impact on crop yield than projected changes in precipitation.

The negative results of this work for sorghum are reinforced by more recent work by Ramirez-Villegas, Jarvis, and Läderach (2011). They find significant negative impacts on sorghum suitability in the western Sahelian region and in Southern Africa in this timeframe, which corresponds to a warming of about 1.5°C above pre-industrial levels globally.[42]

In interpreting the significance and robustness of these results there are a number of important methodological caveats. It should be kept in mind that the methodological approach of Schlenker & Lobell (2010) does not consider the potential fertilization effect of increased CO_2 concentration, which might improve projected results. However, maize, sorghum, and millet are C4 crops with a lower sensitivity to higher levels of CO_2 than other crops. The authors also do not take into account any potential future developments in technology, shifts in the growing season as a potential adaptation measure, or potential changes in rainfall distribution within growing seasons (though temperature has been identified as the major driver of changes in crop yield in this study). Further, a potential disadvantage of the panel data used by Schlenker and Lobell (2010) is that responses to permanent changes in climatic conditions might be different compared to responses to weather shocks, which are measured by the observational data. The estimates presented should be assumed as conservative, but relevant as a comparison of predicted impacts on maize yields to previous studies (Schlenker and Lobell 2010).

Further evidence of the potential for substantial yield declines in Sub-Saharan Africa comes from a different methodological approach applied by Berg et al. (2012). Berg et al. assess the potential for impacts on the crop productivity on one of the most important staple foods, a C4 millet cultivar, in a tropical domain, including Africa and India, for the middle (2020–49) and end of the century (2070–99), compared to the 1970–99 baseline. Across both regions and for all climatic zones considered, the overall decline in productivity of millet was –6 percent (with a range of –29 to +11 percent) for the highest levels of warming by the 2080s. Changes in mean annual yield are consistently negative in the equatorial zones and, to a lesser extent, in the temperate zones under both climate change scenarios and both time horizons.

A robust long-term decline in yield in the order of 16–19 percent is projected for the equatorial fully humid climate zone (which includes the Guinean region of West Africa, central Africa, and most parts of East Africa) under the SRESA1B scenario (3.6°C above pre-industrial levels globally) and the SRESA2 scenario (4.4°C), respectively, for 2100. Although projected changes for the mid-century are smaller, changes are evident and non-negligible, around 7 percent under the A1B – (2.1°C) and –6 percent under the A2 (1.8°C) scenario for the equatorial fully humid zone.

The approach of Berg et al. (2012) accounts for the potential of an atmospheric CO_2 effect on C4 crop productivity for the A2 scenario; the projections show that, across all models, the fertilization effect is limited (between 1.6 percent for the equatorial fully humid zone and 6.8 percent for the arid zone). This finding is consistent with the results of prior studies.

The yield declines by Berg et al. (2012) are likely to be optimistic in the sense that the approach taken is to estimate effects based on assumptions that are not often achieved in practice: for example, optimal crop management is assumed as well as a positive CO_2 fertilization effect. Berg et al. (2012) also point out that the potential to increase yields in Sub-Saharan Africa through improved agricultural practices is substantial and would more than compensate for the potential losses resulting from climate change. When considering annual productivity changes, higher temperatures may facilitate shorter but more frequent crop cycles within a year. If sufficient water is available, no changes in total annual yield would occur, as declining yields per crop cycle are compensated by an increasing number of cycles (Berg et al. 2012). As this much-needed progress has not been seen in past decades, it can be assumed that climate change will represent a serious additional burden for food security in the region.

[40] Note that the model fit for cassava is poor because of its weakly defined growing season.

[41] These are damages projected for the period 2045–2065, compared to the period 1961–2006.

[42] The authors use an empirical model (EcoCrop) and analyze the impact of the SRESA1B scenario driven by 24 general circulation models in the 2030s for sorghum climate suitability.

Reductions in the Length of the Growing Period

A recent study conducted by Thornton et al. (2011) reinforces the emerging picture from the literature of a large risk of substantial declines in crop productivity with increasing warming. This work projects changes in the average length of growing periods across Sub-Saharan Africa, defined as the period in which temperature and moisture conditions are conducive to crop development, the season failure rate, and the climate change impact on specific crops.[43] The projections are relatively robust for large areas of central and eastern Sub-Saharan Africa (20 percent or less variability in climate models) and more uncertain for West Africa and parts of southern Africa (variability of climate models up to 40 percent) and for southwest Africa and the desert in the north (more than 50 percent variability).

The length of the growing period is projected to be reduced by more than 20 percent across the whole region by the 2090s (for a global-mean warming of 5.4°C above pre-industrial levels); the only exceptions are parts of Kenya and Tanzania, where the growing season length may moderately increase by 5–20 percent. The latter is not expected to translate into increased crop production; instead, a reduction of 19 percent is projected for maize and 47 percent for beans, while no (or only a slightly) positive change is projected for pasture grass (Thornton et al. 2011). Over much of the rest of Sub-Saharan Africa, reductions for maize range from –13 to –24 percent, and for beans from –69 to –87 percent, respectively, but the variability among different climate models is larger than the variability for East Africa. The season failure rate is projected to increase across the whole region, except for central Africa. For southern Africa, below the latitude of 15°S, Thornton et al. (2011) project that rainfed agriculture would fail once every two years absent adaptation.

Another risk outlined in the study by Philip K Thornton, Jones, Ericksen, and Challinor (2011) is that areas may transition from arid-semiarid, rainfed, mixed cropland to arid-semiarid rangeland, with consequential loss of cropland production. The authors project that about 5 percent of the area in Sub-Saharan Africa (some 1.2 million km²) is at risk of such a shift in a 5°C world; this would represent a significant loss of cropland.

Relative Resilience of Sequential Cropping Systems

Waha et al. (2012) identify and assess traditional sequential cropping systems[44] in seven Sub-Saharan African countries in terms of their susceptibility to climate change.[45] Compared to single-cropping systems, multiple-cropping systems reduce the risk of complete crop failure and allow for growing several crops in one growing season. Thus, multiple cropping, which is a common indigenous agricultural practice, is a potential adaptation strategy to improve agricultural productivity and food security.

The study by Waha et al. (2012) finds that, depending on the agricultural management system and the respective climate change scenario, projected crop yields averaged over all locations included in the analysis decrease between 6–24 percent for 2070–99. Projections indicate that the decline is lowest for traditional sequential cropping systems (the sequential cropping system most frequently applied in the respective district is composed of two short-growing crop cultivars) as compared to single cropping systems (only one long-growing cultivar) and highest-yielding sequential cropping systems (a sequential cropping system composed of two short-growing crop cultivars with the highest yields).[46] There are significant spatial differences. While maize and wheat-based traditional sequential cropping systems in such countries as Kenya and South Africa might see yield increases of more than 25 percent, traditional sequential cropping systems based on rice in Burkina Faso and on groundnut in Ghana and Cameroon are expected to see declines of at least 25 percent (Waha et al. 2012).

The study indicates that sequential cropping is the preferable option (versus single cropping systems) under changing climatic conditions. However, the survey data show that farmers apply sequential cropping in only 35 percent of the administrative units studied and, in some countries, such as Senegal, Niger, and Ethiopia, growing seasons are too short for sequential cropping. Waha et al. (2012) point out that the high labor intensity of sequential cropping systems, lack of knowledge, and lack of market access are also reasons for not using sequential cropping. Capacity development and improvements in market access have been identified in the scientific literature as likely support mechanisms to promote climate change adaptation.

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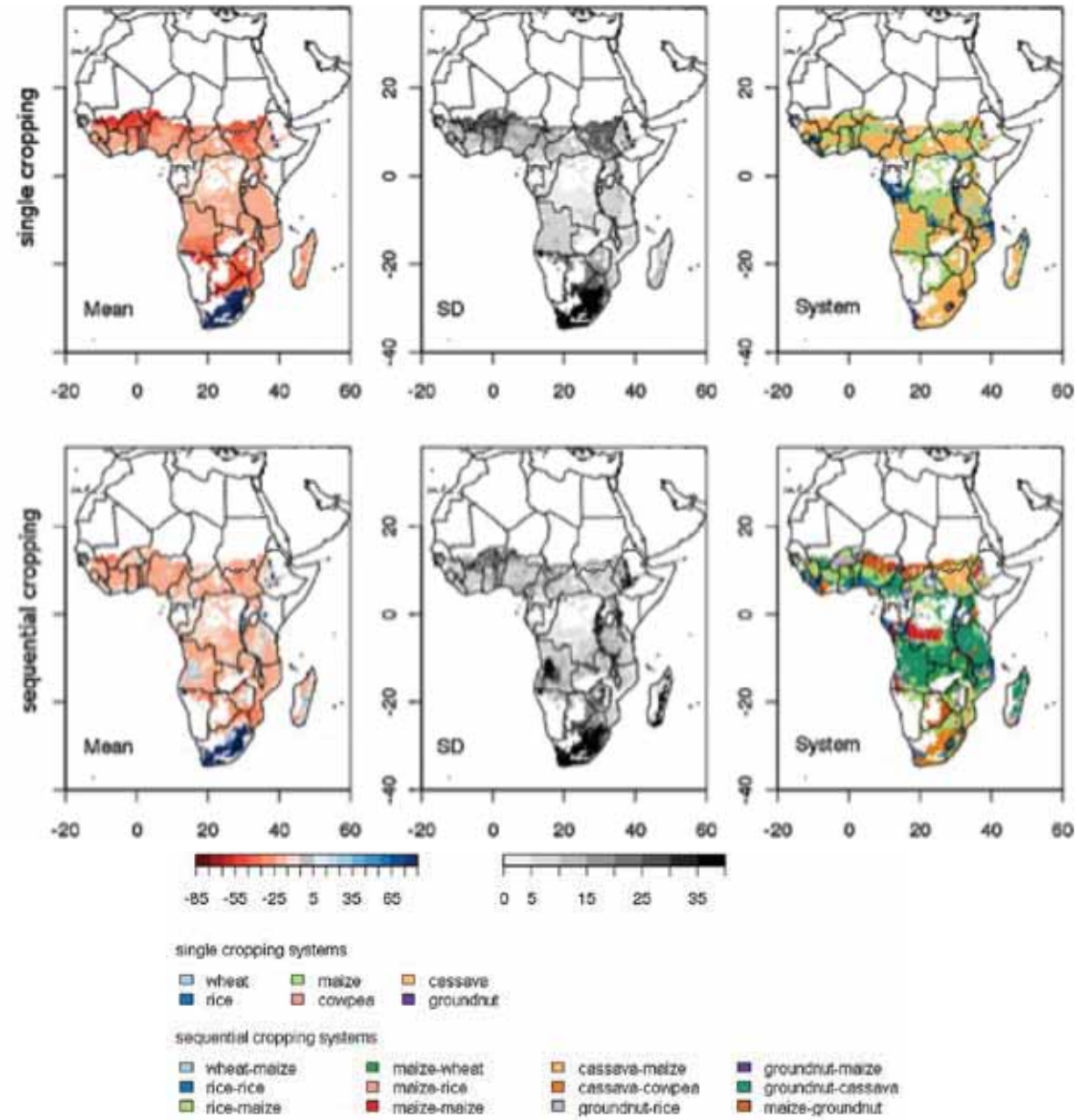
43 The study uses three SRES scenarios, A2, A1B, and B1, and 14 GCMs and increased both the spatial and temporal resolution of the model with historical gridded climate data from WorldClim and daily temperature, precipitation, and solar radiation data by using MarkSim (a third-order Markov rainfall generator). Crop simulations are projected by the models in the decision support system for agro-technology transfer.

44 Waha et al. (2012) define this as "a cropping system with two crops grown on the same field in sequence during one growing season with or without a fallow period. A specific case is double cropping with the same crop grown twice on the field." See their Table 1 for definitions of different systems.

45 For their assessment, Waha et al. (2012) use historical climate data for the 30-year period 1971–2000 and climate projections for 2070–2099 generated by three GCMs (MPI-ECHAM5, UKMO-HadCM3, and NCAR-CCSM3) for the A2 SRES emissions scenario (global-mean warming of 3°C for 2070–2099 above pre-industrial levels). Atmospheric CO_2 concentrations are kept constant in the study. Growing periods and different cropping systems are identified from a household survey dataset, encompassing almost 8,700 households. To simulate yields of different crop cultivars, a process-based global vegetation model (LPJmL) is applied.

46 On average, single cropping systems only attain 38–54 percent of crop calorific yields of sequential cropping systems). While the highest-yielding sequential cropping systems do obtain higher absolute yields, traditional sequential cropping systems are more resilient to climate change impacts. Further, the results indicate that adjusting the sowing dates to the start of the main rainy season is beneficial, as mean future crop yields are higher than in corresponding scenarios where sowing dates are kept constant with only few exceptions. Exceptions may be explained by the fact that temperature and precipitation are the limiting factors in the respective region, which is especially the case in mountainous areas (Waha et al. 2012)

Figure 3.15: Mean crop yield changes (percent) in 2070–2099 compared to 1971–2000 with corresponding standard deviations (percent) in six single cropping systems (upper panel) and thirteen sequential cropping systems (lower panel)



Maps in the last column show the systems with lowest crop yield declines or highest crop yields increases. White areas in Sub-Saharan Africa are excluded because the crop area is smaller than 0.001 percent of the grid cell area or the growing season length is less than five months. The high standard deviation in Southern Africa is mainly determined by the large difference in climate projections.

Source: Waha et al. (2012).

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Shifting Crop Climates

A different perspective on risks to crop production can be gained by looking at the changes in land area suitable for different kinds of crops under climate change. This method does not specifically calculate changes to crop production. It can show the changes in regional distribution of suitable crop areas, as well as the emergence of novel climates that are quite dissimilar from the climatic zones in which crops are presently grown. The latter is also an indicator of risk as it implies a need to adjust agricultural practices, crop cultivars, and policies to new climatic regimes.

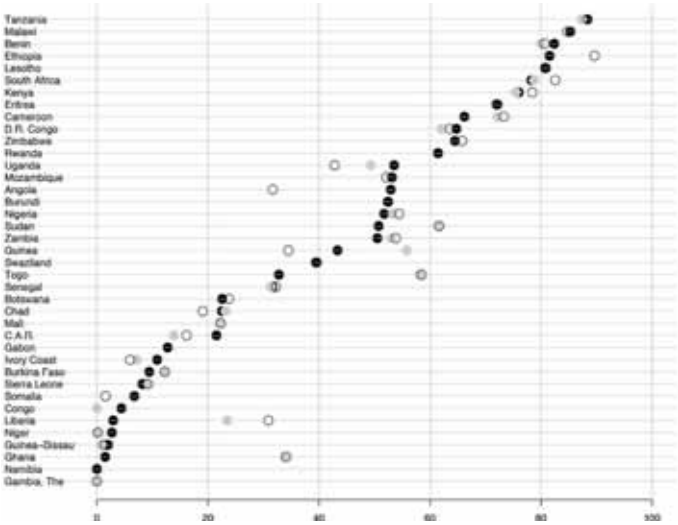
Applying this framework, Burke, Lobell, and Guarino (2009) estimated shifts in crop climates for maize, millet, and sorghum. They find that the majority of Sub-Saharan African countries are projected to be characterized by novel climatic conditions in more than half of the current crop areas by 2050 (see below), for a warming of about 2.1°C above pre-industrial levels.[47]

Increasing warming leads to greater fractions of cropping area being subject to novel climatic conditions. For specific crops, Burke et al. (2009) estimate that the growing season temperature for any given maize crop area in Africa will overlap[48] on average 58 percent with observations of historical conditions by 2025 (corresponding approximately to 1.5°C above pre-industrial levels), 14 percent by 2050 (2.1°C), and only 3 percent by 2075 (3°C). For millet, the projected overlaps are 54 percent, 12 percent, and 2 percent, respectively; for sorghum 57 percent, 15 percent, and 3 percent. Departures from historical precipitation conditions are significantly smaller than those for temperature (Burke et al. 2009).

In a second step in this analysis, present and projected crop climates are compared within and among countries in order to determine to what extent the future climate already exists in the same or in another country on the continent. Diminishing climate overlap means that current cultivars would become progressively less suitable for the crop areas.

If, as this study suggests, some African countries (mostly in the Sahel) could as early as 2050 have novel climates with few analogs for any crop, it might not be possible to transfer suitable cultivars from elsewhere in the world. Formal breeding of improved crop varieties probably has an important role to play in adaptation. However, current breeding programs are likely to be insufficient for adapting to the severe shifts in crop climates projected and, given the quick changes of growing season temperatures, a severe time lag for the development of suitable crops can be expected (Burke et al. 2009).

Figure 3.16: Percentage overlap between the current (1993–2002 average) distribution of growing season temperatures as recorded within a country and the simulated 2050 distribution of temperatures in the same country



In areas of little overlap, current cultivars become less suitable for the current crop areas as climatic conditions shift. Black: maize; grey: millet; white: sorghum.

Source: Burke et al. (2009).

Reprinted from Global Environmental Change, 19, Burke et al., Shifts in African crop climates by 2050, and the implications for crop improvement and genetic resources conversation, 317-325, Copyright (2009), with permission from Elsevier. Further permission required for reuse.

Implications for Food Security

A recent assessment by Nelson and colleagues is a fully integrated attempt to estimate global crop production consequences of climate change. Nelson et al. (2009, 2010)[49] estimate the direct effects of climate change on the production of different crops with and without the effect of CO_2 fertilization under a global-mean warming of about 1.8–2°C above pre-industrial levels by 2050. Without climate change, crop production is projected to increase significantly by 2050; however, the population is projected to nearly triple by that time. Consequently, per capita cereal production is projected to be about 10 percent lower in 2050 than in 2000. When food trade is taken into account, the net effect is a reduction in food availability per capita (measured as calories per capita) by about 15 percent compared to the availability in 2000. There is also an associated projected increase in malnutrition in children under the age of five. Without climate change, the number of children with malnutrition is projected to increase from 33 million to 42 million; climate change adds a further 10 million children by 2050.

In summary, there is substantial evidence that climate change impacts may have detrimental effects on agricultural yields in

47 Projections of temperature and precipitation change are derived from the 18 climate models running the A1B scenario, which lead to temperatures approximately 1.6°C in 2050 above 1980–99 temperatures globally (2.1°C above pre-industrial levels). The projections are based on a comparison of historical (1960–2002) climatic conditions at a specific location, crop area, and months constituting the growing season with the projected climate for that location for different time slices.

48 An overlap occurs when land on which a crop is presently growing overlaps with the land area projected to be suitable for growing that crop type at a later time under a changed climate. In other words, the overlap area is an area where the crop type is presently grown and which continues to be suitable under a changed climate. A present crop growing region that is not in an overlap area is one in which the future climate is projected to be unsuitable for that crop type.

49 The estimates are based on the global agriculture supply and demand model IMPACT 2009, which is linked to the biophysical crop model DSSAT. Climate change projections are based on the NCAR and CSIRO models and the A2 SRES emissions scenario leading to a global mean warming of about 2.0°C above pre-industrial levels by 2050 (Nelson et al. 2009, 2010). To capture the uncertainty in the CO_2 fertilization effect, simulations are conducted at two levels of atmospheric CO_2 in 2050—the year 2000 level of 369 ppm (called the no-CO_2 fertilization scenario) and the projected level in 2050 of 532 ppm under the SRES A2 scenario (termed the with-CO_2 fertilization scenario).

Table 3.3: Sub-Saharan Africa crop production projections

	Crop Production (Year 2000 mmt)	Crop as % of Total 2000	Crop Production 2050 – No Climate Change (mmt)	Crop Production 2050 – with Climate Change and no CO_2 Fertilization Effect (mmt)
Rice	8	9%	18	16
Wheat	5	6%	11	7
Maize	37	46%	54	49
Millet	13	16%	48	45
Sorghum	19	23%	60	59
Total	81	100%	192	176
kg/capita	122		111	101
Calories per capita	2316		2452	1928
Total population (million)	666		1,732	1,732
Net cereal exports (mmt)	–23		–65	–29
Value of net cereal trade (million $)	–$2,995		–$12,870	–$11,034
Malnutrition (millions of children under 5)	33		42	52

Source: Nelson et al. (2010).Based on the global agriculture supply and demand model IMPACT 2009, which is linked to the biophysical crop model DSSAT. Climate change projections are based on the NCAR and the CSIRO models and the A2 SRES emissions scenario leading to a global-mean warming of about 2.0°C above pre-industrial levels by 2050 (see footnote 48).

Sub-Saharan Africa. Further, potential reductions in yields have to be seen in view of future population growth in Africa and the fact that agricultural productivity must actually grow in the region in order to improve and ensure food security (Berg et al. 2012; Müller 2013). There is still great uncertainty in model projections, mainly because of different assumptions and simplifications underlying the diverse methodological approaches but also because of uncertainty in climate projections, especially projections of precipitation.

Roudier et al. (2011) highlighted important general sources of uncertainty: the uncertainties about the response of different crops to changing climatic conditions, the coupling of climate and crop models, which are regularly based on different temporal and spatial scales and require downscaling of data, and assumptions about future adaptation. Furthermore, different cultivars, which are not specified in most of the studies, may respond differently to changing climatic conditions; this may partly explain the broad range of projections. The majority of studies included in the review of Roudier et al. (2011) do not explicitly take adaptation into account.

Despite the broad range of projections, robust overall conclusions on the risks to agricultural production in Sub-Saharan Africa can be drawn based on several lines of evidence:

- The projections for crop yields in Sub-Saharan Africa agree that changing climatic conditions, in particular higher temperatures and heat extremes, pose a severe risk to agriculture in the region. The risk is greater where rainfall declines.
- High temperature sensitivity thresholds for crops have been observed. Where such thresholds are exceeded, reductions in yield may result. With temperature extremes projected to grow, there is a clear risk of large negative effects.
- Reductions in growing season length are projected in many regions.
- Large shifts in the area suitable for present crop cultivars are projected.

The magnitude of the CO_2 fertilization effect remains uncertain and, for many African crops, appears to be weak.

While there is also evidence that, with agricultural development and improvement in management techniques, the potential to increase yields relative to current agricultural productivity is substantial, it is also clear that such improvements have been difficult to achieve. Adaptation and general improvements in current agricultural management techniques are key for short and long-term improvements in yield productivity. There would be mounting challenges in the next few decades, however, as some countries in Sub-Saharan Africa may even see novel crop climatic conditions develop quickly with few or no analogs for current crop cultivars.

The Impacts of Food Production Declines on Poverty

Agricultural production shocks have led to food price increases in the past, and particular types of households have been found to be more affected than others by food price increases because of climate stressors and other economic factors. Kumar and Quisumbing (2011), for example, found that rural female-headed

households are particularly vulnerable to food price increases. Hertel, Burke, and Lobell (2010) show that, by 2030, poverty implications because of food price rises in response to productivity shocks have the strongest adverse effects on non-agricultural, self-employed households and urban households, with poverty increases by up to one third in Malawi, Uganda, and Zambia. On the contrary, in some exporting regions (for example, Australia, New Zealand, and Brazil) aggregate trade gains would outweigh the negative effect of direct crop losses. Overall, Hertel et al. (2010) expect global trade to shrink, which leads to an overall efficiency loss and climate change impacts on crop production are projected to decrease global welfare by $123 billion, which would be the equivalent of approximately 18 percent of the global crops sector GDP. In contrast to other regions assessed in this study, no poverty reduction for any stratum of society is projected in most countries in Sub-Saharan Africa when assuming a low or medium agricultural productivity scenario.

Similarly, in a scenario approaching 3.5°C above pre-industrial levels by the end of the century, Ahmed, Diffenbaugh, and Hertel (2009) project that urban wage-labor-dependent populations across the developing world may be most affected by once-in-30-year climate extremes, with an average increase of 30 percent in poverty compared to the base period. This study finds that the poverty rate for this group in Malawi, for example, is estimated to as much as double following a once-in-30-year climate event, compared to an average increase in poverty of 9.2 percent among rural agricultural households. The work by Thurlow, Zhu, and Diao (2012) is consistent with this claim that urban food security is highly sensitive to climatic factors; it indicates that two-fifths of additional poverty caused by climate variability is in urban areas.

Of a sample of 16 countries across Latin America, Asia, and Africa examined in a study by Ahmed et al. (2009), the largest "poverty responses" to climate shocks were observed in Africa. Zambia's national poverty rate, for example, was found to have increased by 7.5 percent over 1991–92, classified as a severe drought year, and 2.4 percent over 2006–07, classified as a severe flood year (Thurlow et al. 2012). (See Box 3.3).

Livestock

Climate change is expected to have impacts on livestock production in Sub-Saharan Africa, which would have implications for the many households that are involved in some way in the livestock industry across the Sub-Saharan African region (see Figure 3.17). These households can rely on livestock for food (such as meat and milk and other dairy products), animal products (such as leather), income, or insurance against crop failure (Seo and Mendelsohn 2007). In Botswana, pastoral agriculture represents the chief source of livelihood for over 40 percent of the nation's residents, with cattle representing an important source of status and well-being for the vast majority of Kalahari residents (Dougill, Fraser, and Mark 2010).

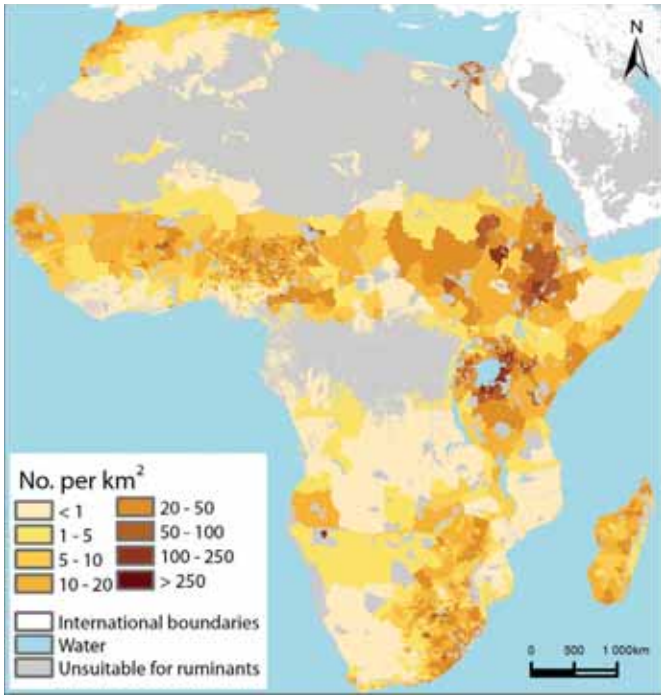
Box 3.3: Agricultural Production Declines and GDP

Several historical case studies have identified a connection between rainfall extremes and reduced GDP because of reduced agricultural yields. Kenya suffered annual damages of 10–16 percent of GDP because of flooding associated with the El Niño in 1997–98 and the La Niña drought 1998–2000. About 88 percent of flood losses were incurred in the transport sector and 84 percent of drought losses in hydropower and industrial production (World Bank 2004, cited in Brown 2011). Barrios et al. (2008) provide evidence that both rainfall and temperature have significantly contributed to poor economic growth in Africa.

Dell, Jones, and Olken (2012) show that historical temperature increases have had substantial negative effects on agricultural value added in developing countries. The authors find that a 1°C higher temperature in developing countries is associated with 2.66-percent lower growth in agricultural output. For developed countries, the temperature effect is substantially smaller and not statistically significant (0.22 percent lower growth in agricultural output for each additional 1°C of temperature). These results support Jones and Olken (2010), who also found that 1°C higher temperature in developing countries negatively affects agricultural production. Dell and Jones (2012) in turn estimate that, in poor countries, each degree of warming can reduce economic growth by an average of 1.3 percentage points (Dell and Jones 2012) and export growth by 2.0–5.6 percentage points (Jones and Olken 2010). Dell and Jones (2012) expect that (at least in one scenario studied) this temperature effect may be particularly pronounced in Sub-Saharan Africa.

While climate change poses a long-term risk to crop production and ecosystem services, Brown, Meeks, Hunu, and Yu (2011) present evidence that high levels of hydroclimatic variability, especially where it leads to drought, tends to have the most significant influence, with increasing poverty counts strongly associated (99 percent) with severe drought. Based on regression analysis and an index of rainfall extremes and taking into account GDP growth and agricultural production, Brown et al. (2011) find a significant and negative correlation between drought and GDP growth per capita: a 1-percent increase in the area of a Sub-Saharan African country experiencing moderate drought correlates with a 2–4 percent decrease in GDP growth. Agricultural value added (meaning the percentage of GDP from agriculture, including forestry, fishing, and hunting) and poverty headcount at $1/day were also observed to be significantly and negatively affected. This is consistent with evidence at the household scale.

Figure 3.17: Observed cattle density in year 2000



Source: Adapted from Robinson et al. (2007) with updated data, with permission from Veterinaria Italiana. Further permission required for reuse.

Regional climate change is found to be the largest threat to the economic viability of the pastoral food system (Dougill et al. 2010). However, pastoral systems have largely been ignored in the literature on climate impacts, which has a bias toward the effects of climate change on crop production (Dougill et al. 2010; Thornton, Van de Steeg, Notenbaert, and Herrero 2009). Less is known, therefore, about the effects of climate change on livestock (Seo and Mendelsohn 2007).

Climate change is expected to affect livestock in a many ways, including through changing means and variability of temperature and precipitation (Thornton et al. 2009), thereby potentially placing livelihoods dependent on the sector at risk (Box 3.4). The savannas and grasslands in which pastoral societies are often located are typically characterized by high variability in temperature and precipitation (Sallu, Twyman, and Stringer 2010). The pastoral systems of the drylands of the Sahel depend highly on natural resources, such as pasture, fodder, forest products, and water, all of which are directly affected by climate variability (Djoudi, Brockhaus, and Locatelli 2011). Sallu et al. (2010) note that historical drought events in the drylands of Botswana have reduced the diversity and productivity of vegetation, thereby limiting available grazing and fodder resources.

A study of pastoral farmers' responses to climate variability in the Sahel, Barbier, Yacoumba, Karambiri, Zorome, and Some (2009) reports that farmers are more interested in the specific characteristics of a rainy season, not necessarily total rainfall, reflecting the finding in some of the literature on crops about the importance of the temporal distribution of rainfall. Increased unpredictability of rainfall poses a threat to livestock (Sallu et al. 2010). Livestock is vulnerable to drought, particularly where it depends on local biomass production (Masike and Ulrich 2008), with a strong correlation between drought and animal death (Thornton et al. 2009).

Specific factors that are expected to affect livestock include the following:

- The quantity and quality of feeds: through changes in herbage because of temperature, water, and CO_2 concentration, and species composition of pastures, which in turn can affect production quantity and nutrient availability for animals and quality.
- Heat stress: altering feed intake, mortality, growth, reproduction, maintenance, and production).
- Livestock diseases, both due to change to diseases themselves and the spread of disease through flooding.
- Water availability: especially considering that water consumption increases with warmer weather.
- Biodiversity: the genetic variety of domestic animals is being eroded as some breeds die out, while the livestock sector is a significant driver of habitat and landscape change and can itself cause biodiversity loss. (Thornton et al. 2009; Thornton and Gerber 2010).

The factors listed above may interact in complex ways; for example, relationships between livestock and water resources or biodiversity can be two-way (Thornton et al. 2009). The ways in which climate change impacts interact with other drivers of change (such as population increases, land use changes, urbanization, or increases in demand for livestock) need to be considered (Thornton et al. 2009). Available rangeland may be

Box 3.4: Livestock Vulnerability to Droughts and Flooding

The impacts of climatic conditions on livestock can be severe. As a result of droughts between 1995 and 1997, pastoralists in southern Ethiopia lost 46 percent of their cattle and 41 percent of their sheep and goats (FAO 2008). Damage to livestock stocks by flooding in the 1990s has also been recorded in the Horn of Africa, with mortality rates as high as 77 percent (Little, Mahmoud, and Coppock 2001).

reduced by human influences, including moves toward increased biofuel cultivation (Morton 2012), veterinary fencing (Sallu et al. 2010), increasing competition for land (Sallu et al. 2010), and land degradation. Thorny bush encroachment, for example, is brought about by land degradation (Dougill et al. 2010), as well as rising atmospheric CO_2 concentrations ((Higgins and Scheiter 2012; see also Chapter 3 on "Agricultural Production"). Finally, the implications of climate change impacts on livestock for the human populations that depend on pastoral systems are equally complex. Deleterious effects on livestock health may directly affect food and economic security and human health where populations depend on the consumption or sale of animals and their products (Caminade et al. 2011; Anyamba et al. 2010). This issue is touched on briefly in Chapter 3 on "Human Impacts" in the context of Rift Valley fever.

In some cases, less specialized rural households have been observed to display higher resilience to environmental shocks. In the drylands of Botswana, households that previously had specialized in livestock breeding were forced to diversify their income strategy and take up hunting and crop farming (Sallu et al. 2010); this may be seen as a form of adaptation. However, climate change impacts are expected to affect not only livestock production but also all alternative means of subsistence, such as crop farming and harvesting wild animals and plant products. Droughts in Botswana, for example, have resulted in declines in wild animal populations valued as hunting prey, wild herbs and fruits, wild medicines, and plant-based materials used for building construction and crafts (Sallu et al. 2010). It would appear, therefore, that diversification is not necessarily always a solution to dwindling agricultural production.

Furthermore, in some instances, pastoralists—particularly nomadic pastoralists—appear to be less vulnerable than crop farmers, as they may be afforded some flexibility to seek out water and feed. Mwang'ombe et al. (2011) found that extreme weather conditions in Kenya appeared to affect the agro-pastoralists more than the pastoralists. Corroborating this, Thornton et al. (2009) describe livestock as "a much better hedge" against extreme weather events, such as heat and drought, despite their complex vulnerability. In fact, in southern Africa, reductions in growing season length and increased rainfall variability is causing some farmers to switch from mixed crop-livestock systems to rangeland-based systems as farmers find growing crops too risky in these marginal areas. These conversions are not, however, without their own risks—among them, animal feed shortages in the dry season (P. K. Thornton et al. 2009). In Sahelian Burkina Faso, for example, farmers have identified forage scarcity as a factor preventing expansion of animal production (Barbier et al. 2009). Furthermore, pastoralists who rely at least in part on commercial feed may be affected by changes in food prices (Morton 2012).

Projected Impacts on Livestock

Butt, McCarl, Angerer, Dyke, and Stuth (2005) present projections of climate change impacts on forage yields and livestock on a national scale. They compare 2030 to the 1960–91 period using two global circulation models and a range of biophysical models. For local temperature increases of 1–2.5°C, forage yield change in the Sikasso region in Mali is projected to be –5 to –36 percent, with variation in magnitude across parts of the region and the models. The livestock considered are cattle, sheep, and goats; these are affected through their maintenance requirements and loss of appetite as a result of thermal stress. Food intake for all livestock decreases. The rate of cattle weight gain is found to be –13.6 to –15.7 percent, while the rate of weight gain does not change for sheep and goats. The CO_2 fertilization effect is accounted for in this study.

Decreased rainfall in the Sahelian Ferlo region of northern Senegal has been found to be associated with decreases in optimal stocking density, which can lead to lower incomes for affected farmers, especially if combined with increased rainfall variability. A 15-percent decrease in rainfall, for example, in combination with a 20-percent increase in rainfall variability, would lead to a 30-percent reduction in the optimum stocking density. Livestock keeping is the main economic activity and essential to local food security in this region (Hein, Metzger, and Leemans 2009).

In contrast with these findings, Seo and Mendelsohn (2007) project precipitation decreases to negatively affect livestock revenues. They analyze the sensitivity of livestock revenue to higher temperatures and increased precipitation across nine Sub-Saharan African countries (Ethiopia, Ghana, Niger, Senegal, Zambia, Cameroon, Kenya, Burkina Faso, and South Africa) and Egypt. This is because although precipitation increases the productivity of grasslands it also leads to the encroachment of forests (see Chapter 3 on "Terrestrial Ecosystems") and aids the transmission of livestock diseases.

Seo and Mendelsohn (2007) analyze large and small farms separately as they function in different ways. Small farms use livestock for animal power, as a meat supply, and, occasionally for sale; large farms produce livestock for sale. The study finds that higher temperatures reduce both the size of the stock and the net value per stock for large farms but not for small farms. It is suggested that the higher vulnerability of larger farms may be due to their reliance on breeds, such as beef cattle, that are less suited to extreme temperatures, which smaller farms tends to be able to substitute with species, such as goats, that can tolerate higher temperatures. Interestingly, the discrepancy in the vulnerability of large and small farms observed with temperature increases is not as marked when it comes to precipitation impacts; here, both large and small farms are considered vulnerable.

The apparent inconsistencies in the above findings with respect to how changes in precipitation is projected to affect livestock yield

and the relative vulnerability of large and small farms underline the inadequacy of the current understanding of the impacts that climate change may have on pastoral systems. The impacts on forage yields and livestock sensitivity to high temperatures and associated diseases, however, do highlight the sector´s vulnerability to climate change.

Projected Ecosystem Changes

The impacts on livestock described in the previous section are closely tied to changes in natural ecosystems, as changes in the species composition of pastures affect livestock productivity (Thornton et al. 2009; Seo and Mendelsohn 2007). Processes, such as woody plant encroachment, threaten the carrying capacity of grazing land (Ward 2005). Thus, food production may be affected by climate-driven biome shifts. This is a particular risk to aquatic systems, as will be discussed below.

Africa's tourism industry highly depends on the natural environment; it therefore is also exposed to the risks associated with climate change. It is currently growing at a rate of 5.9 percent compared to a global average of 3.3 percent (Nyong 2009). Adverse impacts on tourist attractions, such as coral reefs and other areas of natural beauty, may weaken the tourism industry in Sub-Saharan Africa. It is believed that bleaching of coral reefs in the Indian Ocean and Red Sea has already led to a loss of revenue from the tourism sector (Unmüßig and Cramer 2008). Likewise, the glacier on Mount Kilimanjaro, a major attraction in Tanzania, is rapidly disappearing (Unmüßig and Cramer 2008).

Terrestrial Ecosystems

Sub-Saharan Africa encompasses a wide variety of biomes, including evergreen forests along the equator bordering on forest transitions and mosaics south and north further extending into woodlands and bushland thickets and semi-arid vegetation types. Grasslands and shrublands are commonly interspersed by patches of forest (W J Bond, Woodward, and Midgley 2005).

Reviewing the literature on ecosystem and biodiversity impacts in southern Africa, Midgley and Thuiller (2010) note the high vulnerability of savanna vegetation to climate change. Changes in atmospheric CO_2 concentration are expected to lead to changes in species composition in a given area (Higgins and Scheiter 2012). In fact, during the last decades, the encroachment of woody plants has already affected savannas (Buitenwerf, Bond, Stevens, and Trollope 2012; Ward 2005). The latter are often unpalatable to domestic livestock (Ward 2005).

Grasslands and savannas up to 30° north and south of the equator are typically dominated by heat tolerant C4 grasses and mixed tree-C4 grass systems with varying degrees of tree or shrub cover (Bond et al. 2005), where the absence of trees demarks grasslands in contrast to savannas. Forest trees, in turn, use the C3 pathway, which selects for low temperatures and high CO_2 concentrations (Higgins and Scheiter 2012). However, William J. Bond and Parr (2010) classify as savannas those forests with a C4 grassy understory that burn frequently. At a global scale, the rainfall range for C4 grassy biomes ranges from approximately 200 mm mean annual precipitation (MAP) to 3000 mm MAP, with tree patches associated with higher precipitation (Bond and Parr 2010). According to Lehmann, Archibald, Hoffmann, and Bond (2011), however, the wettest African savanna experiences 1750 mm MAP.

The Role of Fire

Fires contribute to the stability of these biomes through a positive feedback mechanism, effectively blocking the conversion of savannas to forests (Beckage, Platt, and Gross 2009). C4 grasses are heat-tolerant and shade-intolerant, such that a closed tree canopy would hinder their growth. Efficient growth of C4 plants at high growing season temperatures allows for accumulation of highly flammable material, increasing the likelihood of fire that in turn hinders the encroachment of woody plant cover. Fire-promoting ground cover is absent in the humid microclimate of closed canopy woods, further stabilizing these systems (Lehmann et al. 2011). A further factor promoting the wider spread of savannas in Africa compared to other continents is the prevalence of mega-herbivores, as browse disturbance reduces woody plant cover in arid regions (Lehmann et al. 2011). However, grazing and trampling simultaneously reduce fuel loads and promote tree growth (Wigley, Bond, and Hoffman 2010).

While short-term responses of and biological activity in African biomes are typically driven by water availability and fire regimes, in the longer term African biomes appear highly sensitive to changes in atmospheric CO_2 concentrations (Midgley and Thuiller 2010). Increases in CO_2 concentrations are expected to favor C3 trees over C4 grasses, as at leaf-level the fertilization effect overrides the temperature effect; this shifts the competitive advantage away from heat tolerant C4 plants, resulting in a risk of abrupt vegetation shifts at the local level (Higgins and Scheiter 2012). The effect may be further enhanced by a positive feedback loop. Trees are expected to accumulate enough biomass under elevated atmospheric CO_2 concentrations to recover from fires (Kgope, Bond, and Midgley 2009). This might shade out C4 grass production, contributing to lower severity of fires and further promoting tree growth. Fire exclusion experiments show that biome shifts associated with the processes above can occur on relatively short time scales. High rainfall savannas can be replaced by forests in less than 20–30 years (Bond and Parr 2010).

The Role of Changing Land Uses

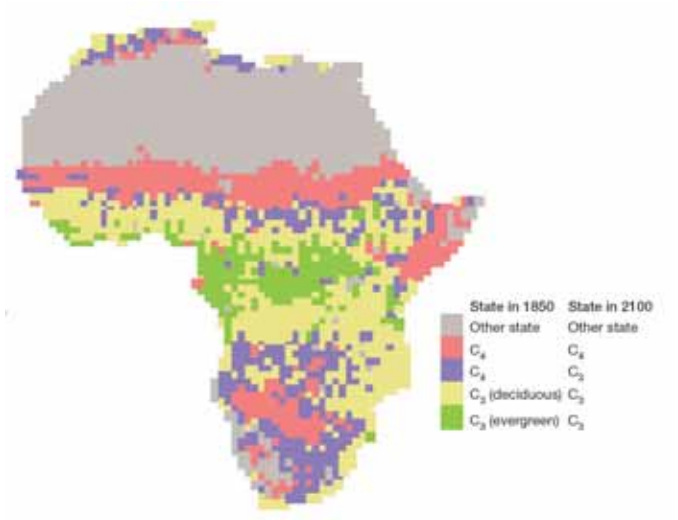
In order to determine to what extent tree cover is affected by land-use practices (as opposed to global processes, such as climate change), Wigley et al. (2010) compared woody increases in three neighboring areas in the Hlabisa district, KwaZulu-Natal, South Africa, in 1937, 1960, and 2004. Overall, they observe the prevalence of a global driver over local factors. Different management of the otherwise comparable study sites did not yield predicted outcomes, where conservation and communal sites was expected to result in a decrease of tree cover (because of the prevalence of browsers, frequent fires, and wood harvesting in the latter). Instead, total tree cover increased from 14 percent in 1937 to 58 percent in 2004 in the conservation area, and from 6 percent to 25 percent in the communal farming area. The third area, used for commercial ranching that is associated with high cattle and low browser density and suppressed fires, experienced an increase from 3 percent to 50 percent. These results lead Wigley et al. (2010) to conclude that either increased CO_2 or atmospheric nitrogen deposition drove the observed changes during the study period. Kgope et al. (2009) further corroborated this result by conducting an open-top chamber experiment with two African acacia species and a common C4 savanna grass under different CO_2 levels (150, 240, 387, 517, 709, and 995 ppm). Fire effects on seedling establishment were simulated by clipping the plants after the first growing season. Results show that because of increased root reserves under elevated CO_2 concentrations, trees should be more resistant to fire than at pre-industrial levels, such that fires are less likely to kill seedlings and effectively control tree growth. In this experiment, CO_2 sensitivity was observed to be highest at sub-ambient and ambient CO_2 levels and decreasing with above-present levels.

Projected Vegetation Shifts

To assess future potential vegetation shifts in grassland, savanna, and forest formation based on the changing competitive advantages of C3 and C4 vegetation types, Higgins and Scheiter (2012) applied a dynamic vegetation model under the SRES A1B scenario (3.5°C above pre-industrial levels). Their results yielded marked shifts in biomes in 2100 (compared to 1850) in which parts of deserts replace grasslands, grasslands are replaced by savannas and woodlands, and savannas are replaced by forests. The most pronounced change appears in savannas, which in this study are projected to decrease from 23 percent to 14 percent of total land coverage. The overall area dominated by C3 vegetation (woodlands, deciduous forests, and evergreen forests) increases from 31 percent to 47 percent in this projection (see Figure 3.18).

The rate of temperature change appears to influence the timing of the transition, as rapid temperature shifts allow for competitive advantage of C4 plants. Furthermore, with rising CO_2 concentration, C4 vegetation is more likely to occur in regions with low rainfall (less than 250 mm). It is essential to note that rainfall was kept constant in this projection.

Figure 3.18: Projections of transitions from C4-dominated vegetation cover to C3-dominated vegetation for SRES A1B, in which GMT increases by 2.8°C above 1980–99



Source: Higgins & Scheiter (2012).

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Risks to Forests

Although the above projections indicate that climate-change-induced vegetation shifts would often favor forests, forests are also at risk from changes in temperature and precipitation. Bond and Parr (2010) note that if extreme weather conditions increase because of climate change, forests may shrink at the expense of grasses (Box 3.5).

In their literature review, C. A. Allen et al. (2010) note the increasing number of instances where climate-related tree mortality has been observed, spanning a wide array of forest ecosystems (including savannas). Despite insufficient coverage and comparability between studies precluding the detection of global trends in forest dieback attributable to climate change, observations are consistent with the present understanding of responses to climatic factors (particularly drought) influencing tree mortality. These climatic factors include carbon starvation because of water stress leading to metabolic limitations, often coinciding with increases in parasitic insects and fungi resulting from warmer temperatures. Furthermore, warmer winters

Box 3.5: Tree Mortality in the Sahel

At a regional scale, Gonzalez, Tucker, and Sy (2012) observe a 20-percent decline in tree density in the western Sahel and a significant decline in species richness across the Sahel in the last half of the 20th century. Based on an econometric model and field observations, they attribute the observed trend to changes in temperature and rainfall variability, which in turn are attributable to climate change. Furthermore, available data on tree density at Njóobéen Mbataar (Senegal) and precipitation data suggests a threshold of resilience to drought stress for Sudan and Guinean tree species at approximately one standard deviation below the long-term average five out of six years (Gonzalez et al. 2012).

can lead to elevated respiration at the expense of stored carbon, again posing the risk of carbon starvation (McDowell et al. 2008). These mechanisms and their interdependencies are likely to be amplified because of climate change (McDowell et al. 2011). Despite persistent uncertainties pertaining to these mechanisms and thresholds marking tree mortality, C. A. Allen et al. (2010) conclude that increases in extreme droughts and temperatures pose risks of broad-scale climate-induced tree mortality. According to Allen et al. (2010), the potential for abrupt responses at the local level, once climate exceeds physiological thresholds, qualifies this as a tipping point of non-linear behavior (Lenton et al. 2008).

In light of the opposing trends described above, William J. Bond & Parr (2010) conclude that "it is hard to predict what the future holds for forests vs. grassy biomes given these contrasting threats." Thus, whether drought-related tree feedback may prevail over CO_2- stimulated woody encroachment, remains unclear.

Aquatic Ecosystems

Climate change is expected to adversely affect freshwater as well as marine systems (Ndebele-Murisa, Musil, and Raitt2010; Cheung et al. 2010including declines in key protein sources and reduced income generation because of decreasing fish catches (Badjeck, Allison, Halls, and Dulvy 2010). Non-climatic environmental problems already place stress on ecosystem services. For example, overfishing, industrial pollution, and sedimentation have degraded water resources, such as Lake Victoria (Hecky, Mugidde, Ramlal, Talbot, and Kling 2010), reducing fish catches.

Freshwater Ecosystems

Reviewing the literature on changes in productivity in African lakes, Mzime R. Ndebele-Murisa et al. (2010) note that while these lakes are under stress from human usage, much of the changes observed are attributable to years of drought. Associated reductions in river inflow can contribute to a decrease in nutrient concentrations. Increasing water temperatures and higher evaporation further lead to stronger thermal stratification, further inhibiting primary productivity as waters do not mix and nutrients in the surface layers are depleted. Similarly, Mzime R. Ndebele-Murisa, Mashonjowa, and Hill (2011) state that temperature is an important driver of fish productivity in Lake Kariba, Zimbabwe, and best explains observed declines in *Kapenta* fishery yields.

Inland freshwater wetlands are another freshwater ecosystem likely to be affected by climate change. One such wetland is the Sudd in Sahelian South Sudan, which provides a rich fishery, flood recession agriculture, grazing for livestock, handcrafts, and building materials, and plant and animal products (including for medicinal purposes). The Sudd, which is fed by the White Nile originating in the Great Lakes region in East Africa, could be depleted by reduced flows resulting from changes in precipitation patterns (Mitchell 2013).

Furthermore, increasing freshwater demand in urban areas of large river basins may lead to reducing river flows, which may become insufficient to maintain ecological production; this means that freshwater fish populations may be impacted (McDonald et al. 2011).

Ocean Ecosystems

Climate-change related changes in ocean conditions can have significant effects on ocean ecosystems. Factors influencing ocean conditions include increases in water temperature, precipitation, levels of salinity, wind velocity, wave action, sea-level rise, and extreme weather events. Ocean acidification, which is associated with rising atmospheric CO_2 concentrations, is another factor and is discussed in Chapter 4 under "Projected Impacts on Coral Reefs" in the context of coral reef degradation. Ocean ecosystems are expected to respond to altered ocean conditions with changes in primary productivity, species distribution, and food web structure (Cheung et al. 2010). Theory and empirical studies suggest a typical shift of ocean ecosystems toward higher latitudes and deeper waters in response to such changes (Cheung et al. 2010a). However, there is also an associated risk that some species and even whole ecosystems will be placed at risk of extinction (Drinkwater et al. 2010).

Taking into account changes in sea-surface temperatures, primary production, salinity, and coastal upwelling zones, Cheung et al. (2010) project changes in fish species distribution and regional patterns of maximum catch potential by 2055 in a scenario leading to warming of approximately 2°C in 2050 (and 4°C by 2100). The results are compared to a scenario in which conditions stabilize at year 2000 values. Comparing both scenarios shows potential yield

increases of 16 percent along the eastern and southeastern coast of Sub-Saharan Africa (Madagascar, Mozambique, Tanzania, and Kenya). However, for the same regions with closer proximity to the coast, yield changes of –16 to –5 percent are projected. Increases of more than 100 percent at the coast of Somalia and South Africa are projected. Apart from the southern coast of Angola, for the western African coast—where fish contributes as much as 50 percent of animal protein consumed (Lam, Cheung, Swartz, and Sumaila 2012)—significant adverse changes in maximum catch potential are projected of – 16 to –5 percent for Namibia, –31 to 15 percent for Cameroon and Gabon, and up to 50 percent for the coast of Liberia and Sierra Leone (Cheung et al. 2010). Lam et al. (2012), applying the same method and scenario, report decreases ranging from 52–60 percent, Côte d'Ivoire, Liberia, Togo, Nigeria, and Sierra Leone.

The analysis by Cheung et al. (2010) does not account for changes in ocean acidity or oxygen availability. Oxygen availability has been found to decline in the 200–700m zone and is related to reduced water mixing due to enhanced stratification (Stramma, Schmidtko, Levin, and Johnson 2010). At the same time, warming waters lead to elevated oxygen demand across marine taxa (Stramma, Johnson, Sprintall, and Mohrholz 2008). Hypoxia is known to negatively impact the performance of marine organisms, leading to additional potential impacts on fish species (Pörtner 2010). Accordingly, a later analysis by Cheung, Dunne, Sarmiento, and Pauly (2011), which built on that of William Cheung et al (2010), found that acidification and a reduction of oxygen content in the northeast Atlantic ocean lowered the estimated catch potentials by 20–30 percent relative to simulations not considering these factors.

Changes in catch potential can lead to decreases in local protein consumption in regions where fish is a major source of animal protein. For example, in their study of projected changes to fishery yields in West Africa by 2055 in a 2°C world, V. W. Y. Lam, Cheung, Swartz, and Sumaila (2012) compare projected changes in catch potential with projected protein demand (based on population growth, excluding dietary shifts). They show that in 2055 Ghana and Sierra Leone are expected to experience decreases of 7.6 percent and 7.0 percent respectively from the amount of protein consumed in 2000. Furthermore, they project economic losses of 21 percent of annual total landed value (from $732 million currently to $577 million, using constant 2000 dollars). Côte d'Ivoire, Ghana, and Togo, with up to 40 percent declines, are projected to suffer the greatest impacts on their land values. The job loss associated with projected declines in catches is estimated at almost 50 percent compared to the year 2000 (Lam et al. 2012). Of the whole of Sub-Saharan Africa, Malawi, Guinea, Senegal, and Uganda rank among the most vulnerable countries to climate-change-driven impacts on fisheries. This vulnerability is based on the combination of predicted warming, the relative importance of fisheries to national economies and diets, and limited adaptive capacity (Allison et al. 2009).

The vulnerability to impacts on marine ecosystems, however, differs from community to community. Cinner et al. (2012) measure the vulnerability to observed climate impacts on reef ecosystems in 42 communities across five western Indian Ocean countries (Kenya, Tanzania, Madagascar, Mauritius, and the Seychelles). The study provides evidence that not all sites are equally exposed to factors that cause bleaching. Reefs in Tanzania, Kenya, the Seychelles, and northwest Madagascar are found to experience more severe bleaching, while southwest Madagascar and Mauritius are less exposed because of lower seawater temperatures and UV radiation and higher wind velocity and currents. These findings caution against generalizations about the exposure of both ecosystems and the people dependent on them. The sensitivity of human communities to the repercussions of bleaching events is highest in those communities in Tanzania and parts of Kenya and Madagascar that are most dependent on fishing livelihoods.

Human Impacts

Climate change impacts as outlined above are expected to have further repercussions for affected populations. Other impacts may also occur and interact with these to result in severe threats to human life. The human impacts of climate change will be determined by the socio-economic context in which they occur. The following sections discuss some of the identified risk factors to affected populations and the potential repercussions for society.

Human Health

The increased prevalence of undernutrition is one of the most severe climate-related threats to human health in Sub-Saharan Africa. Insufficient access to nutrition already directly impacts human health, with high levels of undernutrition across the region. Undernutrition is the result of inadequate food intake or inadequate absorption or use of nutrients. The latter can result from diarrheal disease (Cohen, Tirado, Aberman, and Thompson 2008). Undernutrition increases the risk of secondary or indirect health implications because it heightens susceptibility to other diseases (World Health Organization 2009; World Bank Group 2009). It can also cause child stunting, which is associated with higher rates of illness and death and which can have long-term repercussions into adulthood, including reduced cognitive development (Cohen et al. 2008). In fact, undernutrition has been cited as the single most significant factor contributing to the global burden of disease; it is already taking a heavy toll, especially among children (IASC 2009).

In Sub-Saharan Africa in 2011, the prevalence of undernourishment in the population ranges from 15–65 percent depending on the sub-region (Lloyd, Kovats, & Chalabi, 2011). Lloyd et al.

(2011) anticipates modest reductions in these rates in the absence of climate change; with warming of 1.2–1.9°C by 2050,[50] the proportion of the population that is undernourished is projected to increase by 25–90 percent compared to the present. The proportion of moderately stunted children, which ranges between 16–22 percent in the 2010 baseline, is projected to remain close to present levels in a scenario without climate change. With climate change, the rate is projected to increase approximately 9 percent above present levels. The proportion of severely stunted children, which ranges between 12–20 percent in the 2010 baseline, is expected to decrease absent climate change by approximately 40 percent across all regions. With climate change, this overall reduction from present levels would be only approximately 10 percent. The implications of these findings are serious, as stunting has been estimated to increase the chance of all-cause death by a factor of 1.6 for moderate stunting and 4.1 for severe stunting (Black et al. 2008).

Other threats to health that are likely to be increased by climate change include fatalities and injuries due to extreme events or disasters such as flooding (McMichael and Lindgren 2011; World Health Organization 2009). An indirect health effect of flooding is the damage to key infrastructure. This was observed in a case in Kenya in 2009 when approximately 100,000 residents of the Tana Delta were cut off from medical services by floods that swept away a bridge linking the area with Ngao District Hospital (*Daily Nation* September 30, 2009, cited in Kumssa and Jones 2010).

Another risk is heat stress resulting from higher temperatures. Lengthy exposure to high temperatures can cause heat-related illnesses, including heat cramps, fainting, heat exhaustion, heat stroke, and death. More frequent and intense periods of extreme heat have been linked to higher rates of illness and death in affected populations. The young, the elderly, and those with existing health problems are especially vulnerable. Heat extremes are expected to also particularly affect farmers and others engaged in outdoor labor without adequate protective measures (Myers 2012). The populations of inland African cities are expected to be particularly exposed to extreme heat events, as the built-up environment amplifies local temperatures (known as the "urban heat island effect"; UN Habitat 2011). However, as the heat extremes projected for Sub-Saharan Africa are unprecedented, the extent to which populations will be affected by or will be able to adapt to such heat extremes remains unknown. This remains an understudied area of climate-change-related impacts.

Vector and Water-borne Diseases

Further risks to human health in Sub-Saharan Africa include the following: vector-borne diseases including malaria, dengue fever, leishmaniasis, Rift Valley fever, and schistosomiasis, and water and food-borne diseases, including cholera, dysentery and typhoid fever, and diarrheal diseases; all of these diseases can be influenced by local climate (Costello et al. 2009). The diseases most sensitive to environmental changes are those that are vector-borne or food and water-borne. Flooding can be associated with outbreaks of diseases, such as cholera; while drought has been linked to such diseases as diarrhea, scabies, conjunctivitis, and trachoma (Patz et al. 2008). As cold-blooded arthropods (including mosquitoes, flies, ticks, and fleas) carry most vector-borne diseases, a marginal change in temperature can dramatically alter their populations. They are also highly sensitive to water and vegetation changes in their environment. Changes in these factors can, therefore, increase the incidence, seasonal transmission, and geographic range of many vector-borne diseases (Patz et al. 2008).

The incidence of malaria is notoriously difficult to predict, There is great uncertainty about the role of environmental factors vis-à-vis endogenous, density-dependent factors in determining mosquito prevalence; many studies indicate, however, a correlation between increased malaria incidence and increased temperature and rainfall (Chaves and Koenraadt, 2010). In Botswana, for example, indices of ENSO-related climate variability have predicted malaria incidence (Thomson 2006); in Niger, total mosquito abundances showed strong seasonal patterns, peaking in August in connection with the Sahel water cycle (Caminade et al. 2011). This is consistent with observations that the drought in the Sahel in the 1970s resulted in a decrease in malaria transmission (Ermert, Fink, Morse, and Peeth 2012). Land-use patterns can also play a role in determining vector populations, with deforestation affecting temperature, and agricultural landscapes potentially providing suitable microhabitats for mosquito populations (Chaves and Koenraadt 2010).

The areas where malaria is present is projected to change, with malaria pathogens potentially no longer surviving in some areas while spreading elsewhere into previously malaria-free areas. Even today malaria is spreading into the previously malaria-free highlands of Ethiopia, Kenya, Rwanda, and Burundi, with the frequency of epidemics there increasing, and may also enter the highlands of Somalia and Angola by the end of the century (Unmüßig and Cramer 2008). In the Sahel, the northern fringe of the malaria epidemic belt is projected to have shifted southwards (by 1–2 degrees) with a warming of 1.7°C by 2031–50 because of a projected decrease in the number of rainy days in the summer (Caminade et al. 2011); this means that it is possible that fewer people in the northern Sahel will be exposed to malaria.

Outbreaks of Rift Valley fever (RVF), which are episodic, occur through mosquitos as the vector and infected domestic animals as secondary hosts and are linked to climate variability (including ENSO) (Anyamba et al. 2009). Intra-seasonal rainfall

[50] The study use the NCAR and CSIRO scenarios, which project a temperature increase of 1.9°C and 1.2°C above pre-industrial levels, respectively, by 2050.

variability, in particular, is a key risk factor, as outbreaks tend to occur after a long dry spell followed by an intense rainfall event (Caminade et al. 2011). In light of projections of increased rainfall variability in the Sahel, RVF incidence in this area can be expected to increase. Caminade et al. (2011) identify northern Senegal and southern Mauritania as risk hotspots, given these areas' relatively high livestock densities.

Rift Valley fever can spread through the consumption or slaughter of infected animals (cases of the disease in Burundi in May 2007 were believed to originate from meat from Tanzania; Caminade et al. 2011). Because of this, RVF outbreaks can also have implications for economic and food security as livestock contract the disease and become unsuitable for sale or consumption. An outbreak in 1997–98 for example, affected five countries in the Horn of Africa, causing loss of human life and livestock and affecting the economies through bans on exports of livestock (Anyamba et al. 2009).

Africa has the largest number of reported cholera cases in the world. Cholera is an acute diarrheal illness caused by ingestion of toxigenic *Vibrio Cholerae* and is transmitted via contaminated water or food. The temporal pattern of the disease has been linked to climate. The relative significance of temperature and precipitation factors remains somewhat uncertain in projections of future incidence under climate change. Past outbreaks of cholera have been associated with record rainfall events (Tschakert 2007), often during ENSO events (Nyong 2009). The risk increases when water supplies and sanitation services are disrupted (Douglas et al. 2008). This occurred during the severe flooding in Mozambique in 2000, and again in the province of Cabo Delgado in early 2013 (Star Africa 2013; UNICEF 2013), when people lost their livelihoods and access to medical services, sanitation facilities, and safe drinking water (Stal 2009).

Repercussions of Health Effects

The repercussions of the health effects of climate change on society are complex. Poor health arising from environmental conditions, for instance, may lower productivity, leading to impacts on the broader national economy as well as on household incomes. Heat extremes and increased mean temperatures can reduce labor productivity, thereby undermining adaptive capacity and making it more difficult for economic and social development goals to be achieved (Kjellstrom, Kovats, Lloyd, Holt, and Tol 2009). Child undernutrition also has long-term consequences for the health and earning potential of adults (Victora et al. 2008).

The educational performance of children is also likely to be undermined by poor health associated with climatic risk factors. An evaluation of school children's health during school days in Yaounde and Douala in Cameroon found that, in the hot season, high proportions of children were affected by headaches, fatigue, or feelings of being very hot. Without any protective or adaptive measures, these conditions made students absentminded and slowed writing speeds, suggesting that learning performance could be undermined by increased temperatures (Dapi et al. 2010). Child stunting is associated with reduced cognitive ability and school performance (Cohen et al. 2008); in addition, diseases such as malaria have a significant effect on children's school attendance and performance. Sachs and Malaney (2002) found that, because of malaria, primary students in Kenya annually miss 11 percent of school days while secondary school students miss 4.3 percent.

The complexity of the range of environmental and human-controlled factors that affect human health is considerable. Among them, land-use changes (including deforestation, agricultural development, water projects, and urbanization) may affect disease transmission patterns (Patz et al. 2008). Moreover, population movements can both be driven by and produce health impacts. Forced displacement, often in response to severe famine or conflict, is associated with high rates of infectious disease transmission and malnutrition; this can lead to the exposure of some populations to new diseases not previously encountered and against which they lack immunity (McMichael et al. 2012). People who migrate to poor urban areas, are possibly also at risk of disaster-related fatalities and injuries (McMichael et al. 2012), especially in slum areas which are prone to flooding and landslides (Douglas et al. 2008).

Population Movement

Projections of future migration patterns associated with climate change are largely lacking. However, the observed movements outlined below illustrate the nature of potential patterns and the complexity of the factors that influence population movement.

Migration can be seen as a form of adaptation and an appropriate response to a variety of local environmental pressures (Tacoli 2009; Warner 2010; Collier et al. 2008). Migration often brings with it a whole set of other risks, however, not only for the migrants but also for the population already residing at their point of relocation. For example, the spread of malaria into the Sub-Saharan African highlands is associated with the migration of people from the lowlands to the highlands (Chaves and Koenraadt 2010). Some of the health risks to migrants themselves have been outlined above. Other impediments faced by migrants can include tensions across ethnic identities, political and legal restrictions, and competition for and limitations on access to land (Tacoli 2009); these, can also, potentially, lead to conflict (O. Brown, Hammill, and McLeman 2007). In turn, migration is a common response to circumstances of violent conflict (McMichael et al. 2012).

Migration can be driven by a multitude of factors, where notably the socioeconomic context also plays a key role (Tacoli 2009).

Environmental changes and impacts on basic resources, including such extreme weather events as flooding and cyclones, are significant drivers of migration. Drought can also be a driver of migration, according to S. Barrios, Bertinelli, and Strobl (2006), who attribute one rural exodus to rainfall shortages. When the Okovango River burst its banks in 2009 in a way that had not happened in more than 45 years, about 4,000 people were displaced on both the Botswanan and Namibian sides of the river and forced into emergency camps (IRIN 2009). Although this event has not been attributed to climate change, it does illustrate the repercussions that extreme events can have on communities.

Some permanent or temporary population movements are associated with other environmental factors, such as desertification and vegetation cover, which may be affected by human-induced land degradation or climate change (Tacoli 2009). Van der Geest, Vrieling, and Dietz (2010) find that, in Ghana, migration flows can be explained partly by vegetation dynamics, with areas that offer greater vegetation cover and rainfall generally attracting more in-migration than out-migration. This study found that the migration patterns observed also appeared to be related to rural population densities, suggesting that the per capita access to natural resources in each area was at least as important as the abundance of natural resources *per se*. Barbier et al. (2009) show that, in Burkina Faso, some pastoralists have opted to migrate from the more densely populated and more arid north to the south, where population density is lower, pastures are available, and the tsetse fly is under control. Other migrations from dryland areas in Burkina Faso are seasonal; that is, they occur for the duration of the dry season (Kniveton, Smith, and Black 2012). Migration as a response to environmental stresses, however, can be limited by non-climatic factors. In the Kalahari in Botswana, for example, pastoralists have employed seasonal migration as a means of coping with irregular forage, land tenure reform limits previously high herd mobility (Dougill et al. 2010).

Urbanization

The connection between the challenges posed by climate change and by urbanization is particularly noteworthy. Africa has the highest rate of urbanization in the world; this is expected to increase further, with as much as half the population expected to live in urban areas by 2030 (UN-HABITAT 2010a). In the face of mounting pressures on rural livelihoods under climate change, even more people may people may migrate to urban areas (Adamo 2010). For example, patterns of urbanization in Senegal have been attributed to desertification and drought, which have made nomadic pastoral livelihoods less feasible and less profitable (Hein et al. 2009).

Urbanization may constitute a form of adaptation and provide opportunities to build resilient communities, and the potential benefits may extend beyond the urban area. There are, are for example, cases in which urban migrants are able to send remittances to family members remaining in rural areas (Tacoli 2009).

Large numbers of urban dwellers, however, currently live in precarious situations. For example, the residents of densely populated urban areas that lack adequate sanitation and water drainage infrastructure depend on water supplies that can easily become contaminated (Douglas et al. 2008). As discussed above, heat extremes are also likely to be felt more in cities. Levels of poverty and unemployment are often high in these areas, with many unskilled subsistence farmers who move to urban areas experiencing difficulty in finding employment (Tacoli 2009). As discussed in Chapter 3 on "The Impacts of Food Production Declines on Poverty", the urban poor are also among the most vulnerable to food production shocks.

The vulnerability of new urban dwellers is also increased by the pressure that urbanization puts on the natural environment and urban services (Kumssa and Jones 2010). Absent careful urban planning, such pressure can exacerbate existing stressors (for example, by polluting an already limited water supply; Smit and Parnell 2012), and heighten the vulnerability of these populations to the impacts of disasters, including storm surges and flash floods (McMichael et al. 2012). Many settlements are constructed on steep, unstable hillsides, along the foreshores of former mangrove swamps or tidal flats, or in low-lying flood plains (Douglas et al. 2008). Flooding severity is heightened as, for example, natural channels of water are obstructed, vegetation removed, ground compacted, and drains blocked because of uncontrolled dumping of waste (Douglas et al. 2008). Urbanization can hence be seen as both a response to and a source of vulnerability to climate change (see also Chapter 4 on "Risks to Coastal Cities").

Conflict

There are several scenarios under which climate change could trigger conflict (Homer-Dixon,1994; Scheffran, Brzoska, Kominek, Link, and Schilling 2012). Decreased or unequal access to resources following extreme events has been identified as a possible contributing factor to human conflict (Hendrix and Glaser 2007; Nel and Righarts 2008). Similarly, on both long and short time-scales, depletion of a dwindling supply of resources could lead to competition between different groups and increase the threat of conflict (Homer-Dixon 1994; Hendrix and Glaser 2007).

For example, Blackwell (2010) links cattle raiding and violent disputes over scarce water resources to escalating competition for shrinking pasture and water sources. Rowhani, Degomme, Guha-Sapir, and Lambin (2011), who investigated the same phenomena in East Africa, found no strict causal mechanisms, but they did find associations between variables, with both malnutrition and inter-annual ecosystem variability correlated with violent conflict. They argue that the impact of environmental change on human security is indirect and mediated by several political and economic

factors. This more nuanced picture is consistent with the analysis of J. Barnett and Adger (2007), who argue that, in some circumstances, climate change impacts on human security may increase the risk of violent conflict.

There is some evidence that the causal connection operates in the opposite direction, with conflict often leading to environmental degradation and increasing the vulnerability of populations to a range of climate-generated stressors (Biggs and et al. 2004). The breakdown of governance due to civil war can also exacerbate poverty and cause ecosystem conservation arrangements to collapse; both of these factors can potentially cause further exploitation of natural resources (Mitchell 2013).

The potential connection between environmental factors and conflict is a highly contested one, and the literature contains evidence both supporting and denying such a connection. Gleditsch (2012), summarizing a suite of recent studies on the relationship between violent conflict and climate change, stresses that there is to date a lack of evidence for such a connection (see Buhaug 2010 for a similar line of argument). However, given that unprecedented climatic conditions are expected to place severe stresses on the availability and distribution of resources, the potential for climate-related human conflict emerges as a risk—and one of uncertain scope and sensitivity to degree of warming.

Conclusion

Key impacts that are expected to affect Sub-Saharan Africa are summarized in Table 3.4, which shows how the nature and magnitude of impacts vary across different levels of warming.

Agriculture livelihoods are under threat and the viable options to respond to this threat may dwindle. For maize crop areas, for example, the overlap between historical maize growing areas and regions where maize can be grown under climate change decreases from 58 percent under 1.5°C warming above pre-industrial levels to 3 percent under 3°C warming. In other words, even at 1.5°C warming about 40 percent of the present maize cropping areas will no longer be suitable for current cultivars. Risks and impacts grow rapidly with increasing temperature. Recent assessments project significant yield losses for crops in the order of 5–8 percent by the 2050s for a warming of about 2°C, and a one-in-twenty chance that yield losses could exceed 27 percent. As warming approaches 3°C, large areas of Sub-Saharan Africa are projected to experience locally unprecedented growing season temperatures. In a 2°C world, countries with historically high temperatures begin to move toward globally unprecedented crop climates. This means that it becomes increasingly unlikely that existent cultivars can be obtained that are suitable for the temperature ranges in these regions. Should this become impossible, the breeding of new more drought-resistant cultivars tolerant of higher temperatures would appear to be necessary. In a 4°C world, the likelihood that suitable existent cultivars are available further decreases, and the uncertainty surrounding the potential of novel cultivar breeding may increase.

Similarly, diversification options for agro-pastoral systems may decline as heat stress and indirect impacts reduce livestock productivity and CO_2-driven woody plant encroachment onto grasslands diminishes the carrying capacity of the land. Livelihoods dependent on fisheries and other ecosystem services would be similarly placed under threat should critical species cease to be locally available.

Impacts in these sectors are likely to ripple through other sectors and affect populations in Sub-Saharan Africa in complex ways. Undernutrition increases the risk of other health impacts, which are themselves projected to become more prevalent under future climate change. This may undermine household productivity and can cause parents to respond by taking their children out of school to assist in such activities as farm work, foraging, and the fetching of fuel and water. This may ultimately have long-term implications for human capital and poverty eradication in Sub-Saharan Africa.

Threats to agricultural production, which place at risk the livelihoods of 60 percent of the labor force of Sub-Saharan Africa, may further exacerbate an existing urbanization trend. Migration to urban areas may provide migrants with new livelihood opportunities but also expose them to climate impacts in new ways. Some health risk factors, such as heat extremes, are particularly felt in urban areas. Other impacts tend to affect the poorest strata of urban society, to which urban migrants often belong. Conditions that characterize poor urban areas, including overcrowding, inadequate access to water, and poor drainage and sanitation facilities, aid the transmission of vector- and water-borne diseases. As many cities are located in coastal areas, they are exposed to coastal flooding because of sea-level rise. The poorest urban dwellers tend to be located in the most vulnerable areas, further placing them at risk of extreme weather events. Impacts occurring even far removed from urban areas can be felt in these communities. Food price increases following production shocks have the most deleterious repercussions within cities. The high exposure of poor people to the adverse effects of climate change implies the potential for increasing inequalities within and across societies. It is as yet unclear how such an effect could be amplified at higher levels of warming and what this would mean for social stability.

Thus, the range of climate-change-related risks already confronting Sub-Saharan Africa at relatively low levels of warming could have far-reaching repercussions for the region´s societies and economies well into the future. Even in a situation in which warming is limited to below 2°C, there are substantial risks and damages; as warming increases these only grow. With a 2°C warming, and despite persistent uncertainties, large regional risks to development emerge, particularly if adaptation measures fail to adequately anticipate the threat.

Table 3.4: Impacts in Sub-Saharan Africa

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C (≈2030s[1])	Around 2°C (≈2040s)	Around 3°C (≈2060s)	Around 4°C and Above (≈2080s)
Regional Warming				Warm nights expected approximately 45 percent of the time in tropical west and east Africa and about 60 percent of the time in southern Africa		Warm nights approximately 95 percent of time in tropical West and East Africa and about 85 percent of time in southern Africa[2]
Heat Extremes		Virtually absent	About 20–25 percent of land in austral summer months (Dec, Jan, Feb) (DJF)	About 45 percent of land in austral summer months (DJF)	About 70 percent of land in austral summer months (DJF)	>85 percent of land in austral summer months (DJF)
		Absent	About 3–5 percent of land in austral summer months (DJF)	About 15 percent of land in austral summer months (DJF)	About 35 percent of land in austral summer months (DJF)	>55 percent of land in austral summer months (DJF)
Precipitation	**West Africa**			Weak (<10 percent) change in annual precipitation, sign of change uncertain		Weak (<10 percent) change in annual precipitation, sign of change uncertain
	East Africa	Recent abrupt decline since 1999[3] and likely human influence on 2011 long rains failure[4]		Wetter (>10 percent); however, there is significant uncertainty[5]		Substantially wetter (≈30 percent); however, there is significant uncertainty[6]
	Southern Africa			Weak (<10 percent) change in annual precipitation, sign uncertain		Decrease of annual precipitation up to 30 percent
Drought		Increasing drought trends observed since 1950.[7] The recent 2011 drought in East Africa affected 13 million people and led to extremely high rates of malnutrition.[8] Lott et al (2013) show that human influence on climate has increased the probability of East African long rains as dry, or drier than in 2011	Increasing drought risk in southern, central and West Africa, decrease in East Africa, but West and East African projections are uncertain	Likely risk of severe drought in southern and central Africa, increased risk in West Africa, decrease in East Africa but West and East African projections are uncertain	Likely risk of extreme drought in southern Africa and severe drought in central, Africa, increased risk in West Africa, decrease in East Africa[9], but West and East African projections are uncertain[10]	Likely risk of extreme drought in southern Africa and severe drought in central Africa, increased risk in West Africa, decrease in East Africa[11], but West and East African projections are uncertain[12]
Aridity		Increased drying	Little change expected	Area of hyper-arid and arid regions grows by 3 percent. Total arid area increases by 1 percent in a 2°C world		Area of hyper-arid and arid regions grows by 10 percent. Total arid area increases by 5 percent
Sea-level Rise above present (1985–2005)		About 21 cm to 2009[13]	30cm[14]–2040s, 50cm–2070, 70 cm (60–80) cm by 2080–2100.[15] Likely exceeds 50 cm by 2070s and 100 cm not likely exceeded until late 22nd century	30cm–2040s, 50cm–2070, 70cm (60–80) cm by 2080–2100. Likely exceeds 50 cm by 2070s and 100 cm not likely exceeded until mid 22nd century	30cm–2040s, 50cm–2060, 85 cm (70–100) cm by 2080–2100. Likely exceeds 50 cm by 2070s and 100 cm by early 22nd century	30cm–2040s, 50cm–2060, 105 (85–125) cm by 2080–2100. Likely exceeds 50 cm by 2060s and 100 cm by 2080s. Five cm higher rise along east coast Southern Africa (for example, Maputo)

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Table 3.4: Impacts in Sub-Saharan Africa

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C (≈2030s[1])	Around 2°C (≈2040s)	Around 3°C (≈2060s)	Around 4°C and Above (≈2080s)
Ecosystem Shifts		A 20-percent decline in tree density in the western Sahel and significant decline in species richness across the Sahel in the last half of the 20th century.[16] Mali is experiencing a climate zone shift with a shift of agro-ecological zones to the south, evidenced by a decrease in average rainfall of about 200 mm over the past 50 years and an average increase in temperature of 0.5°C.[17] Reduction in river inflow because of droughts contributes to decrease nutrient concentrations and increasing water temperatures and higher evaporation lead to stronger thermal stratification further inhibiting primary productivity.[18] Most hoofed mammal species in Kruger National Park showed severe population declines between the late 1970s and mid 1990s correlated with extreme reduction in dry season rainfall[19]	41–51 percent loss in plant endemic species richness in South Africa and Namibia[20]	10 to 15 percent Sub-Saharan species at risk of extinction (assuming no migration of species)[21]	Savannas are projected to decrease from 23 percent to 14 percent of total land coverage. Area dominated by woodland, deciduous forest, and evergreen forest vegetation increases from 31 percent to 47 percent by 2100 compared to 1850[22] Projections, of 5,197 studied African plant species 25 percent to 42 percent could lose all suitable range by 2085;[23] 25 to 40 percent Sub-Saharan species at risk of extinction (assuming no migration of species)[24]	
Water Availability	**Runoff**				30–50 percent decreases in annual runoff[25] for parts of West Africa (Ghana, the Côte d'Ivoire and southern Nigeria)[26] and Southern Africa (Namibia, east Angola and western South Africa and Zambia)[27]	Increase 10–20 percent in blue water availability in East Africa and parts of West Africa,[28] 10 percent decrease in Ghana, Côte d'Ivoire, Mali, Senegal, 20 to 40 percent decrease in most of Southern Africa; 20 percent decrease in green water availability in most of Africa, except parts of East Africa (10 to 20 percent increase for Somalia, Ethiopia, and Kenya)[29]

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Table 3.4: Impacts in Sub-Saharan Africa

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C (≈2030s[1])	Around 2°C (≈2040s)	Around 3°C (≈2060s)	Around 4°C and Above (≈2080s)
	Groundwater Recharge			50–70 percent decrease in recharge rates in western Southern Africa and southern West Africa 30 percent increase in recharge rate in some parts of eastern Southern Africa and East Africa[30]		
Crop Yields, Areas and Food Production	**Crop Growing Areas**		Maize, millet, and sorghum crop areas are projected to overlap on average 58 percent, 54 percent, and 57 percent by 2025, respectively, compared to 1960–2002 conditions.[31] Increase in failure rate of primary season in mixed rainfed arid-semiarid systems by about 35–40 percent, to about one in four years, up from about one in five at present[32]	Maize, millet, and sorghum crop areas are projected to overlap on average 14 percent, 12 percent and 15 percent by 2050, respectively, compared to 1960–2002 conditions.[31] Increase in failure rate of primary season in mixed rainfed arid-semiarid systems by about 60–70 percent to about one in three years, up from about one in five at present[39]	Maize, millet, and sorghum crop areas are projected to overlap on average 3 percent, 2 percent, and 3 percent by 2075, respectively, compared to 1960–2002 conditions[31]	The length of growing period is projected to be reduced by more than 20 percent across the whole region by the 2090s.[34] In southern Africa, the rate of season failure could increase to one year in two. 20 percent decrease in growing season length in SSA[35]
	Crop Production	Baseline of approximately 81 million tonnes in 2000, about 121 kg/capita.[39]		Without climate change, a projected decrease of 192 million tonnes (111 kg/capita) and with climate change 176 million tonnes (101 kg/capita)[39]		
Yields	**All Crops**		Close to zero or small negative changes[36]	Median losses in the order of –5 percent[37] to –8 percent;[47] 95 percent probability crop damages exceed 7 percent, and 5 percent probability that they exceed 27 percent by the 2050s[38]	Median yield loss –11 percent range of around –50 percent to +90 percent[39]	–20 percent yield reduction[40]
	Maize	About 37 percent of 2000 crop production.[41] Historical data show non-linear heat effects on maize with large potential losses under climate warming[42]		–5 percent[47] to –22 percent[43]		–13 percent for central Africa, –19 percent for east Africa, –16 percent in southern Africa, and –23 percent in west Africa[35]

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Table 3.4: Impacts in Sub-Saharan Africa

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C (≈2030s[1])	Around 2°C (≈2040s)	Around 3°C (≈2060s)	Around 4°C and Above (≈2080s)
	Sorghum	About 19 percent of 2000 crop production[44]	Significant negative impacts on sorghum suitability in the western Sahelian region and Southern Africa[45]	–15[47] to –17 percent[43]		
	Wheat	About 5 percent of 2000 crop production[46]		–17 percent[47]		
	Rice			No trend[47]		
	Millet	About 13 percent of 2000 crop production[48]		–10[47] to –17[43] percent		–6 percent with a range of –29 to +11 percent.[49] –16 to 19 percent for the equatorial fully humid climate zone (Guinean region of West Africa, central Africa and most parts of East Africa)[50]
	Groundnut			–18[43] percent		
	Cassava			–8[43] percent		
Livestock		Severe drought impacts on livestock. Pastoralists in southern Ethiopia lost 46 percent of their cattle and 41 percent of their sheep and goats to droughts between 1995 and 1997.[51] Damage to livestock stocks by flooding in the 1990s has been recorded in the Horn of Africa[52]	Forage yield change in the Sikasso region in Mali is projected to be –5 to –36 percent, and as food intake for livestock decreases, rate of cattle weight gain is found to be reduced by –13.6 to –15.7 percent; while the rate of weight gain does not change for sheep and goats[53]			10 percent increase in yields of *B. decumbens* (pasture species) in east and southern Africa; 4 percent and 6 percent decrease in central and west Africa.[35]

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Table 3.4: Impacts in Sub-Saharan Africa

Risk/Impact	Observed Vulnerability or Change	Around 1.5°C (≈2030s[1])	Around 2°C (≈2040s)	Around 3°C (≈2060s)	Around 4°C and Above (≈2080s)
Marine Fisheries			Potential offshore catch increases along eastern and Southeastern coast of Sub-Saharan Africa of 16 percent (Madagascar, Mozambique, Tanzania, and Kenya). With closer proximity to coast yield reductions of –16 to –5 percent projected. Catch increases up to 100 percent at the coast of Somalia and South Africa.[54] Significant reductions in maximum catch potential for western African coast of –16 to –5 percent for Namibia, –31 to 15 percent for Cameroon and Gabon[54], and up to 50 percent off the coast of Côte d'Ivoire, Ghana, Liberia, Togo, Nigeria, and Sierra Leone.[55] Significant reduction in available protein, economic and job losses projected		
Coastal Areas	Tanzania has 800 km of coast line and multiple islands where impact of sea level rise can already be seen (salination of wells, destruction of infrastructure)[56]	Close to 11 million people flooded every year by 2100 without adaptation.[57] The largest seaport in East Africa, Mombasa, faces major risks. For 0.3 m sea level rise around 17 percent of Mombasa's area could be submerged, and a "larger area rendered uninhabitable or unusable for agriculture because of water logging and salt stress"[58]. Tourism resources such as beaches, historic and cultural monuments, and port infrastructure, would be negatively affected[58]		Tanzania capital city, Dar es Salaam, 70cm sea-level rise by 2070s about US$10 billion of assets projected[59] to be exposed by 2070, corresponding to more than 10 percent of the projected city GDP. Damage to port infrastructure in Dar es Salaam, could have serious economic consequences. The seaport handles approximately 95 percent of Tanzania's international trade and serves landlocked countries further inland	Approximately 18 million people flooded per year[60] by 2100 without adaptation. Mozambique and Nigeria projected to be the most affected African countries with 6 and 3 million being flooded annually by 2100. Guinea-Bissau, Mozambique and Gambia the highest percentage of population affected (more than 10 percent). In Eritrea, a one meter sea level rise is estimated to cause damage of over US$ 250 million (~18 percent of GDP in 2007) as a result of the submergence of infrastructure and other economic installations in Massawa, one of the country's two port cities[61]

(*continued on next page*)

Table 3.4: Impacts in Sub-Saharan Africa

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C (≈2030s[1])	Around 2°C (≈2040s)	Around 3°C (≈2060s)	Around 4°C and Above (≈2080s)
Poverty		Africa has largest 'poverty responses' to climate shocks[62]. Zambia's national poverty rate increased by 7.5 percent over 1991–92, classified as a severe drought year, and 2.4 percent over 2006–07, classified as a severe flood year[63]		The proportion of undernourished children and those suffering from moderate and severe stunting is projected to decrease absent climate change. With climate change the proportion undernourished is expected to increase significantly. The proportion affected by moderate and severe stunting is expected to increase, with the most significant increase 31–55 percent for severe stunting[64]	Urban wage-labor-dependent populations across the developing world may be most affected by once-in–30-year climate extremes, with an average increase of 30 percent in poverty compared to the base period. The poverty rate for this group in Malawi, for example, is estimated to be as much as double following a once-in-30-year climate event, compared to an average increase in poverty of 9.2 percent among rural agricultural households[65]	

Notes to Table 3.4

[1] Years indicate the decade during which warming levels are exceeded with a 50 percent or greater change (generally at start of decade) in a business-as-usual scenario (RCP8.5 scenario). Exceedance with a likely chance (>66 percent) generally occurs in the second half of the decade cited.
[2] Monthly summer temperatures 5.3°C (5oC above the 1951–80 baseline) by 2100.
[3] Lyon and DeWitt (2012).
[4] Lott, Christidis, and Stott (2013).
[5] This is the general picture from CMIP5 models; however, significant uncertainty appears to remain. Observed drought trends (Lyon and DeWitt 2012) and attribution of the 2011 drought in part to human influence (Lott et al. 2013) leaves significant uncertainty as to whether the projected increased precipitation and reduced drought are robust (Tierney, Smerdon, Anchukaitis, and Seager 2013).
[6] This is the general picture from CMIP5 models; however, significant uncertainty appears to remain. Observed drought trends (Lyon and DeWitt 2012) and attribution of the 2011 drought in part to human influence (Lott et al. 2013) leaves significant uncertainty as to whether the projected increased precipitation and reduced drought are robust (Tierney et al. 2013).
[7] Dai (2011).
[8] Karumba (2013); Zaracostas (2011).
[9] Dai (2012). CMIP5 models under RCP4.5 for drought changes 2050–99, warming of about 2.6°C above pre-industrial levels.
[10] Tierney et al. (2013).
[11] Dai (2012).
[12] Tierney et al. (2013).
[13] Above 1880 estimated global mean sea level.
[14] Add 20 cm to get an approximate estimate above the pre-industrial sea level.
[15] For a scenario in which warming peaks above 1.5°C around the 2050s and drops below 1.5°C by 2100. Due to slow response of oceans and ice sheets, the sea-level response is similar to a 2°C scenario during the 21st century, but deviates from it after 2100.
[16] Gonzalez, Tucker, and Sy 2012) attribute changes to the observed trend to changes in temperature and rainfall variability.
[17] Economics of Climate Adaptation (2009).
[18] Ndebele-Murisa, Musil, and Raitt (2010).
[19] Midgley and Thuiller (2010).
[20] Broennimann et al. 2006).
[21] Parry et al. (2007).
[22] SRES A1B about 3.5°C above pre-industrial level.
[23] (Midgley and Thuiller 2010).
[24] Parry et al. (2007).
[25] Under a 2.7°C warming above pre-industrial levels.
[26] Within regions with a strong level of model agreement (60–80 percent).
[27] Much greater consensus among impact models (Schewe et al. 2013).
[28] Gerten et al. (2011).
[29] For 2080s (global-mean warming of 3.5°C above pre-industrial levels) and changes in water availability relative to 1971–2000. In this projection, population is held constant.
[30] Temperature increase of 2.3°C and 2.1°C for the period 2041–79 under SRES A2 and B2 (Döll 2009).
[31] Burke, Lobell, and Guarino (2009).
[32] Jones, P. G. G., & Thornton, P. K. K. (2009). Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to climate change. Environmental Science & Policy, 12(4), 427–437. doi:10.1016/j.envsci.2008.08.006
[33] Jones, P. G. G., & Thornton, P. K. K. (2009). Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to climate change. Environmental Science & Policy, 12(4), 427–437. doi:10.1016/j.envsci.2008.08.006
[34] A global-mean warming of 5.4°C above pre-industrial levels. Exceptions being parts of Kenya and Tanzania, where the growing season length may moderately increase by 5 to 20 percent. The latter is not expected to translate into increased crop production, however; instead a reduction of 19 percent is projected for maize and 47 percent for beans, while no or a slightly positive change is projected for pasture grass. Over much of the rest of SSA reductions for maize range from –13 percent to –24 percent, and for beans from –69 to –87 percent, respectively, but the variability among different climate models is larger than the variability for East Africa. (Thornton, Jones, Ericksen, and Challinor 2011).
[35] Thornton et al. (2011).
[36] For 2020s for most scenario, 1.1–1.3°C above pre-industrial levels globally (Roudier, Sultan, Quirion, and Berg 2011).
[37] By the 2050s 1.6–2.2°C above pre-industrial levels globally (Roudier et al. 2011).
[38] Schlenker and Lobell (2010).
[39] For the 2080s (2.4–4.3°C for SREA B1, B2, A2, A1F above pre-industrial levels globally) but only on data point for SRES A1F; the others are all closer to 3°C. Range is full range with and without CO_2 fertilization.
[40] One data point only for approximately 4°C (Roudier et al. 2011).
[41] Nelson et al. (2010).
[42] Lobell, Schlenker, and Costa-Roberts (2011).
[43] For a 2050s, global-mean warming of about 2.2°C above pre-industrial levels, median impacts across SSA (Schlenker and Lobell 2010).
[44] Nelson et al. (2010).
[45] Ramirez-Villegas, Jarvis, and Läderach (2011).
[46] Nelson et al. (2010).
[47] Knox, Hess, Daccache, and Wheeler (2012) for 2050s range of different scenarios and warming levels.
[48] Nelson et al. (2010).
[49] Across India and Sub-Saharan Africa and all climatic zones considered, for the highest levels of warming by the 2080s (Berg, De Noblet-Ducoudré, Sultan, Lengaigne, and Guimberteau 2012).
[50] SRESA1B scenario (3.6°C above pre-industrial levels globally) and SRESA2 scenario (4.4°C) or 2100 (Berg et al. 2012).
[51] FAO (2008).
[52] Little, Mahmoud, and Coppock (2001), cited in Morton (2012).
[53] For local temperature increases of 1 to 2.5°C, with variation in magnitude across parts of the region and models. (Butt, McCarl, Angerer, Dyke, and Stuth 2005).
[54] Under a 2°C scenario by 2055 (Cheung et al. 2010).
[55] Lam, Cheung, Swartz, and Sumaila (2012). Applying the same method and scenario as Cheung et al. (2010).
[56] ECA (2009).
[57] Hinkel et al. (2011). 64 cm SLR scenario by 2100. In the no sea-level rise scenario, only accounting for delta subsidence and increased population, up to 9 million people would be affected.
[58] Awuor, Orindi, and Adwera (2008).
[59] Socioeconomic changes and increased coastal flooding induced by sea level rise and natural subsidence (Kebede and Nicholls 2011).
[60] Hinkel et al. (2011). High SLR scenario 126 cm by 2100. In the no sea-level rise scenario, only accounting for delta subsidence and increased population, up to 9 million people would be affected.
[61] Boko et al., (2007).
[62] Ahmed, Diffenbaugh, and Hertel (2009). Of a sample of 16 countries across Latin America Asia, and Africa, the largest "poverty responses" to climate shocks were observed in Africa.
[63] Thurlow, Zhu, and Diao (2012).
[64] Lloyd, Kovats, and Chalabi (2011) estimate the impact of climate-change-induced changes to crop productivity on undernourished and stunted children under five years of age by 2050 and find that the proportion of undernourished children is projected to increase by 52 percent, 116 percent, 82 percent, and 142 percent in central, east, south, and west Sub-Saharan Africa, respectively. The proportion of stunting among children is projected to increase by 1 percent (for moderate stunting) or 30 percent (for severe stunting); 9 percent or 55 percent; 23 percent or 55 percent; and 9 percent or 36 percent for central, east, south, and west Sub-Saharan Africa.
[65] Ahmed et al. (2009) scenario approaching 3.5°C above pre-industrial levels by the end of the century.

Chapter 4

South East Asia: Coastal Zones and Productivity at Risk

REGIONAL SUMMARY

In this report, South East Asia refers to a region comprising 12 countries[51] with a population of ~590 million in 2010. In 2050, the population is projected to be around 760 million, 65 percent urban-based, and concentrated along the coast.

Major impacts on the region and its natural resources are projected for warming levels of 1.5–2°C, resulting in coral reefs being threatened with consequent damage to tourism- and fisheries-based livelihoods and decreases in agricultural production in the delta regions due to sea-level rise. For example, by the 2040s, a 30 cm sea-level rise is projected to reduce rice production in the region's major rice growing region—the Mekong River Delta—by about 2.6 million tons per year, or about 11 percent of 2011 production. Marine fish capture is also projected to decrease by about 50 percent in the southern Philippines during the 2050s due to warmer sea temperatures and ocean acidification.

With 4°C global warming, there could be severe coastal erosion due to coral reef dieback. Sea level is projected to rise up to 100 cm by the 2090s; this would be compounded by projected increases in the intensity of the strongest tropical cyclones making landfall in the region. In addition, unprecedented heat extremes over nearly 90 percent of the land area during the summer months (June, July and August) is likely to result in large negative impacts.

Current Climate Trends and Projected Climate Change to 2100

Climate projections for South East Asia are very challenging due to the region's complex terrain, comprising mountains, valleys, and coastal zones across a diverse mix of mainland, peninsulas, and islands; the related regional sea-land interactions; and the large number of interacting climate drivers that give rise to the local climate.

Temperature

In a 2°C world, average summer warming in the region is projected to be around 1.5°C (1.0–2.0°C) by the 2040s. In a 4°C world, South East Asian average summer temperatures over land are projected to increase by around 4.5°C (3.5–6°C) by 2100. This is

[51] Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Papua New Guinea, the Philippines, Singapore, Thailand, Timor Leste, and Vietnam.

substantially lower than the global-mean surface warming over land, because the region's climate is more strongly influenced by sea-surface temperatures that are increasing at a slower rate than in other regions with a larger continental land surface.

In tropical South East Asia, however, heat extremes are projected to escalate with extreme temperature events frequently exceeding temperature ranges due to natural climate variability. For example, under a 2°C global warming scenario, currently unusual heat extremes[52] during the summer are projected to cover nearly 60–70 percent of the land area. Unprecedented heat extremes could occupy up to 30–40 percent of land area. In a 4°C world, summer months that in today´s climate would be termed unprecedented might be the new normal, affecting nearly 90 percent of the land area during the summer months. More important, the South East Asia region is one of two regions (the other being the Amazon) which is projected to see, in the near-term, a strong increase in monthly heat extremes with the number of warm days[53] projected to increase from 45–90 days/year under a 2°C world to around 300 days for a 4°C world.

Rainfall

The use of climate models to project future rainfall changes is especially difficult for South East Asia because both the Asian and the Australian summer monsoons affect the region and large differences remain between individual models. For 4°C warming, there is no agreement across models for South East Asia, with changes either not statistically significant, or ranging from a decrease of 5 percent to an increase of 10 percent in monsoon rainfall. Despite these moderate changes, the latest model projections show a substantial and rising increase in both the magnitude and frequency of heavy precipitation events. The increase of extreme rainfall events[54] is projected to rise rapidly with warming, and to contribute more than a 10-percent share of annual rainfall for 2°C and a 50-percent share for 4°C warming, respectively. At the same time the maximum number of consecutive dry days, which is a measure for drought, is also projected to increase, indicating that both minimum and maximum precipitation extremes are likely to be amplified.

Likely Physical and Biophysical Impacts as a Function of Projected Climate Change

Sea-level Rise

Sea-level rise along the South East Asian coastlines is projected to be about 10–15 percent higher than the global mean by the end of the 21st century. In a 4°C world, the projected regional sea-level rise is likely[55] to exceed 50 cm above present levels[56] by 2060, and 100 cm by 2090, with Manila being especially vulnerable. In a 2°C world, the rise is significantly lower for all locations, but still considerable, at 75 (65–85) cm by 2090. Local land subsidence due to natural or human influences would increase the relative sea-level rise in specific locations.

Tropical Cyclone Risk

An increase in the frequency of the most intense storms[57] along with associated extreme rainfall is projected for South East Asia. Maximum surface wind speed during tropical cyclones is projected to increase by 7–18 percent for a warming of around 3.5°C above pre-industrial levels for the western North Pacific basin, but the center of activity is projected to shift north and eastward. The maximum wind speed of tropical cyclones making landfall is projected to increase by 6 and 9 percent respectively for mainland South East Asia and the Philippines, combined with a decrease of 35 and 10 percent respectively in the overall number of land-falling cyclones. As sea-surface temperatures rise, tropical-cyclone-related rainfall is expected to increase by up to a third, indicating a higher level of flood risk in low lying and coastal regions.

Saltwater Intrusion

For several South East Asia countries, salinity intrusion in coastal areas is projected to increase significantly with rising sea levels. For example, a 1 m sea-level rise by 2100 in the land area affected by saltwater intrusion in the Mahaka River region in Indonesia is expected to increase by 7–12 percent under 4°C warming. In the Mekong River Delta, it is projected that a 30-cm sea-level rise by the 2050s in both the 2°C and 4°C worlds would increase by over 30 percent the total current area (1.3 million ha) affected by salinity intrusion.

Coral Reef Loss and Degradation

Coral reefs flourish in a relatively narrow range of temperature tolerance and are hence highly vulnerable to sea-surface temperature increases; together with the effects of ocean acidification, this exposes coral reefs to more severe thermal stress, resulting in bleaching. Rising sea surface temperatures have already led to major, damaging coral bleaching events[58] in the last few decades. Under 1.5°C warming, there is a high risk (50-percent probability) of annual bleaching events occurring as early as 2030 in the

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52 Extremes are defined by present-day, local natural year-to-year variability of around 1°C, which are projected to be exceeded frequently even with low levels of average warming. Unprecedented = record breaking over the entire measurement recording period.

53 Defined by historical variability, independent of emissions scenario, with temperature beyond the 90th percentile in the present-day climate.

54 Estimated as the share of the total annual precipitation.

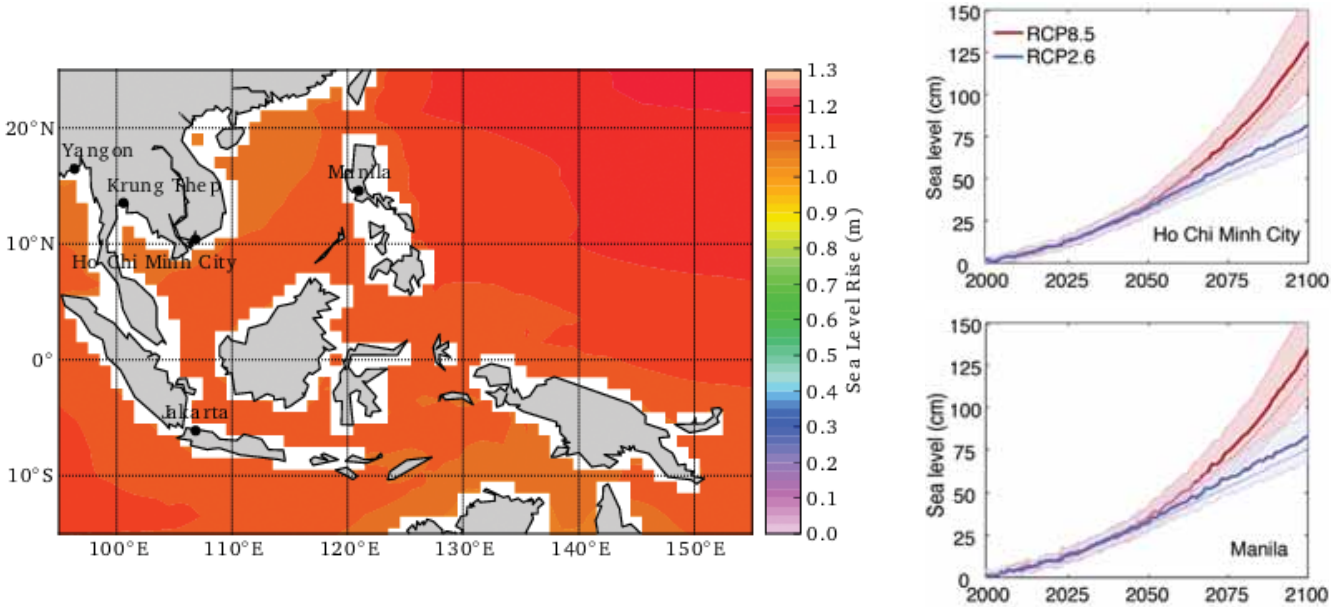
55 Where "likely" is defined as > 66 percent chance of occurring, using the modeling approaches adopted in this report.

56 1986–2005 levels.

57 Category 4 and 5 on the Saffir-Simpson wind scale.

58 Coral bleaching events can be expected when a regional, warm seasonal maximum temperature is exceeded by 1°C for more than four weeks, and bleaching becomes progressively worse at higher temperatures or longer periods over which the regional threshold temperature is exceeded. While coral reefs can survive a bleaching event, they are subject to high mortality and take several years to recover. When bleaching events become too frequent or extreme, coral reefs can fail to recover.

Figure 4.1: South East Asia - The regional pattern of sea-level rise in a 4°C world (left; RCP8.5) as projected by using the semi-empirical approach adopted in this report and time-series of projected sea-level rise for two selected cities in the region (right) for both RCP2.6 (2ºC world) and RCP8.5 (4°C world)



region. Projections indicate that all coral reefs are very likely to experience severe thermal stress by the year 2050 at warming levels of 1.5°C–2°C above pre-industrial levels. In a 2°C world, coral reefs will be under significant threat, and most coral reefs are projected to be extinct long before 4°C warming is reached with the loss of associated marine fisheries, tourism, and coastal protection against sea-level rise and storm surges.

Sector-based and Thematic Impacts

River deltas, such as the Mekong River Delta, experience regular flooding as part of the natural annual hydrological cycle. Such flooding plays an important economic and cultural role in the region's deltas. Climate change projections for sea-level rise and tropical cyclone intensity, along with land subsidence caused by human activities, would expose populations to heightened risks, including excess flooding, saltwater intrusion, and coastal erosion. These consequences would occur even though deltaic regions tend to be relatively resilient to unstable water levels and salinity. The three river deltas of the Mekong, Irrawaddy, and Chao Phraya, all with significant land areas below 2 m above sea level, are highly threatened by these risk factors.

Coastal cities with large and increasing populations and assets are exposed to climate-change-related risks, including increased tropical storm intensity, long-term sea-level rise, and sudden-onset fluvial and coastal flooding. Estimating the number of people exposed to the impacts of sea-level rise is made difficult by uncertainties inherent to sea-level rise projections, as well as population and economic growth scenarios. Bangkok,[59] Jakarta, Ho Chi Minh City, and Manila stand out as being particularly vulnerable to climate-driven impacts. Many millions in Bangkok and Ho Chi Minh City are projected to be exposed to the effects of a 50 cm sea-level rise[60] by the 2070s. High levels of growth of both urban populations and GDP further increase exposure to climate change impacts in these areas. Further, the effect of heat extremes are also particularly pronounced in urban areas due to the urban heat island effect, caused in large part by the density of buildings and the size of cities, which results in higher human mortality and morbidity rates in cities than in the rural surroundings. The urban poor are particularly vulnerable to environmental stresses; floods associated with sea-level rise and storm surges pose significant flood damage and health risks to populations in informal settlements. In 2005, about 40 percent of the urban population of Vietnam and 45 percent of the urban population in the Philippines lived in informal settlements.

Agricultural production in the region, particularly rice production in the Mekong Delta, is exposed to sea-level rise due to

[59] Without adaptation, the area of Bangkok is projected to be inundated resulting from flooding due to extreme rainfall events and sea-level rise increases from around 40 percent under a 15 cm sea-level rise above present levels (which could occur by the 2030s), to about 70 percent under an 88 cm sea-level rise scenario (which would be approached by the 2080s under 4°C warming).

[60] Assuming 50 cm local subsidence.

Table 4.1: Summary of climate impacts and risks in South East Asia[a]

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C[b] (2030s[c])	Around 2°C (2040s)	Around 3°C (2060s)	Around 4°C (2080s)
Regional warming		South China Sea warmed at average rate of 0.3–0.4°C per decade since the 1960s. Vietnam warmed at a rate of about 0.3°C per decade since 1971, more than twice the global average	Increasing frequency of warm nights	Warm nights in present-day climate the new normal		Almost all nights (~95 percent) beyond present-day warm nights
Heat extreme (in the Northern Hemisphere summer period)[d]	Unusual heat extremes	Virtually absent	50–60 percent of land	60–70 percent of land	85 percent of land	> 90 percent of land
	Unprecedented heat extremes	Absent 25–30 percentof land	30–40 percent of land	70 percent of land	> 80 percent of land	
Sea-level rise (above present)		About 20cm to 2010	30cm-2040s 50cm-2060s 75cm by 2080–2100	30cm-2040s 50cm-2060s 75cm by 2080–2100	30cm-2040s 50cm-2060 95cm by 2080–2100	30cm-2040s 50cm-2060 110cm by 2080–2100
Coral reefs		Unusual bleaching events	High risk of annual bleaching events occurring (50 percent probability) as early as 2030	Nearly all coral reefs projected to be experiencing severe bleaching		

[a] A more comprehensive table of impacts and risks for SSA is presented at the end of the Chapter.
[b] Years indicate the decade during which warming levels are exceeded in a business-as-usual scenario exceeding 4°C by the 2080s.
[c] Years indicate the decade during which warming levels are exceeded in a business-as-usual scenario, not in mitigation scenarios limiting warming to these levels, or below, since in that case the year of exceeding would always be 2100, or not at all.
[d] The mean across climate model projections is given. Illustrative uncertainty ranges across the models (minimum to maximum) for 4°C warming are 70–100 percent for unusual extremes, and 30–100 percent for unprecedented extremes. The maximum frequency of heat extreme occurrence in both cases is close to 100 percent as indicator values saturate at this level.

its low elevation above sea level. A sea-level rise of 30 cm, which could occur as early as 2040, is projected to result in the loss of about 12 percent of the cropping area of the Mekong Delta Province due to flooding (5 percent loss) and salinity intrusion (7 percent). Whilst some rice cultivars are more resilient than others, there is evidence that all rice is vulnerable to sudden and total inundation when this is sustained for several days, where flooding, sensitivity thresholds even of relatively resilient rice cultivars may be exceeded and production severely impacted. Temperature increases beyond thresholds during critical rice growth phases (tillering, flowering, grain filling) may further impact productivity.

Aquaculture, which is also at risk from several climate change impacts, is a rapidly growing and economically important industry in South East Asia. In Vietnam, for example, it has grown rapidly; in 2011, it generated about 5 percent of its GDP, up from about 3 percent in 2000. Rapid sectoral growth has also been observed in other South East Asian countries. Aquaculture also supplies nearly 40 percent of dietary animal protein in South East Asia derived from fish, and is thus critical to food security in the region. Aquaculture farms are projected to be damaged by increasingly intense tropical cyclones and salinity intrusion associated with sea-level rise, particularly for freshwater and brackish water aquaculture farms. In addition increasing temperatures may exceed the tolerance thresholds of regionally important farmed species. Extreme weather events, such as tropical cyclones and coastal floods, already affect aquaculture activities in South East Asia. For example, the category 4 Typhoon Xangsane devastated more than 1,200 hectares of aquaculture area in Vietnam in 2006 while the Indonesian Typhoons Vincente (Category 4) and Saola (Category 2) negatively impacted about 3,000 aquaculture farmers and resulted in over $9 million in damages to the fishery sector (Xinhua, 2012).

Fisheries, particularly coral reef fisheries, are expected to be effected by the impacts of sea-level rise, warmer oceans, and ocean acidification associated with rising atmospheric and ocean CO_2 concentrations. Substantial reductions in catch potential are projected. The projected changes in maximum catch potential range from a 16-percent decrease in the waters of Vietnam to a 6–16 percent increase around the northern Philippines. Additionally, marine capture fisheries production (not directly associated with coral systems) are projected to decline by 50 percent around the southern Philippines. Such shifts in catch potential are likely to place additional challenges on coastal livelihoods in the region.

Integrated Synthesis of Climate Change Impacts in the South East Asia Region

South East Asia is highly and increasingly exposed to slow onset impacts associated with sea-level rise, ocean warming and acidification, coral bleaching, and associated loss of biodiversity, combined with sudden-onset impacts associated with increased tropical cyclone intensity and greater heat extremes. The combined impacts are likely to have adverse effects on several sectors simultaneously. The cumulative effects of the slow-onset impacts may undermine resilience and increase vulnerability to more extreme weather events, with this complex pattern of exposure increasing with higher levels of warming and sea-level rise.

Growing Risks to Populations, Livelihoods and Food Production in River Deltas

Populations and associated cropping and fisheries systems and livelihoods along the rivers and in the river deltas are expected to be the most severely affected by risks from rising sea levels, more intense rainfall events, and storm surges associated with tropical cyclones.

For example, the Mekong River and its tributaries are crucial to rice production in Vietnam. A total of 12 provinces constitute the Mekong Delta, popularly known as the "Rice Bowl" of Vietnam; it is home to some 17 million people, of whom 80 percent are engaged in rice cultivation. The delta produces around 50 percent of the country's total production and contributes significantly to Vietnam's rice exports. Any shortfall in rice production in this area because of climate change would not only affect the economy in and food security of Vietnam but would also have repercussions for the international rice market.

The Mekong Delta is also Vietnam's most important fishing region. It is home to almost half of Vietnam's marine fishing vessels and produces two thirds of Vietnam's fish from aquaculture systems. Important industries such as aquaculture are projected to suffer increasing costs and damages associated with salinization and rising temperatures. Observed human vulnerability in deltas in the region is high: When tropical cyclone Nargis[61] hit the Irrawaddy River Delta in Myanmar in 2008 it resulted in over 80,000 deaths, temporarily displaced 800,000 people, submerged large areas of farming land, and caused substantial damage to food production and storage.

Health impacts associated with saltwater intrusion are likely to increase. Sea-level rise and tropical cyclones may increase salinity intrusion, thereby contaminating freshwater resources—an effect that can persist for years. The most common health implication is hypertension; however there are a broad range of health problems potentially linked to increased salinity exposure through bathing, drinking, and cooking. These include miscarriages, skin disease, acute respiratory infection, and diarrheal disease.

Increasing Pressure on Coastal Cities and Urban Exposure

Especially in South East Asia, coastal cities concentrate increasingly large populations and assets exposed to increased tropical storm intensity, long-term sea-level rise, sudden-onset coastal flooding, and other risks associated with climate change. Without adaptation, Bangkok is projected to be inundated due to extreme rainfall events and sea-level rise increases from around 40 percent under a 15 cm sea-level rise above present levels (which could occur by the 2030s) to about 70 percent under an 88 cm sea-level rise scenario (which could occur by the 2080s under 4°C warming). The effect of heat extremes are particularly pronounced in urban areas due to the urban heat island effect; this could result in high human mortality and morbidity rates in cities. These risks are particularly acute, as in the Philippines and Vietnam, where almost 40 percent of the population lives in informal settlements, where health threats can quickly be exacerbated by a lack of, and/or damage to, sanitation and water facilities. The high population density in such areas compounds these risks.

The projected degradation and loss of coral reefs, decreased fish availability, and pressures on other near-coastal rural production due to sea-level rise within the next few decades is likely to lead to diminishing livelihoods in coastal and deltaic areas. Increased migration to urban areas has already been occurring. Urban migration may result in more urban dwellers being exposed to climate impacts in the cities of South East Asia, especially new arrivals who are likely to crowd into existing and densely populated informal settlements.

Compound Risks to the Tourism Industry and to Businesses

Projected increases in sea-level rise, the intensity of tropical cyclones, and the degradation and loss of coral reefs pose significant risks to the tourism industry by damaging infrastructure and natural resources and assets that enhance the region's appeal as a tourist destination. Research indicates that the threat of tropical cyclones appears to have a negative effect on tourists' choice of destination on the same scale as deterrents such as terrorist attacks and political crises.

Loss of coastal assets due to erosion has already been observed and can be expected to accelerate. Sea-level rise has already contributed directly to increased coastal erosion in the Red River Delta and other regions. Coastal erosion in the Mekong River Delta is expected to increase significantly under a 100 cm sea-level rise by 2100. Projected beach losses for the San Fernando Bay area of the Philippines will substantially affect beach assets and a considerable number of residential structures.

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61 Land fall as a Category 4 storm on the Saffir-Simpson scale.

Coral bleaching and reef degradation and losses are very likely to accelerate in the next 10–20 years; hence, revenue generated from diving and sport fishing also appears likely to be affected in the near term. The degradation of coral reefs could result in the loss of fisheries and the coastal protection offered by reefs, as well as the loss of tourists upon whom coastal populations and economies often depend.

The risks and damages projected for a warming level of 1.5–2°C in South East Asia are very significant. The physical exposure to climate change at this level of warming includes substantial areas of South East Asia subjected to unprecedented heat extremes, 50 cm of sea-level rise by the 2050s and 75 cm or more by 2100. The biophysical damages projected include the loss of large areas of coral reefs, significant reductions in marine food production, and more intense tropical cyclones with related storm surges and flooding. Substantial losses of agricultural production in important rice-growing regions are projected to result from sea-level rise, as is the risk of significant flooding in major coastal cities. Significant damages to the tourism industry and to aquaculture are also projected.

Introduction

This report defines South East Asia as Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Papua New Guinea, the Philippines, Singapore, Thailand, Timor-Leste, and Vietnam. Specific attention is given to Vietnam and the Philippines. For the projections on changes to temperature, precipitation, and sea-level rise, the definition of South East Asia from the IPCC´s special report on (SREX) region 24 is used.[62]

Despite continued strong economic growth and a burgeoning middle class, poverty and inequality remain significant challenges in the region. The socioeconomic conditions in these countries are diverse in terms of population size, income, and the distribution of the inhabitants across urban and rural areas. In addition, a number of geographic factors influence the nature and extent of the physical impacts of climate change. Parts of South East Asia are located within a tropical cyclone belt and are characterized by archipelagic landscapes and relatively high coastal population density. This makes the region particularly vulnerable to the following impacts:

- Sea-level rise
- Increases in heat extremes
- Increased intensity of tropical cyclones
- Ocean warming and acidification

These physical impacts are expected to affect a number of sectors, including human health, tourism, aquaculture, and fisheries. Although changes to precipitation and temperature are expected to have adverse effects on terrestrial ecosystems, these and other critical biophysical impacts are outside the scope of this report.

River deltas and coastal areas are a key focus of this regional analysis; these are areas where many of these impacts occur and they pose severe risks to coastal livelihoods. Further attention is given to coastal cities, which are often situated in these deltas and contain a high concentration of people and assets.

Regional Patterns of Climate Change

Making climate projections for South East Asia is challenging due to the complex terrain, the mix of mainlands, peninsulas, and islands, the related regional sea-land interactions, and the large number of complex climate phenomena characterizing the region. The region's climate is mainly tropical and determined by the East Asian monsoon, a sub-system of the Asian-Australian monsoon, which is interconnected with the Indian monsoon (P. Webster 2006).

Observed Trends

Observed trends show a mean temperature increase around the South East Asian Seas at an average rate of between 0.27–0.4°C per decade since the 1960s (Tangang, Juneng, and Ahmad 2006) and, for Vietnam, a rate of about 0.26°C per decade since 1971 (Nguyen, Renwick, and McGregor 2013). This is more than twice the global average rate of about 0.13°C per decade for 1956–2005 (P. D. Jones et al. 2007). Trends in extreme temperature reveal a significant increase in hot days and warm nights and a decrease in cool days and cold nights (Manton et al. 2001). There is some indication of an increase in total precipitation, although these trends are not statistically robust and are spatially incoherent (Caesar et al. 2011). While regionally different, an increase in frequency and intensity of extreme precipitation events is reported (Chang 2010).

Projected Temperature Changes

In a 4°C world the subset of CMIP5 GCMs used within the ISI-MIP framework and this report projects South East Asian summer temperatures over land to increase by 4.5°C (model range from 3.5°C to 6°C) by 2100 (Figure 4.2). This is substantially lower than the global-mean land-surface warming, since the region's climate is driven by sea surface temperature, which is increasing at a smaller rate. In a 2°C world, the absolute summer warming

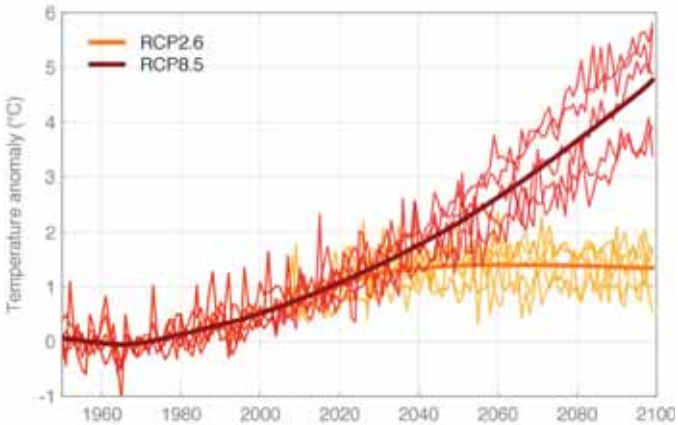
[62] With minor changes at the northern boundary.

would be limited to around 1.5°C (model spread from 1.0–2.0°C) above the 1951–1980 baseline, to be reached in the 2040s. The strongest warming is expected in North Vietnam and Laos, with the multimodel mean projecting up to 5.0°C under 4°C global warming by 2071–2099 and up to 2°C under 2°C global warming (Figure 4.3). The expected future warming is large compared to the local year-to-year natural variability. In a 4°C world, the monthly temperature distribution of almost all land areas in South East Asia shifts by six standard deviations or more toward warmer values. In a 2°C world, this shift is substantially smaller, but still about 3–4 standard deviations.

Projected Changes in Heat Extremes

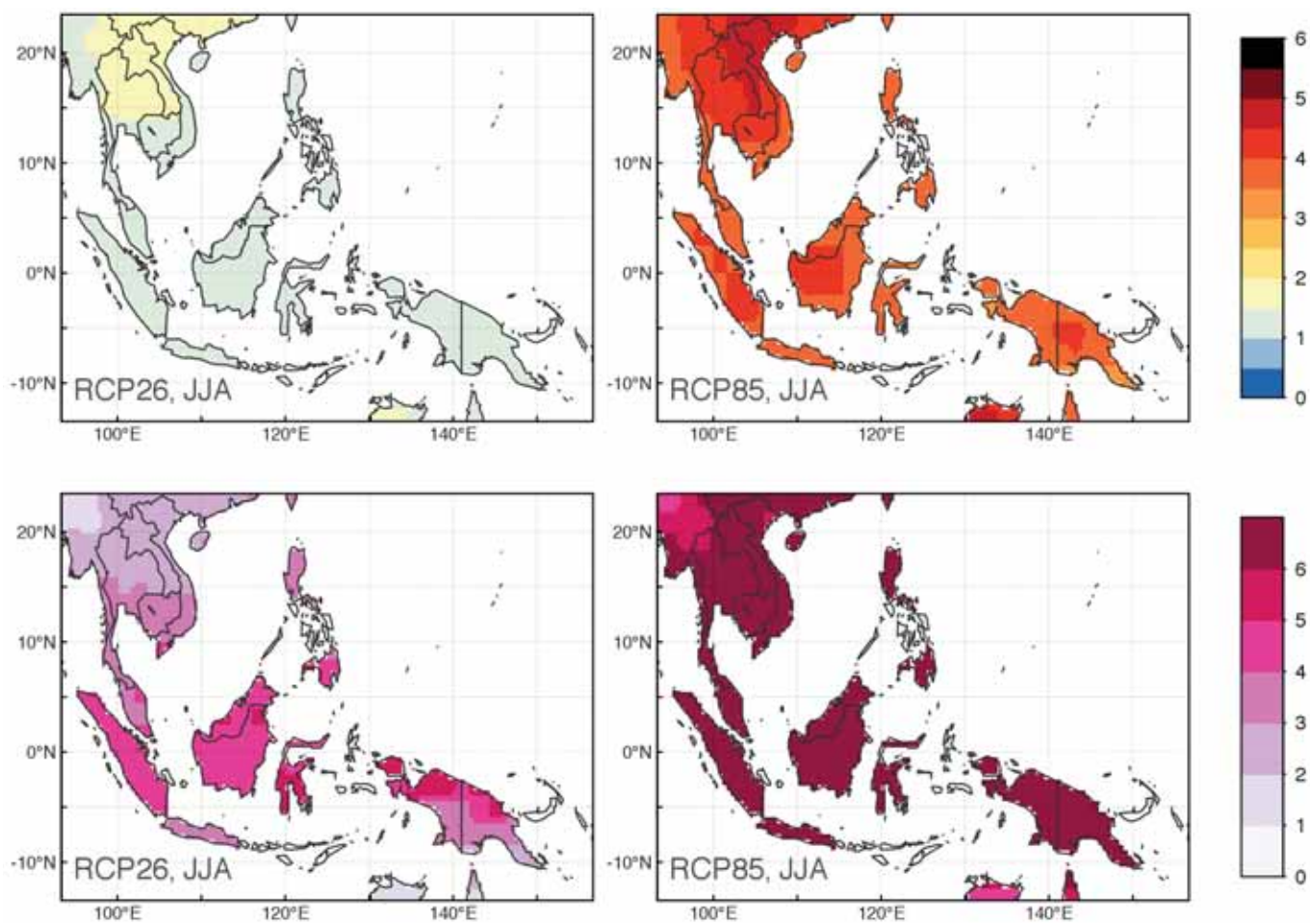
Heat extremes exceeding a threshold defined by the local natural year-to-year variability are projected to strongly increase in South

Figure 4.2: Temperature projections for South East Asian land area, for the multi-model mean (thick line) and individual models (thin lines) under RCP2.6 and RCP8.5 for the months of JJA



The multi-model mean has been smoothed to give the climatological trend.

Figure 4.3: Multi-model mean temperature anomaly for RCP2.6 (left) and RCP8.5 (right) for the months of JJA for South East Asia



Temperature anomalies in degrees Celsius (top row) are averaged over the time period 2071–99 relative to 1951–80, and normalized by the local standard deviation (bottom row).

East Asia (Figures4.4 and 4.5). Even under the 2°C warming scenario, the multimodel mean projects that, during the second half of the 21st century, 30 percent of the South East Asian land area would be hotter than 5-sigma during boreal summer months (see Figure 4.5). Under the 4°C warming scenario, this value approaches 90 percent by 2100. It should be noted, however, that the model spread is large, as the averaging is performed over a small land surface area.

The strongest increases in frequency and intensity of extremes are projected for Indonesia and the southern Philippine islands (see Figure 4.4). Roughly half of the summer months is projected to be beyond 5-sigma under the 2°C warming scenario (i.e., 5-sigma would become the new normal) and essentially all summer months would be 5-sigma under the 4°C warming scenario (i.e., a present-day 5-sigma event would be an exceptionally cold month in the new climate of 2071–99). Mainland South East Asia is projected to be much less impacted; the conditions that are projected for Indonesia under the 2°C warming scenario only occur inland under the 4°C warming scenario. Thus, in the near term, the South East Asian region is projected to see a strong increase in monthly heat extremes, defined by the limited historical variability, independent of emissions scenario.

Consistent with these findings, Sillmann and Kharin (2013a) report that South East Asia is one of two regions (the other being the Amazon) where the number of heat extremes is expected to increase strongly even under a low-emission scenario (although the inter-model spread is substantial). Under a low-emission scenario, warm nights (beyond the 90th percentile in present-day climate) would become the new normal, with an occurrence-probability around 60 percent. In addition, the duration of warm spells would increase to somewhere between 45 and 90 days, depending on the exact location. Under emission scenario RCP8.5, warm spells

Figure 4.4: Multi-model mean of the percentage of boreal summer months in the time period 2071–2099 with temperatures greater than 3-sigma (top row) and 5-sigma (bottom row) for scenario RCP2.6 (left) and RCP8.5 (right) over South East Asia

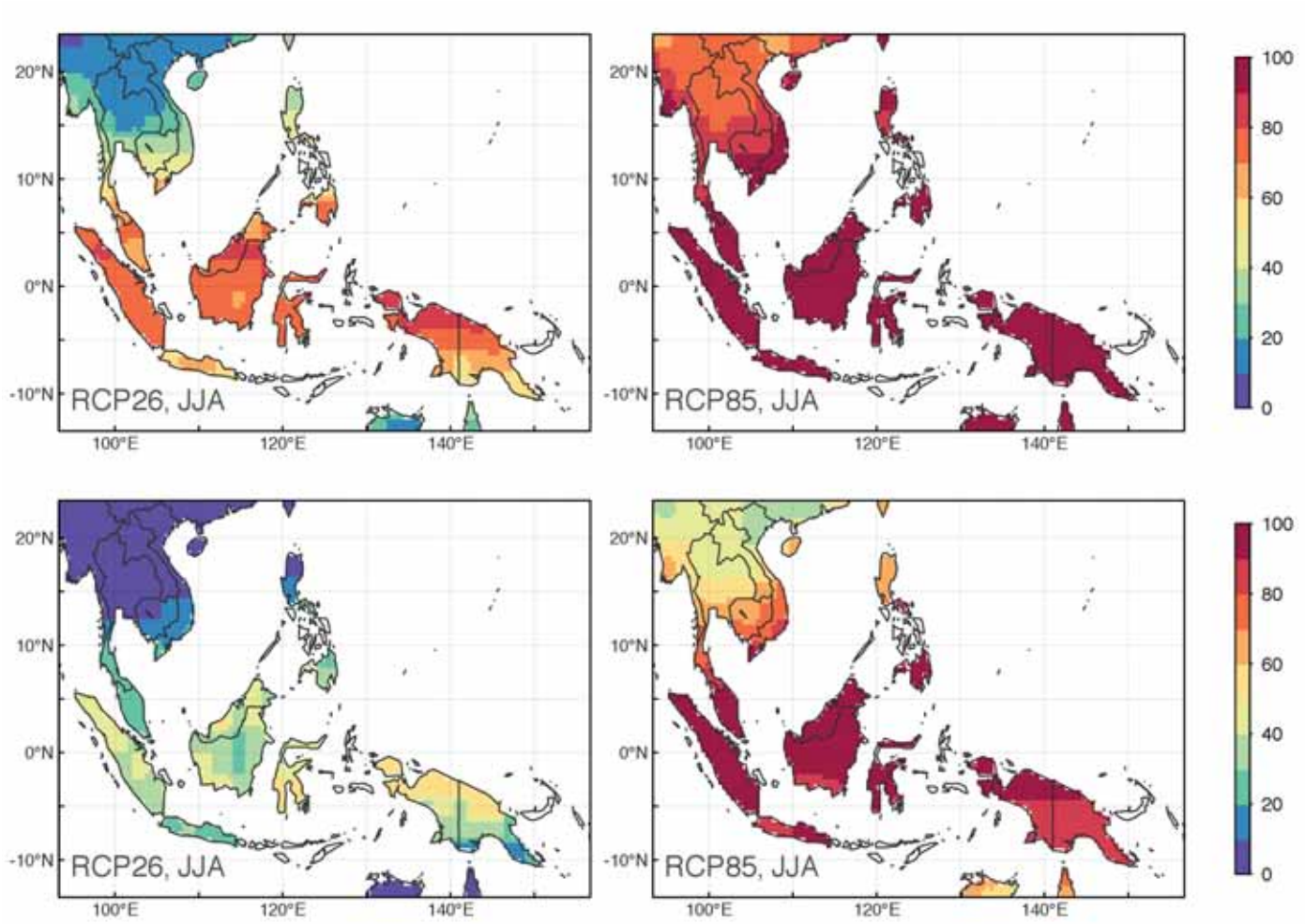
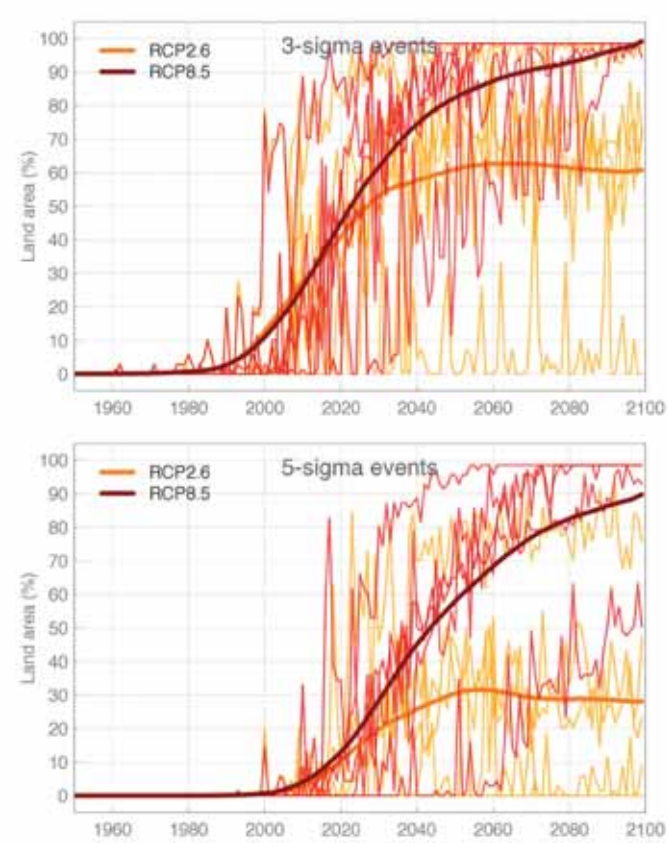


Figure 4.5: Multi-model mean (thick line) and individual models (thin lines) of the percentage of South East Asian land area warmer than 3-sigma (top) and 5-sigma during boreal summer months (JJA) for scenarios RCP2.6 and RCP8.5



would become nearly year-round (~300 days), and almost all nights (~95 percent) would be beyond the present-day 90th percentile (Sillmann and Kharin 2013a).

Precipitation Projections

While multimodel ensembles of GCMs do manage to represent monsoon systems, the difference is large among individual models; some completely fail in reproducing the observed patterns. The monsoon mechanisms in South East Asia are particularly hard to reproduce as both the Asian and the Australian summer monsoons affect the region (Hung, Liu, and Yanai 2004). Nicolas C. Jourdain et al. (2013) present monsoon projections based on CMIP5 models that perform best in reproducing present-day circulation patterns. Although they report an increase of 5–20 percent monsoon rainfall over the whole Indo-Australian region in the second half of the 21st century for 4°C warming, there is no agreement across models over South East Asia. The changes are either not statistically significant or range from a decrease of 5 percent to an increase of 10 percent in monsoon rainfall.

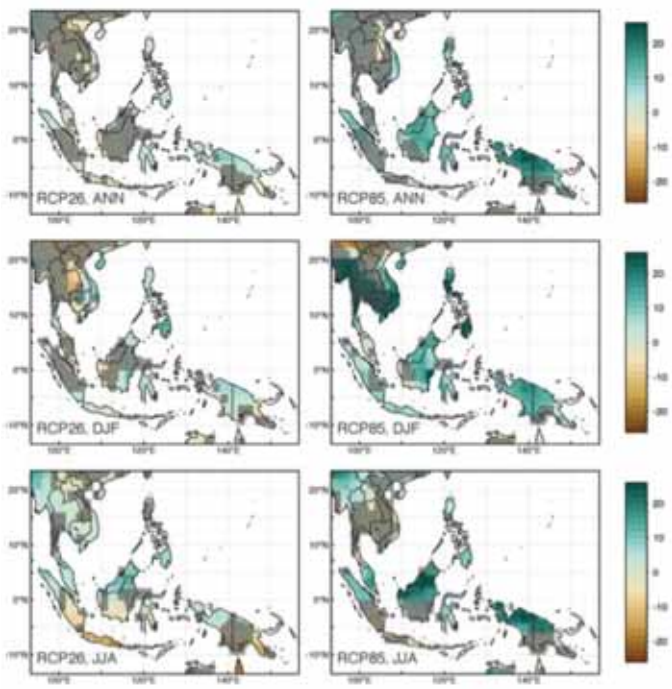
For the CMIP5 models included in the ISIMIP project (Figure 4.6), there is little change in annual mean precipitation over Vietnam and the Philippines in a 2°C world and a slight increase in a 4°C world relative to the 1951–80 reference period. Again, there is very little model agreement for this region. Precipitation appears to increase by about 10 percent during the dry season (DJF) for the 2°C warming scenario and more than 20 percent for the 4°C warming scenario—but it is important to note that these increases are relative to a very low absolute precipitation over the dry season.

In the Mekong River Basin, a United States Agency for International Development (2013) study[63] projects an increase in annual rainfall precipitation ranging from 3–14 percent. Seasonal variability is projected to increase; the wet season would see a rise in precipitation between 5–14 percent in the southern parts of the basin (southern Vietnam and Cambodia). In this area, as a consequence, the wet season is expected to become wetter and the dry season drier. Drier areas in the north of the basin are projected to experience relative increases in precipitation of 3–10 percent, corresponding to a slight increase of 50 to 100 mm per year.

Although global climate models are needed to project interactions between global circulation patterns of atmosphere and ocean, regional models, which offer a higher spatial resolution, provide a way to take into account complex regional geography. Chotamonsak, Salathé, Kreasuwan, Chantara, and Siriwitayakorn (2011) use the WRF regional climate model for studying climate change projections over South East Asia. Lacking global circulation patterns and interactions across regions, regional models need conditions at the model's boundaries prescribed by global models, for which the authors apply results from ECHAM5 for the A1B scenario by mid-century (about 2°C warming globally). Likewise, Lacombe, Hoanh, and Smakhtin (2012) use the PRECIS regional model—for mainland South East Asia only—with boundary conditions from ECHAM4 under the IPCC SRES scenario A2 and B2 (about 2°C warming globally). These studies find that the largest changes in annual mean precipitation, as well as the extremes, occur over the oceans. For land areas, the regional models largely confirm mean changes of global models (see Figure 4.6), with somewhat increased precipitation over the mainland. Chotamonsak et al. (2011) warn that such regional studies should be expanded with boundary conditions of multiple global models. They further note that changes in mean and

63 The United States Agency for International Development (2013) report projects the impacts of climate change for the period 2045–69 under the IPCC SRES scenario A1B (corresponding to about a 2.3°C temperature increase above pre-industrial levels) for the Lower Mekong Basin. For the study, authors used six GCMs (NCAR CCSM 3.0; MICRO3.2 hires; GISS AOM; CNRM CM3; BCCR BCM2.0; GFDL CM2.1) and used 1980–2005 as a baseline period.

Figure 4.6: Multi-model mean of the percentage change in annual (top), dry season (DJF, middle) and wet season (JJA, bottom) precipitation for RCP2.6 (left) and RCP8.5 (right) for South East Asia by 2071–99 relative to 1951–80



Hatched areas indicate uncertainty regions, with models disagreeing on the direction of change.

extreme precipitation in a regional model over South East Asia might be biased, since high-resolution models produce stronger spatial and temporal variability in tropical cyclones, which in one single model run might not be representative of the broader statistical probability.

Based on their projected changes in precipitation and temperature over mainland South East Asia only, Lacombe et al. 2012 suggest that these changes may be beneficial to the region and generate higher agricultural yields, as precipitation and temperatures may increase in the driest and coldest areas respectively. However, as the authors modelled only changes in climate variables and not in agricultural yields, and did not place their results into the context of literature on projections of the agricultural sector, there is little analytical evidence to support their assertion.[64]

Drought

Dai (2012) used global models to project changes in drought, resulting from the long-term balance of temperature, precipitation, and other variables. While soil-moisture content was projected to decrease over much of the mainland and southern Indonesia, increases were projected for Myanmar and other maritime parts of the region. None of the changes were found to be statistically significant. A different indicator of drought, the Palmer Drought Severity Index (PDSI), relates changes in water balance to locally "normal" conditions. On this relative scale, the projected pattern of drought risk is comparable. By contrast, Taylor et al. (2012) noted a consistent increase in drought risk indicated by PDSI for the whole region, with no significant change across Myanmar.

Extreme Precipitation Events

Despite the projections of moderate changes in mean precipitation, a substantial increase in the magnitude and frequency of heavy precipitation events is projected for South East Asia based on CMIP5 models (Sillmann and Kharin 2013a). The median increase of the extreme wet day precipitation share of the total annual precipitation is projected to be greater than 10 percent and 50 percent for 2°C and 4°C warming scenarios respectively. At the same time, the maximum number of consecutive dry days as a measure of drought is also projected to increase, indicating that both minimum and maximum precipitation extremes are amplified.

This general picture arising from global model results is confirmed by higher-resolution regional modeling studies (Chotamonsak et al. 2011; Lacombe et al. 2012), which add that the largest increase in extreme precipitation, expressed by an index combining changes in frequency and intensity, occurs over the oceans and over Cambodia and southern Vietnam.

Tropical Cyclone Risks

Tropical cyclones (TCs) pose a major risk to coastal human systems. In combination with future sea-level rise, the risk of coastal flooding due to strong TCs is already increasing and could be amplified in the event of future TC intensification (R. J. Nicholls et al. 2008). Tropical cyclones are strongly synoptic to meso-scale, low-pressure systems, which derive energy primarily from evaporation from warm ocean waters in the presence of high winds and low surface pressure and from condensation in convective clouds near their center (Holland 1993). According to their maximum sustained wind speed, tropical low-pressure systems are categorized from tropical depressions (below 63 km/h), tropical storms (63–118 km/h), and tropical cyclones (119 km/h and larger).

[64] In addition, the modeled increase in mean precipitation only concerns Myanmar, for which the regional model of Chotamonsak et al. (2011) shows little change, while the temperature increase seems fairly uniform over mainland South East Asia and the largest increases reported by Lacombe et al. (2012) are found over eastern India and southern China—which is confirmed by Chotamonsak et al. (2011).

According to the Saffir-Simpson hurricane wind scale, TCs can be further classified into five categories according to their wind speed and resulting sea-level rise.

South East Asian Context

In South East Asia, tropical cyclones (TCs) are called typhoons and affect vast parts of the region, particularly the islands and coastal areas of the mainland. Most TCs reaching landfall in South East Asia originate from the western North Pacific basin, the region with the highest frequency of TCs in the world (Holland 1993). There are also some TCs that develop in the northern Indian Ocean basin, specifically in the Bay of Bengal.

Strong TCs have a devastating impact on human settlements, infrastructure, agricultural production, and ecosystems, with damages resulting from flooding due to heavy rainfall, high wind speeds, and landslides (Peduzzi et al. 2012) (Box 4.1). Storm surges associated with tropical cyclones can temporarily raise sea levels by 3–10 meters (Syvitski et al. 2009).

Observed Trends in Tropical Cyclone Frequency and Intensity

The influence of recent climate changes on past TC frequency and intensity is uncertain and shows low confidence regarding detectable long-term trends (Peduzzi et al. 2012). Recent analyses reveal neither a significant trend in the global TC frequency from 1970 to 2004 nor significant changes for individual basins worldwide. The North Atlantic is the notable exception (Knutson et al. 2010). The western North Pacific and northern Indian Ocean do not exhibit a recent change in TC frequency. For example, the number of land-falling TCs in Vietnam and the Philippines does not display a significant long-term trend over the 20th century (Chan and Xu 2009); there is, however, a distinct positive correlation with the phasing of the ENSO (Kubota and Chan 2009). During the same time, western North Pacific TCs exhibited a weak increase in intensity (Intergovernmental Panel on Climate Change 2012) and a significant co-variation with ENSO, with a tendency toward more intense TCs during El Niño years (Camargo and Sobel 2005). This was probably mediated by the associated sea-surface temperature patterns (Emanuel 2007; Villarini and Vecchi 2012).

In contrast to the general absence of a global trend in total TC frequency, there has been a clear upward trend in the global annual number of strong category 4 and 5 tropical cyclones since 1975, as seen in the western North Pacific (1975–89: 85; 1990–2004: 116) and the Northern Indian Ocean (1975–89: 1; 1990–2004: 7) (P. J. Webster, Holland, Curry, and Chang 2005). For the time period 1981–2006, there have been significant upward trends in the lifetime maximum TC wind speeds both globally and for the western North Pacific and Northern Indian Ocean basins (Elsner, Kossin, and Jagger 2008a), with the 30-percent strongest TCs shifting to higher maximum wind speeds.

The relationship between TC intensity and damage potential is generally highly non-linear. This implies that increases in the intensity of the strongest TCs can outperform even a decrease in the overall number of typhoons. Indeed, the observed tendency toward stronger TCs both globally and in South East Asia is accompanied by increasing economic losses. These are also strongly related to robust population and economic growth, especially in the most vulnerable low-lying coastal areas (Peduzzi et al. 2012).

Box 4.1: Observed Vulnerability

Category 4 Tropical Cyclone Nargis, which inundated a wide area up to six meters above sea level in the Irrawaddy River Delta in Myanmar in 2008, illustrates the region's vulnerability to these extreme weather events. Nargis´ official death toll was approximately 84,000, with 54,000 people missing in the aftermath of the disaster. Overall, 2.4 million people were affected and 800,000 people were temporarily displaced (Association of South East Asian Nations 2008). The cyclone severely affected the agricultural sector. The equivalent of 80,000 tons of agricultural production and 251,000 tons of stored crops were damaged, and approximately 34,000 hectares of cropland were affected. Nargis' cumulative damage to farm equipment and plantation crops accounted for Kyatt 47 billion, equal to about $55 million (Association of South East Asian Nations 2008).

Severe damage and losses have also occurred in Vietnam in recent years due to cyclones, including Xangsane in 2006. In the Philippines, 7–8 cyclones make landfall every year (Yumul, Cruz, and Servando 2011).

Projected Changes in Tropical Cyclones

The changes in tropical cyclones as a result of future climate change need to distinguish between TC frequency and TC intensity. Most literature on TC projections draws from climate model runs that reach on average about 3.5°C warming above pre-industrial levels. There appear to be no recent studies on TC projections for global-mean warming levels of 2°C.

Tropical Cyclone Frequency

On a global scale, TC frequencies are consistently projected to either decrease somewhat or remain approximately unchanged by 2100, with a less robust decrease in the Northern Hemisphere (Emanuel, Sundararajan, & Williams 2008; Knutson et al. 2010). Model projections vary by up to 50 percent for individual ocean basins.

Future changes in TC frequency are uncertain for the western North Pacific, which includes the South China Sea and the Philippine Sea and borders mainland South East Asia and countries

like the Philippines and Malaysia. Studies that use atmospheric models that explicitly simulate TCs generally show an overall decrease in the frequency of TCs over this basin as a whole, with some exceptions (Sugi et al. 2009; Knutson et al. 2010; Held and Zhao 2011; Murakami et al. 2012). By contrast, projections of indices for cyclogenesis (the likelihood of TCs developing and hence an indicator of frequency) generally show an increase under warming for multimodel ensembles (Caron and Jones 2007; Emanuel et al. 2008). However, recent work (Zhao and Held 2011) shows that the statistical relationships between cyclogenesis parameters and the frequency of TCs, which are strong in most ocean basins, break down in the western North Pacific. This is particularly the case with the South China Sea, possibly because the interactions between monsoon circulation, sea-surface temperatures, and cyclone activity are not properly accounted for through commonly applied cyclogenesis parameters. Within the western North Pacific basin, the different methods and models generally agree on a north and/or eastward shift of the main TC development region (Emanuel et al. 2008; Held and Zhao 2011; Kim, Brown, and McDonald 2010; Li et al. 2010; Yokoi and Takayabu 2009); the strongest agreement across models and methods on a decrease in frequency is found for the South China Sea (Held and Zhao 2011; Murakami, Sugi, and Kitoh 2012; Yokoi and Takayabu 2009). In a recent study, these changes lead to a decrease in frequency of TCs making landfall of 35 percent and 10 percent for mainland South East Asia and the Philippines respectively (Murakami et al. 2011).

Tropical Cyclone Intensity

Future surface warming and changes in the mean thermodynamic state of the tropical atmosphere lead to an increase in the upper limit of the distribution of TC intensities (Knutson et al. 2010), which was also observed over the years 1981–2006 (Elsner, Kossin, and Jagger 2008). Consistently, the number of strongest category 5 cyclones is projected to increase in the western North Pacific, with both mean maximum surface wind speed and lifetime maximum surface wind speed during TCs projected to increase statistically significantly by 7 percent and 18 percent, respectively, for a warming of about 3.5°C above pre-industrial levels (Murakami et al. 2012). The average instantaneous maximum wind speed of TCs making landfall is projected to increase by about 7 percent across the basin (Murakami et al. 2012), with increases of 6 percent and 9 percent for mainland South East Asia and the Philippines, respectively (Murakami et al. 2011).

With higher sea-surface temperatures, atmospheric moisture content is projected to increase over the 21st century, which might lead to increasing TC-related rainfall. Various studies project a global increase in storm-centered rainfall over the 21st century of between 3–37 percent (Knutson et al. 2010). For the western North Pacific, a consistent corresponding trend is found, with rates depending on the specific climate model used (Emanuel et al. 2008).

Regional Sea-level Rise

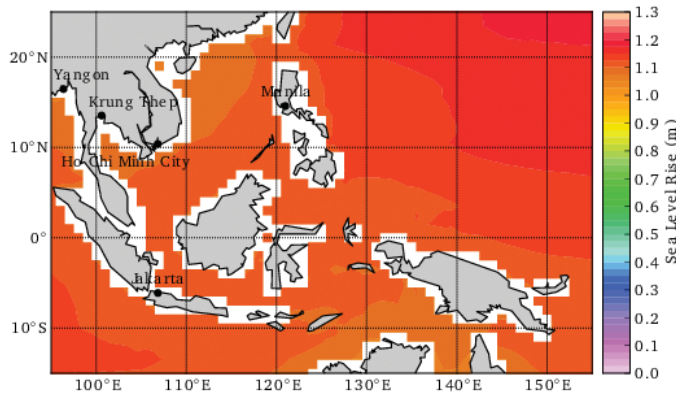
As explained in Chapter 2, current sea levels and projections of future sea-level rise are not uniform across the world. South East Asian coastlines stretch roughly from 25° north to 15° south latitude. Closer to the equator, projections of local sea-level rise generally show a stronger increase compared to higher latitudes. Land subsidence, in the tropics mainly induced by human activities, increases the risks to coastal areas due to sea-level rise. Without taking land subsidence into account, sea-level rise in the region is projected to reach up to 100 cm and 75 cm by the 2090s in a 4°C and 2°C world, respectively.

Climate Change-induced Sea-level Rise

Due to the location of the region close to the equator, sea-level rise along the South East Asian coastlines projected by the end of the 21st century relative to 1986–2005 is generally 10–15 percent higher than the global mean. Figure 4.7 shows the regional sea-level rise in 2081–2100 in a 4°C world. As described in Chapter 2, these projections rely on a semi-empirical approach developed by (Rahmstorf (2007) and Schaeffer, Hare, Rahmstorf, and Vermeer (2012) for global-mean rise, combined with Perrette, Landerer, Riva, Frieler, and Meinshausen (2013) to derive regional patterns.[65]

Figure 4.8 shows a time series for locations in South East Asia that receive special attention in Chapter 4 under "Risks to Coastal Cities" and "Coastal and Marine Ecosystems." In a 4°C world, locations in South East Asia are projected to face a sea-level rise around 110 cm (66 percent uncertainty range 85–130) by 2080–2100

Figure 4.7: Regional sea-level rise projections for 2081–2100 (relative to 1986–2005) under RCP8.5



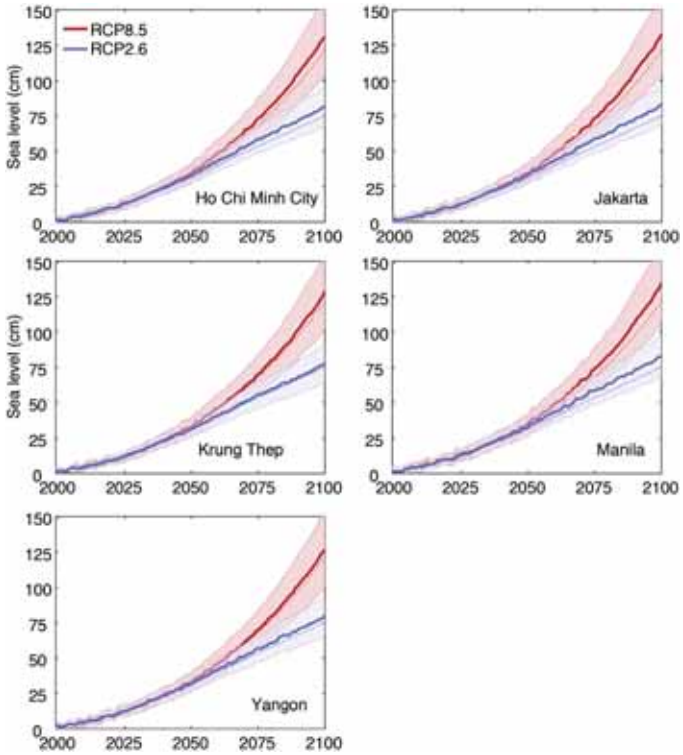
[65] More details on the methodology used to assess regional sea-level rise in the report can be found in Chapter 2 on "Sea-level Rise."

(a common time period in the impact studies assessed in the following sections). The rise near Yangon and Krung Thep (Bangkok) is a bit lower (by 5 cm). For all locations, sea-level rise is projected to be considerably higher than the global mean and higher than the other regions highlighted in this report, with Manila at the high end. For these locations, regional sea-level rise is likely (> 66 percent chance) to exceed 50 cm above 1986–2005 levels by about 2060 and 100 cm by 2090, both about 10 years before the global mean exceeds these levels.

In a 2°C world, the rise is significantly lower for all locations, but still considerable at 75 (66 percent uncertainty range 65–85) cm. An increase of 0.5 meters is likely exceeded by about 2070, only 10 years after this level is exceeded under a pathway that reaches 4°C warming by the end of the century. However, by the 2050s, sea-level rise in the 2°C and 4°C scenarios diverges rapidly and 1 meter is not likely to be exceeded until well into the 22nd century under 2°C warming.

It should be noted that these projections include only the effects of human-induced global climate change and not those due to local land subsidence.

Figure 4.8: Local sea-level rise above 1986–2005 mean level as a result of global climate change (excluding local change due to land subsidence by natural or human causes)



Shaded areas indicate 66-percent uncertainty range and dashed lines indicate the global mean sea-level rise.

Additional Risk Due to Land Subsidence

Deltaic regions are at risk of land subsidence due to the natural process whereby accumulating weight causes layers of sediment to become compressed. Human activities such as drainage and groundwater extraction significantly exacerbate this process, which increases the threat of coastal flooding. The most prominent examples of such anthropogenic subsidence are found at the mega-deltas of Mekong, Vietnam (6 mm per year); Irrawaddy, Myanmar (3.4–6 mm per year); and Chao Phraya, Thailand (13–150 mm) (Syvitski et al. 2009). The Bangkok metropolitan area in the Chao Phraya delta has experienced up to two meters of subsidence over the 20th century and a shoreline retreat of one kilometer south of the city (Robert J. Nicholls and Cazenave 2010). The coastal zone of Semarang, among the ten largest cities in Indonesia with about 1.5 million inhabitants and one of the most important harbors in Central Java, is another example of the impact of land subsidence. The area is increasingly affected, with an estimated area of 2,227 hectares lying below sea-level by 2020 (Marfai and King 2008).

Risks to Rural Livelihoods in Deltaic and Coastal Regions

Flooding as part of the natural annual cycle plays an important economic and cultural role in the Mekong and other river deltas (Warner 2010). Processes of sea-level rise and land subsidence, however, increase the vulnerability of human populations and economic activities such as agriculture and aquaculture to risks, including saltwater intrusion and coastal erosion. Cyclones and other extreme events exacerbate these threats.

Observed and Projected Biophysical Stressors in Deltaic and Coastal Regions

Deltaic and coastal regions are already vulnerable to the consequences of coastal flooding and tropical cyclones. It is projected that saltwater intrusion and coastal erosion will adversely impact human and economic activities carried out in these areas. Agriculture and aquaculture occurring in coastal and deltaic regions, which are strong components of South East Asian livelihoods, are projected to be significantly affected by climate change.

Vulnerability Context

South East Asian deltas are densely populated areas. The population density of the Mekong River Delta province, at 427 people per square kilometer, is the third highest in the country (General Statistics Office Of Vietnam 2011). The river deltas are also the region's rice bowls. The Mekong River Delta province is densely farmed and home to

approximately 47 percent of the farms in Vietnam (General Statistics Office Of Vietnam 2011). In 2011, this delta produced about 23.2 million tons of rice, or approximately 55 percent of the total Vietnamese rice production (General Statistics Office Of Vietnam 2013). The rice production of the Mekong Delta is of significant importance in terms of both food security and export revenues. In 2011, the Mekong River Delta produced 23.2 million tons of rice paddy (General Statistics Office Of Vietnam 2013); 18.4 million tons were supplied to the population. The Delta rice production represents about 125 percent of the Vietnamese rice supply for 2011. Furthermore, 72.4 percent of the aquaculture, an industry which accounts for nearly 5 percent of GDP in Vietnam, was located in the Mekong River Delta province in 2010 (General Statistics Office of Vietnam 2012).

Past flooding events have highlighted the vulnerability of the South East Asian deltas. Critical South East Asian rice-growing areas are already considered to be in increasingly greater peril (Syvitski et al. 2009). The area of land that lies below 2 m above sea level—which in the Mekong River Delta is as much as the total land area—is vulnerable to the risks associated with sea-level rise and land subsidence. The area affected by past storm surge and river flooding events indicates further vulnerability.

Table 4.2 shows the areas of land in the three main deltas in the region that are at risk.

Saltwater Intrusion

Saltwater intrusion poses risks to agricultural production as well as to human health. The movement of saline ocean water into freshwater aquifers can result in contamination of drinking water resources. For example, following high levels of saltwater intrusion in the Mekong River Delta in 2005, Long An province's 14,693 hectares of sugar cane production was reportedly diminished by 5–10 percent; 1,093 hectares of rice in Duc Hoa district were also destroyed (MoNRE 2010).

Factors Influencing Saltwater Intrusion

Salinity intrusion into groundwater resources occurs naturally to some extent in most coastal regions via the hydraulic connection between groundwater and seawater including through canals and drainage channels. Due to its higher density, saltwater can push inland beneath freshwater (Richard G. Taylor et al. 2012). Human activities (i.e., groundwater extraction from coastal wells that lowers the freshwater table, which is increasingly undertaken to expand shrimp farming) can considerably increase the level of saltwater intrusion and its extension inland (Richard G. Taylor et al. 2012; Ferguson and Gleeson 2012). In addition, long-term changes in climatic variables (e.g., precipitation, temperature) and land use significantly affect groundwater recharge rates and thus exacerbate the risk of saltwater intrusion associated with non-climatic drivers and reductions in inflows (Ranjan, Kazama, Sawamoto, and Sana 2009).

Sea-level rise and tropical cyclone-related storm surges may increase salinity intrusion in coastal aquifers (Werner and Simmons 2009; Anderson 2002; A. M. Wilson, Moore, Joye, Anderson, and Schutte 2011), thereby contaminating freshwater resources (Green et al. 2011; Richard G. Taylor et al. 2012). The effects of saltwater intrusion due to tropical cyclones remain long after the event itself; coastal aquifer contamination has been observed to persist for years (Anderson 2002). In the South East Asian mega-deltas, saltwater intrusion into coastal aquifers is expected to be more severely affected by storm surges than by mean sea-level rise (Taylor et al. 2012). The risk of saltwater intrusion is particularly relevant for smaller islands, where freshwater can only be trapped in small layers and the resulting aquifers are highly permeable (Praveena, Siraj, and Aris 2012).

There is an ongoing debate about the possible long-term effects of rising mean sea levels on saltwater intrusion. A case study in California revealed that groundwater extraction is a much larger contributor to saltwater intrusion than rising mean sea levels (Loáiciga, Pingel, and Garcia 2012). The response of coastal aquifers to seawater intrusion is highly non-linear, however, as depth, managerial status (volume of groundwater discharge), and timing of rise each act as critical factors determining the intrusion depth in response to even small rises in sea levels. This implies the potential existence of local tipping points, whereby a new state

Table 4.2: Areas at risk in South East Asian river deltas

Delta	Total Land Area (in km^2)	Area <2m Above Sea Level (km^2)	Area that Has Experienced Recent Flooding Due to Storm Surges (in km^2)	Area that Has Experienced Recent River Flooding (km^2)
Irrawaddy, Myanmar	20,571	1,100	15,000	7,600
Mekong, Vietnam	40,519 (for the Mekong River Delta Province)	20,900	9,800	36,750
Chao Phraya, Thailand	11,329	1,780	800	4,000

Source: Syvitski et al. (2009).

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is reached in which responses to small changes in conditions are large and can rapidly lead to full seawater intrusion into a coastal aquifer (Mazi, Koussis, and Destouni 2013).

Projections of Saltwater Intrusion

Salinity intrusion into rivers is projected to increase considerably for several South East Asian countries. In the case of the Mahakam river region in Indonesia, for example, the land area affected by saltwater intrusion is expected to increase by 7–12 percent under a 4°C warming scenario and a 100 cm sea-level rise by 2100 (Mcleod, Hinkel, et al. 2010). In the Mekong River Delta, it is projected that the total area affected by salinity intrusion with concentrations higher than 4 g/l will increase from 1,303,000 hectares to 1,723,000 hectares with a 30 cm sea-level rise (World Bank 2010b).

A United States Agency for International Development (2013) study[66] also projects changes in salinity intrusion under a 30 cm sea-level rise during the 2045–2069 period, which are expected to be moderate during the wet season but significantly more severe during the dry season. During the wet seasons, salinity intrusion levels are projected to be close to 1980–2005 levels, both in terms of maximum salinity and duration at a level of 4g per liter. During the dry season, salinity is expected to increase over 133,000 hectares located in the Mekong River Delta. Maximum salinity concentration is projected to increase by more than 50 percent compared to the reference period and the salinity level is projected to exceed 4g/l.

While recent work by Ranjan et al. (2009) concludes that most parts of South East Asia display a relatively low-to-moderate risk of saltwater intrusion into coastal groundwater resources, this is for a sea-level rise of only about 40 cm above 2000 by 2100, significantly lower than this report's projections.[67] Using the approach to sea-level rise in this report, sea-level rise under the A2 scenario (corresponding to a warming of approximately 4°C), is about 100 cm by 2100. This projected value for sea-level rise, as well as that for a 2°C world, is well above the value used by Ranjan et al. (2009) and would certainly lead to a greatly increased risk of saltwater intrusion.

Health Impacts of Saltwater Intrusion

Coastal aquifers provide more than one billion people living in coastal areas with water resources. Saltwater intrusions already affect these coastal aquifers in different regions of the globe (Ferguson and Gleeson 2012). The consumption of salt-contaminated water can have detrimental health impacts (A. E. Khan, Ireson, et al. 2011; Vineis, Chan, and Khan 2011). The most common consequence of excessive salt ingestion is hypertension (He and MacGregor 2007). Along with hypertension, there is a broad range of health problems potentially linked with increased salinity exposure through bathing, drinking. and cooking; these include miscarriage (A. E. Khan, Ireson, et al. 2011b), skin disease, acute respiratory infection, and diarrheal disease (Caritas Development Institute 2005).

Coastal Erosion

Many South East Asian countries, notably Vietnam, Thailand, and the Philippines, are highly vulnerable to the effects of climate-change-induced coastal erosion. For example, about 34 percent of the increase in erosion rates in the south Hai Thinh commune in the Vietnamese Red River delta between 1965–95 and 12 percent for the period 1995–2005 has been attributed to the direct effect of sea-level rise (Duc et al. 2012).

Coastal erosion, leading to land loss, is one of the processes associated with sea-level rise (Sorensen et al. 1980) and storm surges. Increasing wind stress and loss of vegetation are further factors known to enhance coastal erosion (Prasetya 2007).

The mechanisms of coastal erosion and the associated impacts depend on the specific coastal morphology (Sorensen et al. 1980):

- Beaches: Sand transport on beaches can be affected by sea-level rise. At higher mean sea level, wind wave action and wind-generated currents change the beach profile.
- Cliffs: Thin protecting beaches can be removed due to rising sea levels, increasing the exposure to wave action and leading to an undermining of the cliff face—finally resulting in cliff recession.
- Estuaries: Because estuary shorelines are typically exposed to milder wave action and exhibit relatively flat profiles, rising sea levels are expected to result in land losses primarily due to inundation (rather than due to erosion).
- Reefed coasts: Reefs cause wave breaking and thus reduce wave action on the beach. Higher mean sea levels reduce this protecting effect and thus increase the coastline's exposure to wave stress, which results in increased coastal erosion (see also Chapter 4 on "Projected Impacts on Coral Reefs" for more on the implications of reef loss).

Sandy beach erosion can lead to increasing exposure and possible destruction of fixed structures (e.g., settlements, infrastructures) close to the coastline due to the direct impact of storm waves. In general, empirical results indicate that the rate of sandy beach erosion significantly outperforms that of actual sea-level rise (Zhang et al. 2004). However, deriving reliable projections of coastal erosion under future sea-level rise and other climate change-related effects, such as possible increases in wind stress and heavy rainfall, require complex modeling approaches (Dawson et al. 2009).

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66 The United States Agency for International Development (2013) report projects the impacts of climate change for the period 2045–69 under the IPCC SRES scenario A1B (corresponding to a 2.33°C temperature increase above pre-industrial levels) for the Lower Mekong Basin. For the study, authors used six GCMs (NCAR CCSM 3.0; MICRO3.2 hires; GISS AOM; CNRM CM3; BCCR BCM2.0; GFDL CM2.1) and used 1980–2005 as a baseline period.

67 This work assumed a global-mean temperature increase of about 4°C above pre-industrial levels (IPCC SRES scenario A2); however, the sea-level rise component came from the thermal expansion of the oceans only (i.e., no contribution from the melting of glaciers and ice caps that currently contribute about half of global sea-level rise).

In the Mekong River Delta, coastal erosion is expected to increase significantly by 2100 under a 100 cm rise (Mackay and Russell 2011). Under the same conditions, projected beach loss for the San Fernando Bay area of the Philippines amounts to 123,033 m², with a simultaneous land loss of 283,085 m² affecting a considerable number of residential structures (Bayani-Arias, Dorado, and Dorado 2012). The projected loss of mangrove forests due to sea-level rise[68] and human activities (which are known to increase coastal erosion) is also a significant concern and is likely to accelerate coastal erosion. The presence of the mangrove forests is known to provide coastal protection: for the coastline of southern Thailand, studies report an estimated 30-percent reduction in coastal erosion in the presence of dense mangrove stands (Vermaat and Thampanya 2006).

Impacts on Agricultural and Aquaculture Production in Deltaic and Coastal Regions

Agriculture and aquaculture are the two main components of rural livelihoods in the South East Asian rivers deltas and coastal areas. Salinity intrusion and coastal erosion, along with the increased frequency and intensity of extreme weather events, sea-level rise and coastal flooding, and increased air and water temperature are projected to severely impact rural economic activities.

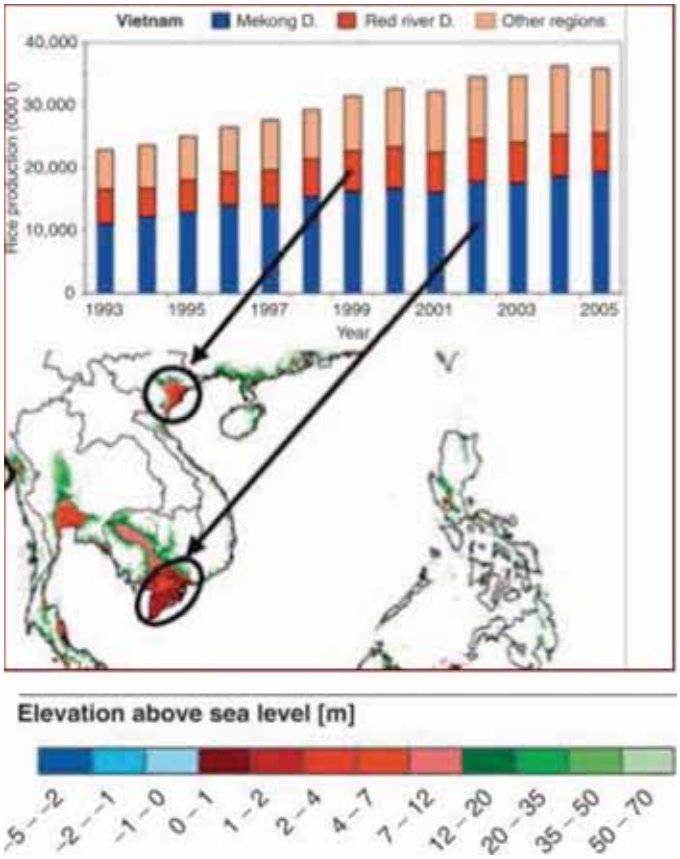
Agriculture

Agricultural production in deltaic regions is largely based on rice, a crop that is relatively resilient to unstable water levels and salinity. Nevertheless, rising sea levels and increasing tropical cyclone intensity leading to increasing salinity intrusion and inundation pose major risks to rice production in deltaic regions (Wassmann, Jagadish, Heuer, Ismail, and Sumfleth 2009). Impacts are known to vary according to a number of factors, such as cultivar and duration and depth of flooding (Jackson and Ram 2003). While some cultivars are more resilient than others, there is evidence that all rice is vulnerable to sudden and total inundation when flooding is sustained for several days. The effect can be fatal, especially when the plants are small (Jackson and Ram 2003). Temperature increases beyond thresholds during critical growing seasons may further impact productivity (Wassmann, Jagadish, Heuer, Ismail, and Sumfleth 2009). Rice production in the Mekong Delta is particularly exposed to sea-level rise due to its low elevation (see Figure 4.9).

The World Bank Economics of Adaptation to Climate Change estimated the impact of a 30 cm sea-level rise by 2050 in the Mekong River Delta. The projections undertaken for the present report find that this level of sea-level rise may be reached as early as the 2030s. Such sea-level rise is found to result in a loss of 193,000 hectares of rice paddies (about 4.7 percent of the province) due to inundation. A larger area of 294,000 hectares (about 7.2 percent of the Mekong River Delta province) might also be lost for agricultural purposes due to salinity intrusion. Without implementing adaptation measures, rice production could decline by approximately 2.6 million tons per year, assuming 2010 rice productivity. This would represent a direct economic loss in export revenue of $1.22 billion at 2011 prices (World Bank 2010b).

Furthermore, consistent with other studies estimating the impacts of climate change on crop yields in South East Asia (MoNRE 2010; Wassmann, Jagadish, Sumfleth, et al. 2009; World Bank 2010b), the United States Agency for International Development (2013)[69] projects a decrease in crop yields and, more specifically, in rice yields. The World Bank (2010b) estimates rice yield

Figure 4.9: Low elevation areas in the Vietnamese deltas



Source: Wassmann et al. (2009).

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[68] See Chapter 4 on "Coastal Wetlands."

[69] The United States Agency for International Development (2013) projects the impacts of climate change for the period 2045–69 under the IPCC SRES scenario A1B (corresponding to a 2.33°C temperature increase above pre-industrial levels) for the Lower Mekong Basin. For the study, the authors used six GCMs (NCAR CCSM 3.0; MICRO3.2 hires; GISS AOM; CNRM CM3; BCCR BCM2.0; GFDL CM2.1) and used 1980–2005 as a baseline period.

declines from 6–12 percent in the Mekong River Delta. Other crops may experience decreases ranging from 3–26 percent by 2050 in a wet and dry scenario under the SRES scenario A1B.

In light of the importance of deltaic regions for rice production, impacts such as those outlined above pose a major risk to affected populations and the region's economy.

Aquaculture

Aquaculture in South East Asia plays a significant role in the region's economic and human development, and both the population and the national economies rely considerably on sea products and services. In Vietnam, for example, aquaculture output constitutes a growing share of the gross domestic product (GDP). Between 1996 and 2011, aquaculture output was multiplied by 24 and its share of GDP increased from 2.6 percent to about 4.8 percent. In addition, since 2001, aquaculture production has yielded higher output than capture fisheries (General Statistics Office of Vietnam 2012). Similar trends can be observed in the other South East Asian countries (Delgado, Wada, Rosegrant, Meijer, and Ahmed 2003). Fisheries and aquaculture also supply the region and populations with affordable seafood and fish, which constitute an average of 36 percent of dietary animal protein consumed in South East Asia (Food and Agriculture Organization of the United Nations 2010).

Sea-level rise, intense extreme weather events, associated saltwater intrusion, and warmer air temperatures may impact aquaculture—especially when it takes place in brackish water and deltaic regions (Box 4.2). The extent of the impact, however, remains uncertain (Silva and Soto 2009).

Heat waves and associated warmer water temperatures may affect aquaculture in South East Asia. The two most cultured species in the region, brackish water tiger shrimp (*Penaeus monodon*) and freshwater striped catfish (*Pangasianodon hypophthalmus*), have very similar temperature tolerance ranges around 28–30°C (Hargreaves and Tucker 2003; Pushparajan and Soundarapandian 2010). More frequent temperatures above the tolerance range would create non-optimum conditions for these species and would be expected to decrease aquaculture yields.

As a consequence of salinity intrusion, freshwater and brackish aquaculture farms may have to relocate further upstream. To respond to this new salinity pattern, local farmers may further have to breed more saline-tolerant species. Upstream relocation and farming more saline-tolerant species are expected to be economically costly. Implementing these measures and their associated costs would most certainly affect the socioeconomic status of aquaculture-dependant households. Neither the cost of adapting aquaculture farming practices to the consequences of salinity intrusion nor the direct economic losses for aquaculture-dependent livelihoods has yet been evaluated (Silva and Soto 2009).

Another study[70] (United States Agency for International Development 2013) finds that four climate stressors are projected to significantly affect aquaculture production: increased temperatures, changes in rainfall patterns, increased storm intensities, and higher sea levels. According to the study's projections, intensive aquaculture practices are expected to experience a decrease in yields due to the combination of these four climate stressors. Semi-intensive and extensive systems may only be vulnerable to extreme weather events such as droughts, floods, and tropical cyclones. The authors do not, however, provide aquaculture yield decrease estimates due to climate stressors.

Two recent studies estimated the cost of adapting shrimp and catfish aquaculture to climate change in the Mekong river delta. Estimates range from $130 million per year for the period 2010–50[71] (World Bank 2010b) to $190.7 million per year for the period 2010–20 (Kam et al. 2012). These valuations may, however, be underestimated. Kam et al. (2012) only took into account the costs of upgrades to dykes and water pumping. As explained earlier in this chapter, other climate-change-associated consequences may affect the final calculation of the adaptation costs in the aquaculture sector. First, the existing studies do not account for the costs of relocating aquaculture farms upstream of

Box 4.2: The Threat of Typhoons to Aquaculture

Extreme weather events, such as tropical cyclones and coastal floods, already affect aquaculture activities in South East Asia. For example, the category 4 typhoon Xangsane devastated 1,278 hectares of aquaculture area in Vietnam in 2006 (International Federation Of Red Cross and Red Crescent Societies 2006). Similarly, in Indonesia, typhoons Vicente (category 4) and Saola (category 2) jointly generated $9.26 million in damages to the fishery sector and affected about 3,000 aquaculture farmers (Xinhua 2012). The impacts on aquaculture farming include the physical destruction of facilities, the spread of diseases, and the loss of fish stock (Silva and Soto, 2009). More intense storms are expected to diminish the life span of aquaculture equipment and infrastructure and increase the maintenance costs of the installations (Kam, Badjeck, Teh, Teh, and Tran 2012).

[70] The United States Agency for International Development (2013) report projects the impacts of climate change for the period 2045–69 under the IPCC SRES scenario A1B (corresponding to a 2.33°C temperature increase above pre-industrial level) for the Lower Mekong Basin. For the study, the authors used six GCMs (NCAR CCSM 3.0; MICRO3.2 hires; GISS AOM; CNRM CM3; BCCR BCM2.0; GFDL CM2.1) and used 1980–2005 as a baseline period.

[71] For the World Bank study, projections were calculated from a set of 21 global models in the multimodel ensemble approach, from 1980–99 and 2080–99 under the IPCC A1B scenario, corresponding to a 2.8°C temperature increase globally (3.3°C above pre-industrial levels).

rivers, despite the fact that most aquaculture activities take place in low-lying areas below one meter of elevation above sea level (Carew-Reid 2008). Second, warmer air temperatures may force aquaculture farmers to dig deeper ponds in order to keep water pond temperatures in the tolerance range of the species being cultured (Silva and Soto 2009). Finally, the costs of coping with the consequences of tropical cyclones on aquaculture activities have not been taken into account. Since the intensity of tropical cyclones is expected to increase, so are the associated damages and losses (Mendelsohn et al. 2012).

Risks to Coastal Cities

South East Asian coastal cities are projected to be affected by several climate change stressors, including increased tropical cyclone intensity, sea-level rise, and coastal flooding (Brecht, Dasgupta, Laplante, Murray, and Wheeler 2012; Dutta 2011; Hanson et al. 2011; Muto, Morishita, and Syson 2010; Storch and Downes 2011). The consequences of these stressors are likely to be exacerbated by human-induced subsidence in low-lying, deltaic regions (Brecht et al. 2012a; Hanson et al. 2011). South East Asian cities have already been exposed to the consequences of coastal flooding, and significant economic losses have occurred due to flooding-induced damage to public and private infrastructure. Increasingly intense rainfall events that exacerbate river flooding (Kron 2012) and heat waves (World Bank 2011a) may also have a negative impact on coastal cities (see also Chapter 4 on "Regional Patterns of Climate Change").

Vulnerability Context

South East Asia currently experiences high rates of urban population growth, which are led by two converging drivers: a rural exodus and demographic growth (Tran et al. 2012). By 2025, the population of South East Asian cities is projected to be significantly higher than at present. Ho Chi Minh City, for example, is expected to have a population of approximately 9 million people (compared to close to 6 million in 2010); 8.4 million people are projected to be living in Bangkok (compared to 7 million in 2010) and 14 million in Manila (compared to 11.6 million in 2010) (UN Population Prospects 2009).

As a result, increasingly large populations and significant assets are projected to be exposed to sea-level rise and other climate change impacts in low-lying coastal areas. The effect of heat extremes are particularly pronounced in urban areas due to the urban heat island effect, caused in large part by the density of buildings and the size of cities. This results in higher human mortality and morbidity rates in cities than in the rural surroundings (Gabriel and Endlicher 2011). High levels of urban population growth and GDP further increase exposure to climate change impacts in coastal urban areas.

Most of the national economic production of the region is also concentrated in South East Asia's cities. It has been estimated, for example, that Ho Chi Minh City in 2008 accounted for approximately 26 percent ($58 billion) and Hanoi for 19 percent ($42 billion) of Vietnam's $222 billion GDP (based on Purchasing Power Parity). Metro Manila's GDP, at 49 percent ($149 billion), represented a significant share of that country's $305 billion GDP (PricewaterhouseCoopers 2009; World Bank 2013a). In addition, it is estimated that, by 2025, Metro Manila's GDP will be approximately $325 billion, Hanoi's GDP will be $134 billion, and Ho Chi Minh City's GDP will be $181 billion (PricewaterhouseCoopers 2009). In other words, the GDP values in these coastal cities are expected to double or even quadruple from the present day. Table 4.3 presents the population and GDP growth trends in these and other South East Asian cities.

Urban density is a further factor that may influence a city´s vulnerability to climate-driven impacts (World Bank 2011a). Figure 4.10 shows different types of cities in terms of population and density. Cities like Jakarta and Manila clearly stand out in

Table 4.3: Current and projected GDP and population of Jakarta, Manila, Ho Chi Minh, and Bangkok

Indicators	Current / Projected	Jakarta	Manila	Ho Chi Minh City	Bangkok	Yangon
GDP (US$ billion, PPP)	2008	92.0	149.0	58.0	119.0	24.0
	2025	231.0	325.0	181.0	241.0	53.0
Population (million)	2010	9.2	11.6	6.1	6.9	4.3
	2025	10.8	14.9	8.9	8.5	6.0
Urban Growth Rate in 2001 at Country Level	2001	4%	4%	3%	2%	3%

Sources: PricewaterhouseCoopers (2009); UN Population Prospects (2009); UN-HABITAT (2013).*

* Current and projected GDP data from PricewaterhouseCoopers (2009); urban growth rate in 2001 from UN-HABITAT (2013); and current and projection urban populations from UN Population Prospects (2009).

terms of population size; however, the density of Jakarta, for example, is lower than that of smaller cities like Yangon and Zamboanga. In cities where adequate infrastructure and institutional capacity are lacking to support large urban populations, density can increase the vulnerability to climate-driven impacts by exposing larger numbers of people and assets in a given area of land (Dodman 2009).

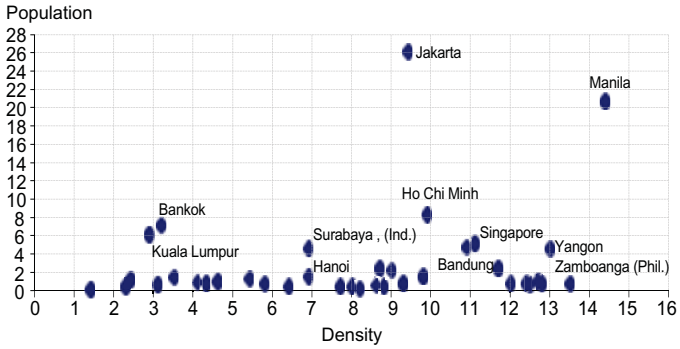
Informal Settlements

High urban growth rates, combined with inadequate responses to the housing needs of urban populations in the region, are leading to the expansion of informal settlements. For example, 79 percent of the urban population in Cambodia, 41 percent in Vietnam, and 44 percent in the Philippines lived in informal settlements in 2005 (UN-HABITAT 2013).

Informal settlements are characterized by a lack of water, a lack of sanitation, overcrowding, and nondurable housing structures (UN-HABITAT 2007). Durable housing, in contrast, has been defined as "a unit that is built on a non-hazardous location and has a structure permanent and adequate enough to protect its inhabitants from the extreme of climate conditions, such as rain, heat, cold, and humidity" (UN-HABITAT 2007). In informal settlements, populations are chronically exposed to health risks from perinatal complications to diarrheal diseases to physical injuries (C. McMichael et al. 2012). If the number of people living in informal settlements continues to grow, the number of people vulnerable to these threats will grow too (Box 4.3).

Water in South East Asia is a major vector for diseases such as diarrhea and cholera. Improved water sources and sanitation facilities contribute to keep water-borne diseases at bay. Despite significant improvements in South East Asian cities, large proportions of the region's urban populations (27 percent in Indonesia and nine percent in Vietnam) still lack access to improved sanitation facilities. In addition, eight percent of the urban population in Indonesia and one percent in Vietnam do not have access to clean water sources (World Bank 2013c). Lack of access to these resources contributes to the vulnerability of South East Asian cities to climate-change-induced impacts and associated health complications. Table 4.4 summarizes the key vulnerabilities of the South East Asian countries studied in this report.

Figure 4.10: Population size against density distribution. The population axis refers to population in millions; the density axis to population in thousands/km^2



Source: Demographia 2009.

Box 4.3: Freshwater Infrastructure

Cyclones can damage infrastructure, such as water treatment plants, pump houses, and pipes. Natural disasters reportedly contribute to the shortening of infrastructure and system life spans from 15–20 years to 3–4 years (SNV 2010). Recent tropical cyclones in the Philippines highlight the vulnerability of the country's freshwater infrastructure and systems to climate change. In the aftermath of category 2 cyclone Ondoy in 2009, over 100,000 households were left without piped-in water as 92 percent of the water supply capacity was suspended in Central Luzon province. In combination with damage incurred by cyclone Pepeng, Ondoy generated $24.3 million in damages to the water and sanitation sector in the Philippines (GFDRR 2009).

Projected Impacts on Coastal Cities

Projected Exposed Populations

Applying the Dynamic Interactive Vulnerability Assessment model, Hanson et al. (2011) project impacts of sea-level rise, taking into account natural subsidence (uplift), human-induced subsidence, and population and economic growth. They assume a homogenous sea-level rise of 50 cm above current levels by 2070 and a uniform decline in land level of 50 cm from 2005–70 to reflect human-induced subsidence. Note that the projections produced in this report give a global mean sea-level rise of 50 cm likely as early as the 2060s in a 4°C world (greater than 66-percent probability) and by the 2070s in a 2°C world. There is also a 10-percent chance of this level of rise occurring globally by the 2050s (above 2000 sea levels).

For tropical storms, Hanson et al. (2011) assume a 10 percent increase in high water levels with no expansion in affected areas; this may actually underestimate future exposure. They also estimate population in the cities in the 2070s according to three factors: projected regional population, the change in urbanization rate, and specific properties of each city. Population data are based on the United Nations' World Urbanization Prospects (2005). Urban population projections for 2070 are extrapolated from the 2005–30 trends in urbanization and assume that urbanization rates saturate at 90 percent. Depending on the national context, this may over- or underestimate future population exposure in urban areas.

Table 4.4: Vulnerability indicators in Indonesia, Myanmar, the Philippines, Thailand, and Vietnam

Indicators	Indonesia	Myanmar	The Philippines	Thailand	Vietnam
Urban population with access to improved sanitation	73%	83%	79%	95%	94%
Urban population living in areas where elevation is below 5 meters	5%	4%	4%	9%	9%
Population living in informal settlements (2005)	26%	46%	44%	26%	41%

Sources: Center for International Earth Science Information Network (2011); UN-HABITAT (2013); World Bank (2013c, 2013k).

The authors find that 3.9 million people in South East Asian cities were exposed to coastal flooding in 2005 caused by storm surges and sea-level rise. Based on these assumptions, they estimate that 28 million people are projected to be exposed to 50 cm sea-level rise, taking into account human-induced subsidence and increased storminess in the 2070s.

Jakarta, Yangon, Manila, Bangkok, and Ho Chi Minh City are projected to be among the cities in South East Asia most affected by sea-level rise and increased storm surges. Table 4.5 shows the number of people projected to be exposed to the impacts of sea-level rise, increased storminess, and human-induced subsidence for five cities in the region.

Brecht et al. (2012) examine the consequences for a 100 cm sea-level rise in the same region, making the assumption that the urbanization rate will remain constant between 2005 and 2100. Based on this fixed urbanization rate, which may significantly underestimate future population exposure, they find slightly lower numbers of affected people for a 100 cm sea-level rise scenario, increased tropical storm intensity, and human-induced subsidence. For 2100, the authors calculate the increased tropical storm intensity by multiplying projected sea-level rise by 10 percent. Their results are shown in Table 4.6.

Brecht et al. (2012) and Hanson et al. (2011) apply contrasting assumptions, therefore comparing the change in affected population in the different levels of sea-level rise (50 cm and 100 cm) is difficult. The estimates do, however, offer relevant indications concerning the order of magnitude of people projected to be exposed in coastal cities by these sea-level rises. Overall, the studies give a potential range of the total projected population exposed to sea-level rise and increased storminess in South East Asian of 5–22 million during the second half of the 21st century.

Projected Exposed Assets

Hanson et al. (2011) also estimate the current and projected asset exposure for South East Asian coastal cities. Their study is based

Table 4.6: Current population and projected population exposed

Key South East Asian Agglomerations	Population (2005, in millions)	Change in Affected Population (2100) – 100 cm SLR, 50 cm land subsidence and 10 percent wave height increase (in millions)
Jakarta	13.215	0.83
Yangon	4.1	0.38
Manila	10.7	3,44
Bangkok	6.6	0.55
Ho Chi Minh City	5.1	0.43
Total	39.7	5.63

Source: Brecht et al. (2012a).

Brecht et al., Journal of Environment & Development (21:1), pp. 120-138, copyright © 2012. Reprinted by Permission of SAGE Publications. Further permission required for reuse.

Table 4.5: Current and projected population exposed to 50 cm sea-level rise, land subsidence and increased storm intensity in 2070 in Jakarta, Yangon, Manila, Bangkok, and Ho Chi Minh City

Key South East Asian Agglomerations	Population (2005, in millions)	Projected Exposed Population (2070, in millions)	Local Sea Level Rise Projections in a 4°C World in 2070 (above 1986–2005)
Jakarta	13.2	2.2	66cm
Yangon	4.1	4.9	63cm
Manila	10.6	0.5	66cm
Bangkok	6.5	5.1	65cm
Ho Chi Minh City	5.0	9.2	65cm

Source: Population data from Hanson et al. (2011); SLR RCP8.5 (in this report).

on the physical (i.e., sea level, storms, and subsidence) and demographic assumptions discussed in Chapter 4 under "Projected Impacts on Economic and Human Development.". To evaluate asset exposure, they estimate cities' future GDP by assuming that urban GDP grows at the same rate as the respective national or regional GDP per capita trends throughout the period 2005–75. The projected exposed population is transposed into exposed assets by multiplying each country's GDP per capita by five (projected exposed asset = projected exposed population * estimated GDP per capita * 5). According to Hanson et al. (2011), this methodology is widely used in the insurance industry.

The projected asset exposure for South East Asia in 2070 rises significantly due to the increased impacts of rising sea levels, more-intense tropical storms, and fast economic growth. Based on the assumptions and calculations, the authors project that coastal cities' asset exposure will rises by 2,100–4,600 percent between 2005–70. Table 4.7 summarizes the current and projected exposed assets.

The figures presented in this table should be interpreted with care as the asset exposure projections in the study by Hanson et al. are based on population exposure projections that assume a steady urbanization rate (saturating at 90 percent of the country population). As a consequence, projected asset exposure is extremely high. The table only displays an order of magnitude of the impacts of a 50-cm sea-level rise, increased storminess, and human-induced subsidence on exposed assets in coastal cities in South East Asia in 2070 if no adaptation measures are carried out.

Projected Impacts on Individual Cities

The current understanding of the impacts of sea-level rise on specific coastal cities in South East Asia is rather limited. Despite global studies for port and coastal cities (e.g., Brecht et al. 2012; Hanson et al. 2011), studies conducted at the city level on the impacts of sea-level rise and increased storm intensity are scarce. However, projections accounting for sea-level rise, increased cyclone intensity, and human-induced subsidence are available for Ho Chi Minh City, Manila, and Bangkok.

Table 4.7: Current and projected asset exposure to sea-level rise for South East Asian coastal agglomerations

South East Asian Agglomerations	Exposed Assets (billions of dollars in 2005)	Projected Exposed Assets (billions of dollars in 2070)	Projected Exposed Assets Growth (%)
Jakarta	10.10	321.24	3080.59%
Yangon	3.62	172.02	4651.93%
Manila	2.69	66.21	2361.34%
Bangkok	38.72	1117.54	2786.21%
Ho Chi Minh City	28.86	652.82	2162.02%

Source: Adapted from Hanson et al. (2011).

Ho Chi Minh City

Storch and Downes (2011) quantify current and future citywide flood risks to Ho Chi Minh City by taking into account urban development (population and asset growth) and sea-level rise scenarios. Due to the lack of data available on land subsidence for the city, however, their assessment does not include subsidence. They use two possible amplitudes of change for sea-level rise in the study: 50 cm and 100 cm. Combined with the current tidal maximum of 150 cm, they quantify built-up land exposed to water levels of 150 cm, 200 cm, and 250 cm. According to the report's projections, a 50-cm sea-level rise would be reached between 2055–65 in the RCP8.5 scenario and between 2065–75 in the RCP2.6 scenario. According to the draft land-use plan for 2010–25, the built-up areas increase by 50 percent (approximately 750 km²). In these conditions, the authors project that up to 60 percent of the built-up area will be exposed to a 100 cm sea-level rise. In the absence of adaptation, the planned urban development for the year 2025 further increases Ho Chi Minh City's exposure to sea-level rise by 17 percentage points.

Bangkok

Dutta (2011) assesses the socioeconomic impacts of floods due to sea-level rise in Bangkok. He uses a model combining surface and river flows to simulate different magnitudes of sea-level rise and uses 1980 as the baseline year. The study takes into account two different sea-level rise scenarios: 32 cm in 2050 and 88 cm in 2100. For the projections of future population and urbanization, the author uses the IPCC SRES B1 scenario. For this simulation, the maximum population density is 20,000 people per square kilometer (compared to 16,000 in Manila, the highest urban population density in 2009), effectively leading to an expansion of the total area. Based on this simulation of flood and population, Dutta projects that 43 percent of the Bangkok area will be flooded in 2025, and 69 percent in 2100. The results are displayed in Table 4.8.

According to this simulation, the population is expected to be increasingly affected as the sea level rises. Dutta (2011) projects that, if no adaptation is carried out, 5.7 million people in 2025 and 8.9 million people in 2100 are going to be affected by inundations in Bangkok when the sea level reaches 88 cm. According to the report's projections, a sea-level rise of 88 cm in Bangkok may be reached between 2085 and 2095 in a 4°C world. In a 2°C world, sea-level rise of around 75 cm by the end of the 21st century would likely limit the percentage of total area of Bangkok exposed to inundations between 57–69 percent.

Manila

Muto et al. (2010) assess the local effects of precipitation, sea-level rise, and increased storminess on floods in metropolitan Manila

Table 4.8: Total flood inundation area in Bangkok for sea-level rise projections from 14cm to 88cm from 2025 to 2100

Year	2025	2050	2075	2100
Sea-level rise projection (cm)	14	32	58	88
Total flood inundation area (km²)	1429	1611	1917	2311
Percentage of total Bangkok area	43%	48%	57%	69%

Source: Adapted from Dutta (2011).

in 2050 under the IPCC SRES scenarios B1 (1.6°C above pre-industrial levels) and A1F1 (2.2°C above pre-industrial levels). According to the study, these scenarios correspond to 19 cm and 29 cm increases in sea-level elevation and 9.4 percent and 14.4 percent increases in rainfall precipitations (in scenarios B1 and A1F1, respectively). The storm surge height as a consequence of the increased tropical storm intensity is projected to rise by 100 cm in both scenarios. In the A1F1 scenario, the authors find that a 100-year return-period flood is projected to generate damages of up to 24 percent of Manila's total GDP by 2050 and a 30-year return-period flood would generate damages of approximately 15 percent of GDP. The authors find, however, that projected damages would be only nine percent of the GDP for a 100-year return-period flood and three percent for a 30-year return-period flood if infrastructures improvements based on the Master Plan designed in 1990 are properly implemented.

Coastal and Marine Ecosystems

Livelihoods in the Asia-Pacific region, particularly in South East Asia, are often highly dependent on the ecosystem services provided by ocean and coastal environments. The associated ecosystem goods and services include food, building materials, medicine, tourism revenues, and coastal protection through reduced wave energy (Hoegh-Guldberg 2013; Villanoy et al. 2012). The fisheries supported by coral reefs, for example, are often vital to the livelihoods and diets of populations along reef coastlines (Ove Hoegh-Guldberg 1999; Cinner et al. 2012). Marine ecosystems are increasingly at risk from the impacts of climate change, including ocean acidification (Meissner, Lippmann, and Sen Gupta 2012), sea-surface water warming (Lough 2012), and rising sea levels (Gilman, Ellison, Duke, and Field 2008).

Coastal Wetlands

Coastal wetlands, including mangrove forests, provide important ecological services for the region. Mangroves contribute to human wellbeing through a range of activities, including provisioning (timber, fuel wood, and charcoal), regulating (flood, storm, and erosion control and the prevention of saltwater intrusion), habitat (breeding, spawning, and nursery habitats for commercial fish species and biodiversity), and cultural services (recreation, aesthetic, non-use). The mean economic value of these activities in South East Asia has been estimated at $4,185 per hectare per year as of 2007 (L. M. Brander et al. 2012). South East Asian countries shared mangrove forests covering an area of about six million hectares as of 2000 (L. M. Brander et al. 2012). Indonesia (3.1 million ha), Malaysia (505,000 ha), Myanmar (495,000 ha), and the Philippines (263,000 ha) are ranked 1, 6, 7 and 15 among countries worldwide with mangrove forests (Giri et al. 2011). Indonesia alone accounts for 22.6 percent of the total global mangrove area. Worldwide, mangrove forests are under significant pressure due to such human activities as aquaculture, harvesting, freshwater diversion, land reclamation, agriculture, and coastal development. These factors were responsible for at least 35 percent of the global mangrove loss between 1980 and 2000, particularly in South East Asia (Valiela, Bowen, and York 2001). Rapid sea-level rise poses additional risks (Mcleod, Hinkel, et al. 2010).

The vulnerability and response of mangrove forests to sea-level rise is connected to various surface and subsurface processes influencing the elevation of the mangroves' sediment surface (Gilman et al. 2008). In the long term, mangroves can react to rising mean sea level by landward migration. This option is limited in many locations, however, by geographic conditions (e.g., steep coastal inclines) and human activities (Ove Hoegh-Guldberg and Bruno 2010). Erosion of the seaward margin associated with sea-level rise and a possible increase of secondary productivity due to the greater availability of nutrients as a result of erosion further threaten mangrove forests (Alongi 2008).

Large losses are projected for countries in the region for a sea-level rise of 100 cm, which is this report's best estimate in a 4°C world warming scenario regionally by the 2080s (and globally by the 2090s). Sea-level rise is expected to play a significant role in the decline of coastal wetland, low unvegetated wetlands, mangroves, coastal forests, and salt marshes with a 100 cm sea-level rise (Mcleod, Hinkel, et al. 2010).[72] The study was conducted using the DIVA model for the six countries of the "Coral Triangle," which includes provinces in the Philippines, Indonesia, Malaysia, Timor-Leste, Papua New Guinea, and the Solomon Islands. In a 4°C world, total coastal wetland area is projected to decrease from 109,000 km² to 76,000 km² (about 30 percent) between 2010 and 2100.

At the level of administrative units, between 12 percent and 73 percent of coastal wetlands are projected to be lost at a 100 cm sea-level rise by the 2080s (compared to wetland area in 2010). Regions with a projected loss of more than 50 percent can be found in Timor-Leste, Indonesia (Jakarta Raya, Sulawesi

[72] The projections for sea-level rise are 100cm by 2100, above 1995 levels.

Tengah, Sulawesi Tenggara, Sumatra Barat, Yogyakarta), Malaysia (Terengganu), and the Philippines (Cagayan Valley, Central Luzon, Central Visayas, Ilocos, Western Visayas), as well as parts of Papua New Guinea and the Solomon Islands. For the Philippines, a coastal wetland loss of about 51 percent by 2100 is projected (compared to 2010) (Mcleod, Hinkel, et al. 2010).

Blankespoor, Dasgupta, and Laplante (2012) apply the DIVA model to assess the economic implications of a 100 cm sea-level rise on coastal wetlands and estimate that the East Asia Pacific region may suffer the biggest loss in economic value from the impacts of such a rise. They find that the region could lose approximately $296.1–368.3 million per year in economic value (2000 U.S. dollars). Vietnam is also expected to lose 8,533 square kilometers of freshwater marsh (a 65-percent loss), and the Philippines is expected to lose 229 square kilometers of great lakes and wetlands by 2100 (or almost 100 percent of the current surface).

Projected Impacts on Coral Reefs

Coral reefs in South East Asia, which play a pivotal role in coastal rural livelihoods by providing affordable food and protection against waves, are exposed to ocean acidification and warming temperature as well as to increased human activities such as pollution and overfishing.

Coral Reefs in South East Asia

The *IPCC Fourth Assessment Report* found that coral reefs are vulnerable to increased sea-surface temperature and, as a result, to thermal stress. Increases of 1–3°C in sea-surface temperature are projected to result in more frequent bleaching events and widespread coral mortality unless thermal adaptation or acclimatization occurs. The scientific literature published since 2007, when the AR4 was completed, gives a clearer picture of these risks and also raises substantial concerns about the effects of ocean acidification on coral reef growth and viability.

Globally, coral reefs occupy about 10 percent of the tropical oceans and tend to occur in the warmer (+1.8°C) parts of lower sea-surface temperature variability in regions where sea-surface temperatures are within a 3.3°C range 80 percent of the time; this compares to temperatures of non-reef areas, which remain within a 7.0°C range for 80 percent of the time (Lough 2012). Coral reefs flourish in relatively alkaline waters. In the Asia-Pacific region, coral reefs occur between 25°N and 25°S in warm, light-penetrated waters (O. Hoegh-Guldberg 2013).

At the global level, healthy coral reef ecosystems provide habitat for over one million species (O. Hoegh-Guldberg 2013) and flourish in waters that would otherwise be unproductive due to low nutrient availability (Ove Hoegh-Guldberg 1999). The loss of coral reef communities is thus likely to result in diminished species richness, species extinctions, and the loss of species that are key to local ecosystems (N. A. J. Graham et al. 2006; K. M. Brander 2007). The IPCC AR4 found with high confidence that climate change is likely to adversely affect corals reefs, fisheries, and other marine-based resources. Research published since 2007 has strongly reinforced this message. This section examines projected changes and impacts due to climate change in the South East Asian region.

One of the highest concentrations of marine species globally occurs in the Coral Triangle. Coral reefs in South East Asia[73] have been estimated to cover 95,790 km²; within this region, reef estimates for the Philippines are approximately 26,000 km² and, for Vietnam, 1,100 km[74] (Nañola, Aliño, and Carpenter 2011). In addition to the climate-change-related risks posed to reefs, including ocean acidification and the increasing frequency and duration of ocean temperature anomalies, reefs are also at risk from such human activities as destructive fishing methods and coastal development resulting in increasing sediment outflow onto reefs (L. Burke, Selig, and Spalding 2002).

Projected Degradation and Loss due to Ocean Acidification and Increasing Temperature

Vulnerability to Ocean Acidification

Coral reefs have been found to be vulnerable to ocean acidification as a consequence of increasing atmospheric CO_2 concentrations. Critically, the reaction of CO_2 with seawater reduces the availability of carbonate ions that are used by various marine biota for skeleton and shell formation in the form of calcium carbonate ($CaCO_3$). Surface waters are typically supersaturated with aragonite (a mineral form of $CaCO_3$), favoring the formation of shells and skeletons. If saturation levels of aragonite are below a value of 1.0, the water is corrosive to pure aragonite and unprotected aragonite shells (R. a Feely, Sabine, Hernandez-Ayon, Ianson, and Hales 2008). Due to anthropogenic CO_2 emissions, the levels at which waters become undersaturated with respect to aragonite have been observed to have shoaled when compared to pre-industrial levels (R. A. Feely et al. 2004).

Mumby et al. (2011) identify three critical thresholds which coral reefs may be at risk of crossing as atmospheric CO_2 concentrations increase: first, the degradation threshold, beyond which an ecosystem begins to degrade (for example, above 350 ppm, coral bleaching has been observed to begin occurring); second, thresholds of ecosystem state and process, which determine whether an ecosystem will exhibit natural recovery or will shift into a more damaged state; and, finally, the physiological threshold, whereby essential functions become severely impaired. These thresholds involve different processes, would have different repercussions,

[73] In the study referred to (L. Burke et al. 2002), South East Asia encompasses Indonesia; the Philippines; Spratly and Paracel Islands; Japan; Thailand; Myanmar; Vietnam; China; Taiwan, China; Brunei Darussalam; Singapore; and Cambodia.

[74] It should be noted that satellite measurements yield lower values (Nañola et al. 2011)

are associated with different levels of uncertainty, and are understood by scientists to varying extents. Mumby et al. (2011) stress that while all types of threshold seriously undermine the healthy functioning of the reef ecosystem, not all of them imply collapse.

Earlier work by Veron et al. (2009) indicates that a level of 350 ppm CO_2 could be a long-term viability limit for coral reefs, if multiple stressors such as high sea surface water temperature events, sea-level rise, and deterioration in seawater quality are included. This level of CO_2 concentration has already been exceeded in the last decade. Even under the lowest of the AR5 scenarios (corresponding to a 2°C world), which reaches a peak CO_2 concentration at around 450 ppm by mid-century before beginning a slow decline, a level of 350 ppm would not be achieved again for many centuries. At the peak CO_2 concentration for the lowest scenario, it has been estimated that global coral reef growth would slow down considerably, with significant impacts well before 450 ppm is reached. Impacts could include reduced growth, coral skeleton weakening, and increased temperature sensitivity (Cao and Caldeira 2008). At 550 ppm CO_2 concentration, which in a 4°C world warming scenario would be reached by around the 2050s, it has been projected that coral reefs will start to dissolve due to ocean acidification (Silverman et al. 2009).

Vulnerability to Warming Waters

Since the 1980s, elevated sea-surface temperatures have been increasingly linked with mass coral bleaching events in which the symbiotic algae (zooxanthellae) and their associated pigments are temporarily or permanently expelled (Glynn 1984; Goreau and Hayes 1994; Ove Hoegh-Guldberg 1999).

Coral mortality after bleaching events increases with the length and extent to which temperatures rise above regional summer maxima (Ove Hoegh-Guldberg 1999). Coral bleaching can be expected when a region's warm season maximum temperature is exceeded by 1°C for more than four weeks; bleaching becomes progressively worse at higher temperatures and/or longer periods during which the regional threshold temperature is exceeded (Goreau and Hayes 1994; Ove Hoegh-Guldberg and Bruno 2010). It is clear from model projections that, within a few decades, warming of tropical sea surface waters would exceed the historical thermal range and alter the physical environment of the coral reefs.

As expected, tropical oceans have been warming at a slower rate than globally (average of 0.08°C per decade over 1950–2011 in the tropics, or about 70 percent of the global average rate). The observed temperatures in the period 1981–2011 were 0.3–0.4°C above 1950–80 levels averaged over the tropical oceans (Lough 2012). Overall, 65 percent of the tropical oceans have warmed significantly while 34 percent have as yet shown no significant change. The observed absolute warming was greatest in the northwest and northeast tropical Pacific and the southwest tropical Atlantic. It is of substantial relevance to South East Asia that, when taking into account inter-annual variability, the strongest changes are observed in the near-equatorial Indian and western Pacific as well as the Atlantic Ocean.

Global warming-induced in exceedance of the temperature tolerance ranges within which coral reefs have evolved has been projected to produce substantial damages through thermal stress to the coral reefs. There is significant evidence that reefs at locations with little natural temperature variability (and thus historically few warm events) are particularly vulnerable to changes in marine chemistry and temperatures (Carilli, Donner, and Hartmann 2012). Environmental conditions and background climate conditions appear to further influence the upper thermal tolerance threshold temperature such that it varies across locations (Carilli et al. 2012). Taking this into account, Boylan and Kleypas (2008) suggest that for areas with low natural variability the threshold temperature for bleaching is better described (compared to the 1°C threshold) with the regionally based threshold twice the standard deviation of warm season sea-surface temperature anomalies. For tropical reef organisms, compromised physiological processes have been observed beyond temperatures of around 30–32°C (Lough 2012).

Significant increases above the historical range of sea-surface temperatures have been observed in the tropics. Lough (2012), for example, finds that coral reef locations with historical (1950–80) ranges of 27–28°C and 28–29°C experienced a shift in the 1981–2011 period toward a range of 29–30°C. The percentage of months within the upper (29–30°C) range increased significantly, up 3.1 percentage points per decade over the period 1950–2011. There was also a significant 0.4 percentage point per decade change in the number of months within the 31–32°C range, indicating that this estimated upper thermal tolerance threshold for tropical coral reefs could be exceeded if this trend continues.

For projections of the risks of global warming on coral reef bleaching, it is now standard to use indicators of thermal exposure; these include degree heating weeks (DHW) and degree heating months (DHM), which are defined as the product of exposure intensity (degrees Celsius above threshold) and duration (in weeks or months) (Meissner et al. 2012). Bleaching begins to occur when the cumulative DHW exceeds 4°C-weeks (1 month within a 12-week period) and severe when the DHW exceeds 8°C-weeks (or 2 months).

Combined Impacts of Ocean Acidification and Increasing Temperature

Meissner et al. (2012) project that a combination of reduced aragonite saturation levels (associated with the process of ocean acidification) and increasing sea-surface temperatures will expose reefs to more severe thermal stress, resulting in bleaching. Projections for a 2°C world show some recovery of both aragonite saturation and sea surface temperatures within the next 400 years. For this scenario, anomalies of mean tropical sea surface temperature do not exceed 1.9°C and zonal mean aragonite saturation remains

above 3 between 30°N and 30°S. It should be noted that present-day open ocean aragonite saturation levels are between 3.28 and 4.06, and no coral reefs are found in environments with levels below 3.

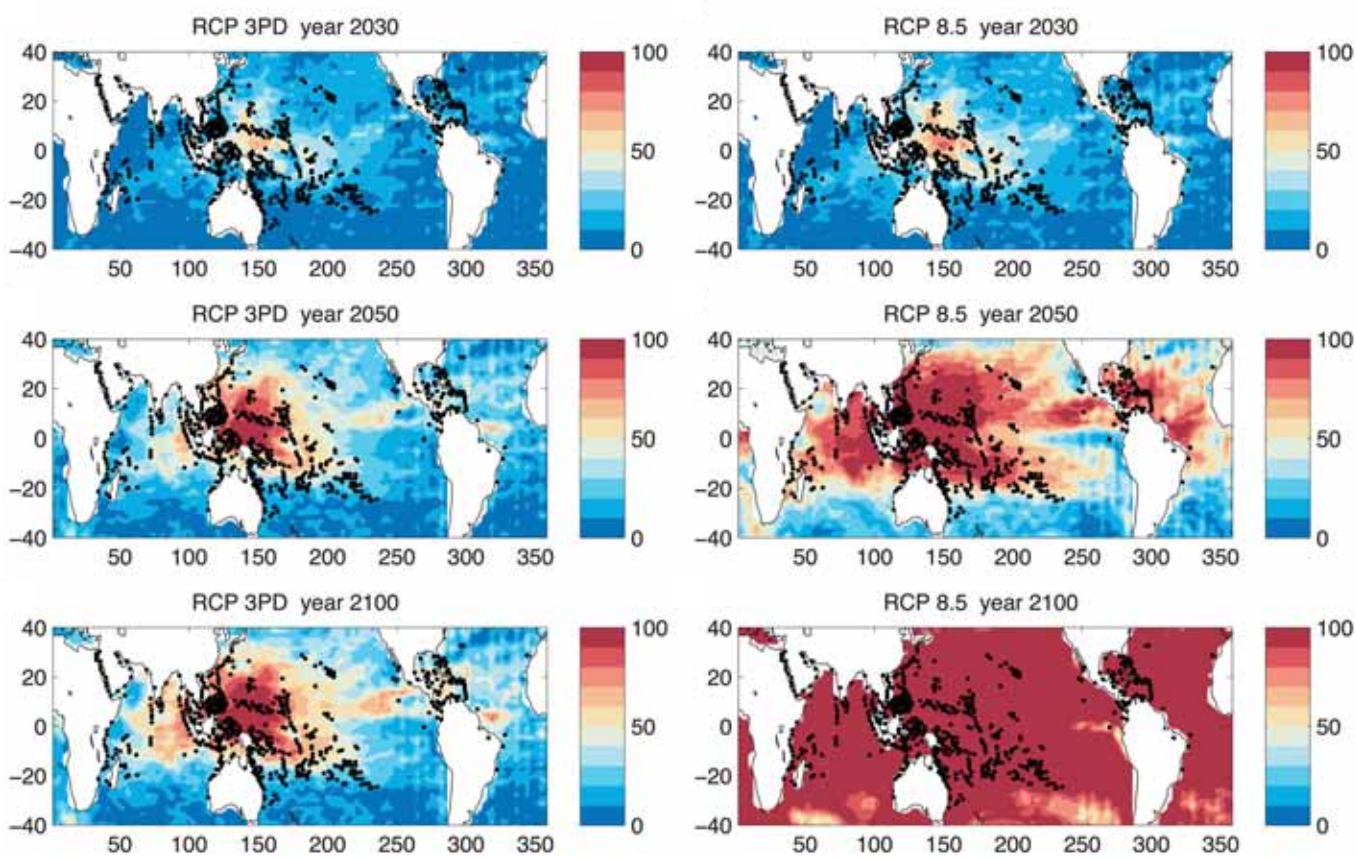
In a 3°C world and in a 4°C world, no recovery of either temperature or aragonite saturation occurs within the next 400 years. Furthermore, the zonal mean aragonite saturation at all latitudes falls below 3.3 as early as 2050 in a 3°C world. In a 4°C world, this level is reached as early as 2040; it reaches 3 by the 2050s, and continues a steady decline thereafter. In both a 3°C world and a 4°C world, open ocean surface seawater aragonite is projected to drop below thresholds by the end of the century (Meissner et al. 2012).

By the 2030s (approximately 1.2°C above pre-industrial levels), 66 percent of coral reef areas are projected to be thermally marginal, with CO_2 concentrations around 420 ppm. In the same timeframe in a 4°C warming scenario (about 1.5°C warming), about 85 percent of coral reef areas are projected to be thermally marginal for a CO_2 concentration of around 450 ppm by the 2030s (Meissner et al. 2012).

By the 2050s, with global mean warming of around 1.5°C under a low emissions (2°C warming by 2100) scenario and about 2°C under a high emissions (4°C warming by 2100) scenario, 98–100 percent of coral reefs are projected to be thermally marginal. In a 4°C warming scenario, in 2100 virtually all coral reefs will have been subject to a severe bleaching event every year (Meissner et al. 2012).

The western Pacific clearly stands out as a highly vulnerable area in all scenarios; even with 2°C warming, in 2100 there is a 60–100 percent probability of a bleaching event happening every year (see Figure 4.11). It is unlikely that coral reefs would survive such a regime. Under all concentration pathways (i.e., ranging from 2°C to above 4°C by the end of the century), virtually every coral reef in South East Asia would experience severe thermal stress by the year 2050 under warming levels of 1.5°C–2°C above pre-industrial levels (Meissner et al. 2012). Furthermore, by the 2030s, there is a 50-percent likelihood of bleaching events under a 1.2°C warming scenario and a 70-percent likelihood under a 1.5°C warming scenario (above pre-industrial levels).

Figure 4.11: Projected impact of climate change on coral systems in South East Asia



Probability of a severe bleaching event (DHW>8) occurring during a given year under scenario RCP2.6 (approximately 2°C, left) and RCP8.5 (approximately 4°C, right).

Source: Meissner et al. (2012).

Reprinted from Springer; Coral Reefs, 31(2), 2012, 309-319, Large-scale stress factors affecting coral reefs:open ocean sea surface temperature and surface seawater aragonite saturation over the next 400 years, Meissner et al., Figure 3, with kind permission from Springer Science and Business Media B.V. Further permission required for reuse.

The analysis of Frieler et al. (2012) produces quite similar results. By 1.5°C warming above pre-industrial levels, about 89 percent of coral reefs are projected to be experiencing severe bleaching (DHM 2 or greater); by 2°C warming, that number rises to around 100 percent. Highly optimistic assumptions on coral reef thermal adaptation potential would be required if even 66 percent of coral reef areas were to be preserved under a 2°C warming scenario; only 10 percent would be preserved without such optimistic interpretations (Frieler et al. 2012), which seems the more likely assumption. Indeed, a recent statistical meta-analysis of over 200 papers published so far on the effects of acidification on marine organisms suggests that increased temperatures enhance the sensitivity of marine species to acidification. This study further strengthens the evidence that acidification negatively impacts the abundance, survival, growth, and development of many calcifying marine organisms with corals, calcifying algae, and molluscs (e.g. shell fish) the most severely impacted (Kroeker et al. 2013).

At finer spatial resolution, and taking further stresses such as coastal pollution and overexploitation into account, Mcleod, Moffitt, et al. (2010) identify the eastern Philippines as the most threatened coral reef area of the Coral Triangle.

Human and Development Implications of Coral Reef Loss and Degradation

Implications for Coastal Protection

Coral reefs play a vital role in coastal protection. This is particularly so in the Philippines. Located in the typhoon belt and consisting of an archipelagic structure, the Philippines is naturally vulnerable to the impacts of projected sea-level rise and the synergistic effects of high-energy waves associated with typhoons (Villanoy et al. 2012).

Villanoy et al. (2012) simulate the role of reefs on coastal wave energy dissipation under sea-level rise (0.3 m and 1 m) and under storm events at two sites in the Philippines facing the Pacific Ocean. Employing a model to simulate wave propagation and prescribing a mean depth of 2 m for the reef, they show that for a sea-level rise scenario where wave height is increased by 1–200 cm, coral reefs continue to afford protection by dissipating wave energy (which reduces wave run-up on land). Under simulated sea-level rise and wave heights of 400 cm, however, the wave dissipating effects of the reefs, while still measurable, are significantly decreased. This shows that efficiency of coastal protection by coral reefs depends on the degree of sea-level rise.

It should be noted, however, that Villanoy et al. (2012) assume a healthy reef with 50–80 percent coral cover and suggest that some corals might grow fast enough to keep pace with projected sea-level rise. While they note that the fast-growing species might be more susceptible to coral bleaching due to warmer waters, they take neither this nor the impacts of ocean acidification into account. Thus, their assessment of the effectiveness of coral reefs for coastal protection may be too optimistic, as oceanic conditions in a 4°C world (which would roughly correspond to a 100 cm sea-level rise) are not considered here. Projections by Meissner et al. (2012) show that even under lower warming scenarios, all coral reefs in South East Asia as early as 2050 will have experienced severe bleaching events every year.

This site-specific modeling study does, however, confirm the importance of coral reefs for protection against wave run-up on land. Thus, natural protection against the impacts of sea-level rise due to climate change would itself be degraded due to the effects of climate change.

Implications for Fishing Communities and the Economic Consequences

Coral reefs are pivotal for the socioeconomic welfare of about 500 million people globally (Wilkinson 2008). South East Asia alone has 138 million people living on the coast and within 30 km of a coral reef (L. Burke, Reytar, Spalding, and Perry 2011)—defined as reef-associated populations. Coral reefs fisheries are mostly suitable for small-scale fishing activities, thanks to the easy accessibility of the coral reefs and the need for only minimal investments in capital and technology (Whittingham, Townsley, and Campbell 2003). Vietnam and the Philippines each have between 100,000 and 1 million reef fishers (excluding aquaculture activities) (L. Burke et al. 2011). Coastal and reef-associated communities are thus likely to suffer major social, economic, and nutritional impacts as a result of climate change (Sumaila and Cheung 2010).

It is important to note that under future stress, reefs may not cease to exist altogether but would become dominated by other species. These species might not, however, be suitable for human consumption (Ove Hoegh-Guldberg 2010). The present understanding of the mid- and long-term economic and social implications of coral reef degradation induced by warming sea temperatures and ocean acidification on reef fisheries is limited (S. K. Wilson et al. 2010). N. A. J. Graham et al. (2006) likewise note the lack of empirical data on the implications of coral bleaching for other components of reef ecosystems, including for the longer-term responses of species such as reef fish.

Nicholas A. J. Graham et al. (2008) and Nicholas A. J. Graham et al. (2011) assess the impacts of climate change on coral fish stock (Box 4.4). In these studies, climate-change-induced impacts on coral reefs were estimated based on the consequences of the 1998 coral bleaching event in the Indian Ocean. The authors find a clear correlation between coral bleaching events and the depletion of some coral fish species (the most vulnerable species to climate disturbance are the obligate and facultative corallivores). Climate change is, however, not the only stressor depleting reef fish stock. The unsustainable use of resources, due primarily to overfishing, also significantly contributes to declines in coral fish stocks (Newton, Côté, Pilling, Jennings, and Dulvy 2007).

Box 4.4: Fundamental Ecosystem Change

Fish may be affected by changes to the physiological conditions of species following coral loss and through the physical breakdown of the reef structure. For example, a severe El-Niño-related bleaching event in the Indian Ocean in 1998 caused a phase shift from a coral-dominated state to a rubble and algal-dominated state of low complexity, with a >90 percent total loss of live coral cover across the inner Seychelles. This coral loss resulted in declines in taxonomic distinctness in reef fish. Loss of physical structure due to bleaching is identified by N. A. J. Graham, et al. (2006) as the main driving force of changes in species richness. This case, while not attributed to climate change in their study, illustrates the nature of the risks to fish species.

As a consequence, species vulnerable to one threat (climate or fishing) is unlikely to be affected by the other. According to Nicholas A J Graham et al. (2011), this reduces the probabilities of strong synergistic effects of fishing and climate disturbances at the species level. Nevertheless, at the coral fish community level, biodiversity is expected to be severely affected as species that are less vulnerable to one stressor are prone to be affected by the other.

Edward H. Allison et al. (2005) developed a simplified econometric model to project the consequences of climate change on per capita fish consumption. The analysis takes into account four different factors to estimate future fish consumption: human population density, current fish consumption, national coral reef area, and an arbitrary range of values for the loss of coral reef (from 5–15 percent over the first 15 years of projections). They find that, in any loss scenario, per capita fish consumption is expected to decrease due to congruent factors: increased population, loss of coral reef at the national level, and the finite amount of fish production per unit of coral area. Expected decreases estimated by this simplified model show that per capita coral fish availability could drop by 25 percent in 2050 compared to 2000 levels. This conclusion should be interpreted with care, however, since the econometric model is extremely simplified. It does nonetheless further highlight the negative contribution of climate and human stressors to coral fish stocks and their availability in the future.

Primary Productivity and Pelagic Fisheries

Open ocean ecosystems provide food and income through fisheries revenues (Hoegh-Guldberg 2013), and capture fisheries remain essential in developing economies due to their affordability and easy accessibility by coastal populations (Food and Agriculture Organization of the United Nations 2012b).

According to the FAO *Fishery Country Profile*,[75] fishery exports in Vietnam in 2004 amounted to $2.36 billion; 90 percent of commercial landings came from offshore fisheries. Exports of overall fish and fishery products in the Philippines amounted to $525.4 million. Major exploited stocks in the Philippines include small pelagic fish, tuna and other large pelagic fish, demersal fish, and invertebrates. Furthermore, pelagic fisheries contribute directly to food security. According to the FAO, small pelagic fish are considered the main source of inexpensive animal protein for lower-income groups in the Philippines.[76]

Changes in ocean chemistry and water temperature are expected to impact fisheries off the coast by leading to decreases in primary productivity[77] and direct impacts on fish physiology, and by changing the conditions under which species have developed—resulting in typically poleward distribution shifts. In fact, these shifts have already been observed (Sumaila, Cheung, Lam, Pauly, and Herrick 2011).

One effect of increasing sea-surface temperatures is enhanced stratification of waters. This is associated with a decline in available macronutrients as waters do not mix and the mixed layer becomes more shallow. The resulting nutrient limitation is expected to lead to a decrease in primary productivity. Inter-comparing four climate models, Steinacher et al. (2010) investigate the potential impacts under approximately 4.6°C above pre-industrial levels by 2100 globally. They find global decreases in primary productivity between 2 and 20 percent by 2100 relative to pre-industrial levels for all four models. While the strength of the signal varies across models, all models agree on a downward trend for the western Pacific region.

Taking into account changes in sea-surface temperatures, primary productivity, salinity, and coastal upwelling zones, Cheung et al. (2010) project changes in species distribution and patterns of maximum catch potential by 2055. It should be noted that while distribution ranges of 1066 species were assessed within this model, changes were not calculated at the species level. Under a scenario of 2°C warming by the 2050s, the western Pacific displays a mixed picture. The changes range from a 50-percent decrease in maximum catch potential around the southern Philippines, to a 16-percent decrease in the waters of Vietnam, to a 6–16 percent increase in the maximum catch potential around the northern Philippines. It is important to note that the impacts of ocean hypoxia and acidification, as further consequences of climate change, are not yet accounted for in these projections. These effects are expected to decrease catch potentials by 20–30 percent in other regions (see

[75] http://www.fao.org/fishery/countrysector/FI-CP_VN/en.
[76] http://www.fao.org/fishery/countrysector/FI-CP_PH/en.
[77] Primary productivity refers to photosynthetic production at the beginning of the food chain (mainly through algae).

also Chapter 3 on "Aquatic Ecosystems") and can be expected to have adverse consequences for South East Asian fisheries.

Oxygen availability has been found to decline in the 200–700 meter zone and is related to reduced water mixing due to enhanced stratification (Stramma, Schmidtko, Levin, and Johnson 2010). Furthermore, warming waters lead to elevated oxygen demand across marine taxa (Stramma, Johnson, Sprintall, and Mohrholz 2008). Hypoxia is known to negatively impact the performance of marine organisms, leading to additional potential impacts on fish species (Pörtner 2010). Accordingly, a later analysis by W. W. L. Cheung, Dunne, Sarmiento, and Pauly (2011) which built on Cheung et al. (2010) found that, for the northeast Atlantic ocean, acidification and a reduction of oxygen content lowered the estimated catch potentials by 20–30 percent relative to simulations not considering these factors. No such assessments are available yet in the literature for South East Asia. Fisheries in Papua New Guinea are also expected to be affected by the consequences of warmer sea temperatures increasing stratification of the upper water column. Under the A2 scenario (corresponding to a 4.4°C degree increase by 2100 above pre-industrial levels) and using the IPSL-CM4, Bell et al. (2013) estimate biomass changes in the Pacific Ocean and in Papua New Guinea. They find that skipjack tuna biomass along PNG's coasts is expected to decrease between 2005 and 2100. Taking only climate change into account, they estimate that tuna biomass will decrease by about 25 percent by 2100. Fishing activities further decrease tuna biomass in the area (by about 10 percent in 2035, 10 percent in 2050, and about 35 percent by 2100 compared to 2000–2010 average catches in the region).

Cheung et al. (2012) project a decrease of 14–24 percent in the average maximum body weight of fish at the global level by 2050. In the study, they analyze the impacts of warmer water temperatures and decreased oxygen levels on the growth and metabolic parameters of fishes. The authors used two climate models (GFDL ESM 2.1 and IPSL-CM4-LOOP) under the SRES scenario A2 (corresponding to a 1.8°C temperature increase by 2050 above pre-industrial levels). According to their projections, the fish of the Java Sea and the Gulf of Thailand are expected to be the most severely affected; in these seas, average maximum body size in 2050 may be reduced 50–100 percent compared to 2000.

On a species level, Lehodey et al. (2010) project changes in the distribution of bigeye tuna larvae and adults. In a 4°C world, conditions for larval spawning in the western Pacific are projected to deteriorate due to increasing temperatures. Larval spawning conditions in subtropical regions in turn are projected to improve. Overall adult bigeye tuna mortality is projected to increase, leading to a markedly negative trend in biomass by 2100.

The analysis above indicates a substantial risk to marine food production, at least regionally for a warming of around 2°C above pre-industrial levels and on a broader scale in a 4°C world.

Projected Impacts on Economic and Human Development

Climate change impacts in South East Asia are expected to affect economic activity and decrease the revenues and incomes associated with these activities. Similarly, human development and primarily health may also be affected by the consequences of climate change.

Projected Impacts on Economic Development

In the following section, three types of economic impacts are explored: decreased tourism revenues due to several factors (including sea-level rise), increased damages due to tropical cyclones, and business disruptions due to extreme weather events.

Combined Risks to the Tourism Industry

The impacts of sea-level rise, increased tropical cyclone intensity, coral bleaching and biodiversity loss can have adverse effects on the tourism industry by damaging infrastructure. In addition, tropical cyclones have a negative effect on tourists' choice of destination countries on the same scale as such deterrents as terrorist attacks and political crises (L. W. Turner, Vu, and Witt 2012).

A growing number of tourists visit South East Asia for its cultural richness, landscapes, beaches, and marine activities. The contribution of tourism to employment and economic wealth is similarly growing. About 25.5 million people in the region benefited from direct, indirect, and induced jobs created in the travel and tourism industry (World Travel and Tourism Council 2012a). Travel and tourism's total contribution to regional GDP was estimated at $237.4 billion (or 10.9 percent) in 2011; the direct contribution was estimated at $94.5 billion (or 4.4 percent) of regional GDP.[78]

In Vietnam, revenues from travel and tourism range from a direct contribution of 5.1 percent of 2011 GDP to a total contribution of 11.8 percent (World Travel and Tourism Council 2012b). In the Philippines, revenues from the travel and tourism industry ranged from 4.9 percent of 2011 GDP (direct contribution) to 19.2 percent (total contribution) (World Travel and Tourism Council 2012c).

The South East Asian region has been identified as one of the most vulnerable regions to the impacts of climate change on tourism. In a global study, Perch-Nielsen (2009) found that when sea-level rise, extreme weather events, and biodiversity losses are taken into account, Thailand, Indonesia, the Philippines, Myanmar, and Cambodia rank among the most vulnerable tourism destinations.[79]

[78] Excluding Timor-Leste.

[79] The assessment by Perch-Nielsen (2009) allows for adaptive capacity, exposure, and sensitivity in a 2°C warming scenario for the period 2041–70. Adaptive capacity includes GDP per capita, the number of Internet users, regulatory quality, and

It is projected that increased weather event intensity—especially of tropical cyclones—combined with sea-level rise will cause severe damage in the region; this is likely to have negative impacts on beach resorts and other tourism infrastructure (Mendelsohn et al. 2012; Neumann, Emanuel, Ravela, Ludwig, and Verly 2012).

Coastal erosion, which can be driven or exacerbated by sea-level rise (Bruun 1962), also poses a threat to recreational activities and tourism—and, consequently, to associated revenues (Phillips and Jones 2006). Studies conducted in other regions—for example, in Sri Lanka (Weerakkody 1997), Barbados (Dharmaratne and Brathwaite 1998), and Mauritius (Ragoonaden 1997)–provide further evidence that coastal erosion can be detrimental to tourism.

Damages to coral reefs following bleaching events have also been found to negatively affect tourism revenue. Doshi et al. (2012) estimate that the 2010 bleaching event off the coasts of Thailand, Indonesia, and Malaysia resulted in economic losses of $50–80 million. Similar studies in Tanzania and the Indian Ocean have also observed that coral bleaching events have a significant negative impact on non-market benefits derived from coral reefs (Andersson 2007; Ngazy, Jiddawi, and Cesar 2004). Doshi et al. (2012) further estimate that the cost of coral bleaching ranges from $85–300 per dive. On the other hand, divers' willingness to pay to support reef quality improvements and protection increases because of coral bleaching events (Ransom and Mangi 2010).

Tropical Cyclone Risks

Across all basins and climate scenarios, tropical cyclone intensity is projected to increase. Combined with economic and demographic growth, increased TC intensity is expected to generate severe damages to both populations and assets. However, TC frequency is expected to decrease, potentially reducing associated damages and losses. Risk associated with tropical cyclones is a function of three parameters: the frequency and intensity of the hazard, the exposure (number of people or assets), and the vulnerability. The following section assesses the existing knowledge of tropical cyclones damages, taking into account climate and economic development changes.

Projected Population Exposure

Peduzzi et al. (2012) show that, at the global level, mortality risks due to tropical cyclones is influenced by tropical cyclone intensity, the exposure to risk, levels of poverty, and governance quality. In their study, poverty is assessed using the Human Development Index and GDP per capita; governance is defined using the following indicators: voice and accountability, government efficiency, political stability, control of corruption, and the rule of law. The authors first estimate the current risks in countries based on the average number of people killed per year and the average number of people killed per million inhabitants. Via this approach, they find that Myanmar is the country with the highest mortality risk index in South East Asia[80] (risk defined as medium high).

At the global level, it is estimated that 90 percent of the tropical cyclone exposure will occur in Asia. This region is also expected to experience the highest increase in exposure to tropical cyclones. It is projected that annual exposure will increase by about 11 million people in Pacific Asia (defined as Asia 2 in the study) and by 2.5 million people in Indian Ocean Asia (Asia 1) between 2010–30.

Projected Damage Costs

Due to the consistent projections of higher maximum wind speeds, and higher rainfall precipitation (Knutson et al. 2010), it can be expected that tropical cyclone damage will increase during the 21st century. Direct economic damages on assets due to strong TCs could double by 2100 compared to the no-climate-change baseline for population and GDP growth (Mendelsohn, Emanuel, Chonabayashi, and Bakkensen 2012).[81] Mendelsohn et al. (2012) project damage for a set of four climate models from the 1981–2000 period to the 2081–2100 period under the IPCC A1B SRES emission scenario, corresponding to an average 3.9°C temperature increase above pre-industrial levels. Total damage costs are projected to increase by a third compared to the no-climate-change baseline for population and GDP growth. The projected costs of TC damage in South East Asia, however, are strongly dominated by Vietnam and the Philippines, which show a large variation in both sign and size of damage across models. Above-average increases in TC damage as a percentage of GDP are projected for East Asia.

Tropical Cyclone Damage to Agriculture in the Philippines

Agricultural production in the Philippines is less vulnerable to the consequences of sea-level rise than production in the Vietnamese, Thai, and Burmese deltas, as most Philippine agriculture does not take place in coastal and low-lying areas. Nonetheless,

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the GDP generated by the travel and tourism industry. Sensitivity accounts for the share of arrivals for leisure, recreation, and holidays, the number of people affected by meteorologically extreme events, the number of people additionally inundated once a year for a sea-level rise of 50 cm, the length of low-lying coastal zones with more than 10 persons/km^2, and the beach length to be nourished in order to maintain important tourist resort areas. Finally, exposure involves the change in modified tourism climatic index, the change in maximum 5-day precipitation total, the change in fraction of total precipitation due to events exceeding the 95th percentile of climatological distribution for wet day amounts, and the required adaptation of corals to increased thermal stress.

80 Philippines: 5; Vietnam: 5; Laos: 5; Thailand: 4.

81 The authors estimate Global World Product in 2100 assuming that least developed countries' economies grow at 2.7 percent per annum, that emerging countries' economies grow at 3.3 percent per annum, and that developed countries grow at 2.7 percent per annum. For the global population projections, the authors project a population of 9 billion people.

tropical cyclones affect rice and other agricultural production in the Philippines—and may even more severely impact them as a result of climate change. The Philippines is located in the typhoon belt; on average, seven or eight tropical cyclones make landfall each year (Yumul et al. 2011). In recent years, tropical cyclones have generated significant damage; the agricultural sector suffered the most losses. For example, category 5 cyclone Bopha generated $646 million in damage to the agricultural sector in December 2012. Due to the impacts of Bopha, the Philippines Banana Growers and Exporters Association reported that about 25 percent of the banana production was devastated and that restoring destroyed farms would cost approximately $122 million (AON Benfield 2012). In the aftermath of category 4 cyclone Imbudo, local farmers in the Isabela Province reported crop losses as a proportion of annual farm household income at 64 percent for corn, 24 percent for bananas, and 27 percent for rice (Huigen and Jens 2006). At the country level, PHP 1.2 billion of damage occurred (about $29 million).

Additional Economic Impacts Due to Business Disruption

Extreme weather events and sea-level rise induced impacts are expected to have two types of economic implications: direct asset losses via damage to equipment and infrastructure and indirect business and economic disruptions affecting business activities and supply chains (Rose 2009).

While the consequences of past events imply that disruption to economic activity is a major potential source of losses incurred by climate impacts, the current understanding of business disruption in developing countries is still very limited. Indirect impacts of disasters include, among other things, off-site business interruption, reduced property values, and stock market effects (Asgary et al. 2012; Rose 2009). Business disruption is principally due to interruptions, changes, and delays in services provided by public and private electricity and water utilities and transport infrastructure (Sussman and Freed 2008). Coastal flooding and tropical cyclones can cause business disruption in developed and developing countries alike, as witnessed in the case of Hurricane Katrina in 2005. These business and economic disruptions generate a major portion of the total commercial insurance losses (Ross, Mills, and Hecht 2007). In the case of Hurricane Katrina, for example, losses due to business interruption, at $10 billion, were estimated to be as high as direct losses. In South East Asia, the 2011 Thai floods generated $32 billion in business interruption and other losses in the manufacturing sector (World Bank and GFDRR 2011).

The consequences of past events indicate that economic losses due to flooding reach beyond the direct point of impact. Future indirect responses to flooding, however, have not yet been projected for the region.

Box 4.5: Business Disruption due to River Flooding

River flooding is another climate-driven risk in low-lying delta regions. Recent observations of the consequence of extreme rainfall events, such as those that led to the 2011 Thailand floods, indicate that river flooding can be associated with significant loss of life and large total economic losses due to business interruption. Damages in the 2011 floods were estimate at $45.7 billion (equivalent to 13.2 percent of GDP); most of the losses were clustered in the Bangkok region (World Bank and GFDRR 2011). Flood damage in this case was 40 times higher than in earlier extreme floods and had substantial secondary effects on global industrial supply systems (Centre for Research on the Epidemiology of Disasters 2013). This report notes only past vulnerability and does not examine the possibility of increased exposure to river flooding in the future.

Projected Human Impacts

The impacts outlined in the above sections are expected to have repercussions on human health and on livelihoods; these impacts will be determined by the socioeconomic contexts in which they occur. The following provides a sketch of some of the key issues in South East Asia.

Projected Health Impacts and Excessive Mortality

South East Asia has been identified as a hotspot for diseases that are projected to pose an increasing risk under climate change. These include water- and vector-borne diseases and diarrheal illnesses (Coker, Hunter, Rudge, Liverani, and Hanvoravongchai 2011). Flooding compounds the risk of these diseases. Flooding is also associated with immediate risks, including drowning and the disruption of sanitation and health services as a result of damages to infrastructure (Schatz 2008).

Drowning is the main cause of immediate death from floods (Jonkman and Kelman 2005). Floodwaters can also damage the sewage systems and contribute to local freshwater and food supply contamination. Faecal contamination due to sewage system failure, which can also affect livestock and crops, was observed in 1999 following Hurricane Floyd in the United States (Casteel, Sobsey, and Mueller 2006).

The transmission of diarrheal diseases is influenced by a number of climatic variables, including temperature, rainfall, relative humidity, and air pressure, all of which affect pathogens in different ways (Kolstad and Johansson 2011). A factor driving the transmission of diarrheal diseases in South East Asia is water scarcity during droughts, which often leads to poor sanitation, in combination with climate-change-induced impacts such as

droughts, floods, and increased storminess (Coker et al. 2011). In a 4°C warming scenario, the relative risk of diarrhea is expected to increase 5–11 percent for the period 2010–39 and 13–31 percent for the period 2070–99 in South East Asia relative to 1961–1990 (Kolstad and Johansson 2011).

Moreover, vector-borne diseases, such as malaria and dengue fever, may also increase due to floods (Watson, Gayer, and Connolly 2007). Increased sea-surface temperature and sea-surface height has been observed to positively correlate with subsequent outbreaks of cholera in developing countries (Colwell 2002).

Heat extremes can also have significant impacts on human health. The elderly and women are considered to be the most vulnerable to heat extremes. South East Asia's populations are rapidly aging; in Vietnam, for example, the percentage of people aged 60 and over is projected to increase 22 percent between 2011–50, to account for a share of 31 percent of the total population in 2050 (United Nations Population Division 2011). These increases in the proportion of older people will place larger numbers of people at higher risk of the effects of heat extremes.

While rural populations are also exposed to climate-related risks, the conditions that characterize densely populated cities make urban dwellers particularly vulnerable. This is especially true of those who live in informal settlements (World Health Organization 2009).

Migration

Human migration can be seen as a form of adaptation and an appropriate response to a variety of local environmental pressures (Tacoli 2009), and a more comprehensive discussion of drivers and potential consequences of migration is provided in Chapter 3 on "Population Movement". While migration is a complex, multi-causal phenomenon, populations in South East Asia are particularly exposed to certain risk factors to which migration may constitute a human response.

Tropical cyclones have led to significant temporary population displacements in the aftermath of landfall. The tropical cyclone Washi, which struck the island of Mindanao in the Philippines in 2011, caused 300,000 people to be displaced (Government of the Philippines 2012) (see also Box 4.6).

South East Asian deltaic populations are expected to be the most severely affected by rising sea levels and storm surges (Marks 2011; Warner 2010; World Bank 2010b). In Vietnam alone, if the sea level rises up to 100 cm, close to five million people may be displaced due to permanent flooding and other climate-change-related impacts resulting in the submergence of deltaic and coastal areas (Carew-Reid 2008). However, there is large uncertainty as to the number of people expected to be affected by permanent migrations and forced relocations due to uncertainties in the projected physical impacts. The impacts of socioeconomic conditions add a further unknown to the projections.

Box 4.6: Planned Resettlement

As part of a flood management and environmental sanitation strategy, Vietnam's Department of Agriculture and Rural Development has undertaken the relocation of particularly vulnerable communities along river banks (Dun 2009). Although these relocations are often within a radius of 1–2 km, the potential disruption of social networks poses a risk to people´s livelihoods (Warner 2010). As the impacts of sea-level rise and tropical cyclones reduce adaptation options, the frequency of internal, temporary, and permanent migrations may increase (Warner 2010). Having lost their fisheries and agriculture-based livelihoods, people have in the past chosen to relocate to urban areas. A migrant to Phnom Penh from the Mekong River Delta explained, "*Flooding occurs every year at my former living place. I could not grow and harvest crops. Life therefore was very miserable. Besides, my family did not know what else we could do other than grow rice and fish. Flooding sometimes threatened our lives. So we came here to find another livelihood*" (Dun 2009: 17)

Conclusion

The key impacts that are expected to affect South East Asia at different levels of warming and sea level rise are summarized in Table 4.9.

Due to a combination of the risk factors driven by sea-level rise, increased heat extremes, and more intense tropical cyclones, critical South East Asian rice production in low lying coastal and deltaic areas is projected to be at increasing risk. Coastal livelihoods dependent on marine ecosystems are also highly vulnerable to the adverse impacts of climate change. Coral reefs, in particular, are extremely sensitive to ocean warming and acidification. Under 1.2°C warming, there is a high risk of annual bleaching events occurring (50-percent probability) in the region as early as 2030. Under 4°C warming by 2100, the likelihood is 100 percent. There are strong indications that this could have devastating impacts on tourism revenue and reef-based fisheries already under stress from overfishing. The coastal protection provided by corals reefs is also expected to suffer. In addition, warming seas and ocean acidification are projected to lead to substantial reductions in fish catch potential in the marine regions around South East Asia.

The livelihood alternative offered by aquaculture in coastal and deltaic regions would also come under threat from the impacts of sea-level rises projected to increase by up to 75 cm in a 2°C world and 105 cm in a 4°C world. Salinity intrusion associated with sea-level rise would affect freshwater and brackish aquaculture farms. In addition, increases in the water temperature may have adverse effects on regionally important farmed species (tiger

shrimp and stripped catfish) as surface waters warm. Increasingly intense tropical cyclones would also impact aquaculture farming.

Migration to urban areas as a response to diminishing livelihoods in coastal and deltaic areas is already occurring. While this response may offer opportunities not available in rural areas, cities are associated with a high vulnerability to the impacts of climate change. The urban poor, who constitute large proportions of city populations in the region, would be particularly hard hit. Floods associated with sea-level rise and storm surges carry significant risks in informal settlements, where damages to sanitation and water facilities are accompanied by health threats. The high population density in such areas compounds these risks.

South East Asia as a region is characterized by a high exposure to both slow-onset impacts associated with sea-level rise, ocean warming, and acidification, and sudden-onset impacts associated with tropical cyclones. The corrosive effects of the slow-onset impacts potentially undermine resilience and increase vulnerability in the face of devastating extreme weather events. This complex vulnerability is set to increase as the world warms toward 4°C.

Table 4.9: Impacts in South East Asia

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C (2030s[1])	Around 2°C (2040s)	Around 3°C (2060s)	Around 4°C and Above (2080s)
Regional Warming		South China Sea warmed at average rate of 0.3–0.4°C per decade since the 1960s.[2] Vietnam warmed at a rate of about 0.3°C per decade since 1971,[3] more than twice the global average rate for 1956–2005 of about 0.13°C per decade[4]		Summer warming[5] about 1.5°C[6] above the 1951–1980 baseline by the 2040s. Strongest warming expected in North Vietnam and Laos.[7] Warm nights (beyond 90th percentile in present-day climate) are projected to become the new normal[8]		Summer temperatures increase by 4.5°C.[9] Strongest warming expected in North Vietnam and Laos (5.0°C). Almost all nights (~95 percent) beyond present-day 90th percentile[10]
Heat Extremes	**Unusual Heat Extremes**	Virtually absent	About 50–60 percent of land boreal summer months (June, July August) (JJA)	About 60–70 percent of land boreal summer months (JJA)	About 85 percent of land boreal summer months (JJA)	>90 percent of land boreal summer months (JJA)
	Unprecedented Heat Extremes	Absent	About 25–30 percent of land boreal summer months (JJA)	30–40 percent of land area during boreal summer months Strongest increase Indonesia and southern Philippine islands with roughly half of summer months experiencing unprecedented heat[11]	About 70 percent of land boreal summer months (JJA)	>80 percent of land area during boreal summer months Indonesia and southern Philippine islands are projected to see the strongest increase, with all summer months experiencing unprecedented heat extremes[12]
Precipitation	**Region**			Slight increase during dry season (DJF)		Large model uncertainty regarding changes in wet season rainfall, ranging from a decrease of 5 percent to an increase of 10 percent[13]
	Extremes			Median >10 percent increase of extreme wet day precipitation share of the total annual precipitation.[14] Both minimum and maximum precipitation extremes are amplified[10]		Median >50 percent increase in extreme wet day precipitation share of the total annual precipitation[10] Both minimum and maximum precipitation extremes are amplified[10]
	Dry Days			Marginal increase in maximum number of consecutive dry days (as a measure for drought)[15]		About 5 percent increase in maximum number of consecutive dry days[16 10]

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Table 4.9: Impacts in South East Asia

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C (2030s[1])	Around 2°C (2040s)	Around 3°C (2060s)	Around 4°C and Above (2080s)
Drought					Increased drought (uncertain) for parts of Indonesia, Vietnam, and New Guinea[17] because of increase in precipitation is not enough to offset increase in evaporation due to strong heating	
Tropical Cyclones	**Tropical Cyclone (frequency)**		High resolution models show an overall decrease in TC frequency[18]; strongest agreement on decrease in frequency is found for the South China Sea[19]	High-resolution models show an overall decrease in TC frequency[18]; strongest agreement on decrease in frequency is found for the South China Sea.[19] Uncertainty remains: For the western North Pacific, other methods that project cyclogenesis indicate an increase in potential TC events by 10 percent[20]	High-resolution models show an overall decrease in TC frequency[18]; strongest agreement on decrease in frequency is found for the South China Sea.[19] Uncertainty remains: For the western North Pacific, other methods that project cyclogenesis indicate an increase in potential TC events by 20 percent[21]	High-resolution models show an overall decrease in TC frequency[18,21]; strongest agreement on decrease in frequency is found for the South China Sea.[19] Decrease in frequency of TCs making landfall of 35 percent for South East Asia and 10 percent for the Philippines.[22] Uncertainty remains: For the western North Pacific, other methods that project cyclogenesis indicate an increase in potential TC events by 20 percent[23]
	Tropical Cyclone (intensity)	Category 4 tropical cyclone Nargis (2008) inundated an area up to 6m above sea level in the Irrawaddy River Delta in Myanmar in 2008. A total of 2.4 million people were affected, including 800,000 people temporarily displaced, a death toll of 84,000, and 54,000 missing. Nargis also severely affected the agricultural sector. In 2011, tropical cyclone Washi, struck the island of Mindanao in the Philippines, caused 300,000 people to be displaced[24]		Global increase in storm-centered rainfall over the 21st century by between 3–37 percent[25]—also in the western North Pacific[26]	Frequency of strongest category 5 cyclones projected to increase with mean maximum surface wind speed increases of 7–18 percent. Total increased TC intensity of 1–7 percent for coastal regions, after taking into account an overall decrease in TC frequencies[27]	Maximum wind velocity at the coast is projected to increase by about 6 percent for mainland South East Asia and about 9 percent for the Philippines[22]
Sea Level Rise (above present)		About 20cm to 2010	30cm–2040s, 50cm–2060s 75cm (65–85 cm) by 2080–2100[28]	30cm–2040s, 50cm–2060s 75cm (65–85 cm) by 2080–2100	30cm–2040s, 50cm–2060 90cm (75–105 cm) by 2080–2100	30cm–2040s, 50cm–2060 110 cm (85–130 cm) by 2080–2100, lower by 5 cm around Bangkok

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Table 4.9: Impacts in South East Asia

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C (2030s[1])	Around 2°C (2040s)	Around 3°C (2060s)	Around 4°C and Above (2080s)
Sea-level Rise Impacts	**Coastal Erosion (loss of land)**	For the south Hai Thinh commune in the Vietnamese Red River delta, about 34 percent (12 percent) of the increase of erosion rate between 1965 and 1995 (1995 and 2005) has been attributed to the direct effect of sea-level rise[29]				A significant increase in coastal erosion for the Mekong Delta[30]
	Population Exposure	20 million people in South-East Asian cities exposed to coastal flooding in 2005[31]				8.5 million more people are projected to be exposed to coastal flooding by 2100[32] for global sea-level rise of 1m, up to 22 million if a very high urbanization rate assumed.[33] In Vietnam, close to 5 million people may be displaced[34]
	City Exposure		Bangkok – For a 14cm sea-level rise in 2025, 43 percent of the city area would be flooded.[35] Manila – For a 0.29m in 2050, a 100-year return-period flood could cause damages of up to 24 percent of the city's GDP by 2050[36]; a 30-year return-period flood could generate damages of approximately 15 percent of the city's GDP		Bangkok – For a 88cm sea level rise in 2100, up to 69 percent of Bangkok area would be flooded in 2100 respectively[37]	Ho Chi Minh City – up to 60 percent of the built-up area would be exposed[38] to a 1m sea-level rise

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Table 4.9: Impacts in South East Asia

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C (2030s[1])	Around 2°C (2040s)	Around 3°C (2060s)	Around 4°C and Above (2080s)
Salinity Intrusion		In the Mekong River Delta in 2005, Long An province's sugar cane production diminished by 5–10 percent; significant rice production in Duc Hoa district was also destroyed[39]	Low to moderate risk of saltwater intrusion into coastal groundwater resources for a 40cm sea-level rise.[40] In Mekong River Delta, with a 30cm sea-level rise the total area affected of 1.3–1.7 million ha[41]. Loss of about 4.7 percent of rice paddies in the province due to inundation and possible agricultural loss of a larger area of 294,000 hectares (about 7.2 percent of the Mekong River Delta province) due to salinity intrusion.[42]			Mahakam river region in Indonesia – increase in land area affected by 7–12 percent[43]
Ecosystem Impacts	**Coral Reefs**		At around 1.5°C warming above pre-industrial levels, about 89 percent of coral reefs are projected to experience severe bleaching.[44] By the 2030s, bleaching events approach 50 percent likelihood levels under 1.2°C warming.[45]	Up to 100 percent of coral reefs are projected to experience severe bleaching.[44] By the 2030s, bleaching events approach 50 percent likelihood levels under 1.2°C warming.[45] By the 2050s, with global mean warming of about 2°C, between 98–100 percent of coral reefs are projected to be thermally marginal.[45]	Under all concentration pathways (i.e., ranging from 2°C to above 4°C by the end of the century), virtually every coral reef in South East Asia would experience severe thermal stress by year 2050 under warming levels of 1.5°C–2°C above pre-industrial levels.[45] By the 2030s, bleaching events approach 70 percent likelihood levels under 1.5°C warming.[45]	Under 4°C warming, in 2100 virtually all coral reefs would be subject to severe bleaching events annually.[45] Under all concentration pathways (i.e., ranging from 2°C to above 4°C by the end of the century), virtually every coral reef in South East Asia would experience severe thermal stress by year 2050 under warming levels of 1.5°C–2°C above pre-industrial levels.[45] By the 2030s, bleaching events approach 70 percent likelihood levels under 1.5°C warming.[45]
	Coastal Wetlands					Coastal wetland area decreases from 109,000 km² to 76,000 km² (about 30 percent) between 2010 and 2100.[46] Vietnam – Loss of 8,533 square kilometres of freshwater marsh (65 percent loss). Philippines – Loss of 229 square kilometres (about 100 percent of the current surface) of lakes and wetlands by 2100.[47]

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Table 4.9: Impacts in South East Asia

Risk/Impact	Observed Vulnerability or Change	Around 1.5°C (2030s[1])	Around 2°C (2040s)	Around 3°C (2060s)	Around 4°C and Above (2080s)
Aquaculture	Between 1996 and 2011, fishing output in Vietnam was multiplied by 13 and its share of GDP from fishing and aquaculture increased from 5.9–8.1 percent[48]	Estimations of the costs of adapting[49] aquaculture in SEA range from $130 million per year for the period 2010–2050 to $190.7 million per year for the period 2010–2020.[50] In their study, Kam et al.[51] identify coastal flooding and salinity intrusion driven by sea-level rise as the main threats to aquaculture	Estimations of the costs of adapting aquaculture in SEA range from $130 million per year for the period 2010–2050[52] to $190.7 million per year for the period 2010–2020[53]		
Marine Fisheries	According to the FAO *Fishery Country Profile*,[54] fishery exports in Vietnam in 2004 amounted to $2.36 billion and 90 percent of commercial landings came from offshore fisheries. Exports of overall fish and fishery products in the Philippines amounted to $525.4 million		A 50 percent decrease in maximum catch potential around the southern Philippines and a 16 percent decrease in the waters of Vietnam to 6–16 percent increases around the northern Philippines[55]		Markedly negative trend in bigeye tuna[56]
Poverty		The relative risk of diarrhea is expected to increase 5–11 percent for the period 2010–2039 in South East Asia relative to 1961–1990[57]	The relative risk of diarrhea is expected to increase 5–11 percent for the period 2010–2039 in South East Asia relative to 1961–1990	The relative risk of diarrhea is expected to increase 5–11 percent for the period 2010–2039 and 13–31 percent for the period 2070–2099 in South East Asia relative to 1961–1990	
Tourism			Thailand, Indonesia, the Philippines, Myanmar, and Cambodia rank among the most vulnerable tourism destinations when sea-level rise, extreme weather events, and biodiversity losses are taken into account[58]		

Notes to Table 4.9

[1] Years indicate the decade during which warming levels are exceeded in a business-as-usual scenario, not in mitigation scenarios limiting warming to these levels, or below, since in that case the year of exceeding would always be 2100, or not at all.
[2] Tangang, Juneng, & Ahmad (2006).
[3] (Nguyen, Renwick, and McGregor (2013).
[4] Trenberth et al. (2007).
[5] The expected future warming is large compared to the local year-to-year natural variability. In a 2°C world, this shift is substantially smaller but still about 3–4 standard deviations.
[6] Model spread from 1.0°C to 2.0°C.
[7] Multimodel mean projecting up to 2°C under 2°C warming by 2071–2099.
[8] Occurrence probability around 60 (Sillmann & Kharin 2013).
[9] CMIP5 model range from 3.5°C to 6°C by 2100. The expected future warming is large compared to the local year-to-year natural variability. In a 4°C world, the monthly temperature distribution of almost all land areas in South East Asia shifts by 6 standard deviations or more toward warmer values.
[10] Sillmann and Kharin (2013), RCP8.5.
[11] Beyond 5-sigma under 2°C warming by 2071–2099.
[12] Beyond 5-sigma under 4°C warming by 2071–2099.
[13] Jourdain, Gupta, Taschetto, et al (2013).
[14] Sillmann and Kharin (2013).
[15] Sillmann and Kharin (2013), RCP2.6.
[16] Sillmann and Kharin (2013), RCP8.5.
[17] Dai (2011); (Dai (2012) using the RCP4.5 scenario.
[18] Held and Zhao (2011); Murakami, Wang, et al. (2012).
[19] Held and Zhao, (2011); Murakami, Sugi, and Kitoh (2012); Yokoi and Takayabu (2009)
[20] Caron and Jones (2007)the main large-scale climatic fields controlling tropical cyclone (TC.
[21] Caron and Jones (2007)the main large-scale climatic fields controlling tropical cyclone (TC.
[22] Murakami, Wang, and Kitoh (2011).
[23] Caron and Jones (2007)the main large-scale climatic fields controlling tropical cyclone (TC.
[24] Government of the Philippines (2012).
[25] Knutson et al. (2010).
[26] Rate of increase depends on the specific climate model used (Emanuel, Sundararajan, and Williams 2008).
[27] Murakami, Wang, et al. (2012). Future (2075–99) projections SRES A1B scenario.
[28] For a scenario in which warming peaks above 1.5°C around the 2050s and drops below 1.5°C by 2100. Due to slow response of oceans and ice sheets, the sea-level response is similar to a 2°C scenario during the 21st century, but deviates from it after 2100.
[29] (Duc, Nhuan, & Ngoi, 2012)
[30] 1m sea-level rise by 2100 (Mackay and Russell 2011).
[31] Brecht et al. (2012). In this study, the urban population fraction is held constant over the 21st century.
[32] Brecht et al. (2012). In this study, the urban population fraction is held constant over the 21st century.
[33] Hanson et al. (2011).
[34] Due to permanent floods and other climate-change-related impacts conducting [leading?] to deltaic and coastal areas submergence (Carew-Reid 2008).
[35] Dutta (2011).
[36] Muto et al. (2010).
[37] Dutta (2011).
[38] Storch and Downes (2011). In the absence of adaptation, the planned urban development for the year 2025 contributes to increase Ho Chi Minh City's exposure to sea-level rise by 17 percent.
[39] MoNRE (2010) states, "Sea-level rise, impacts of high tide, and low discharge in dry season contribute to deeper salinity intrusion. In 2005, deep intrusion (and more early than normal), high salinity, and long-lasting salinization occurred frequently in Mekong Delta provinces."
[40] Ranjan, Kazama, Sawamoto, and Sana (2009) assume a global sea-level rise of about 40cm above 2000 levels by 2100.
[41] World Bank (2010b).
[42] Without adaptation measures, rice production may in consequence decline by approximately 2.6 million tons per year, assuming 2010 rice productivity. This would represent a direct economic loss in export revenue of $1,22 billion, based on 2011 prices (World Bank 2010b).
[43] Under 4°C warming and 100m sea-level rise by 2100 (Mcleod et al. 2010).
[44] Frieler et al. (2012).
[45] Meissner et al. (2012).
[46] 100m sea-level rise (Mcleod et al. 2010).
[47] Blankespoor, Dasgupta, and Laplante (2012). The region could lose approximately $296.1–368.3 million per year in economic value (2000 U.S. dollars).
[48] (General Statistics Office of Vietnam 2012)
[49] Raising pond dikes and water pumping.
[50] World Bank (2010b) projections were calculated from a set 21 global models in the multimodel ensemble approach from 1980–99 and 2080–99 under the IPCC A1B scenario, corresponding to a 2.8°C temperature increase globally (3.3°C above pre-industrial levels).
[51] Kam, Badjeck, Teh, Teh, and Tran (2012).
[52] (World Bank, 2010b)For the World Bank study, projections were calculated from a set 21 global models in the multi-model ensemble approach from 1980–99 and 2080–99 under the IPCC A1B scenario, corresponding to a 2.8°C temperature increase globally (3.3°C above pre-industrial levels).
[53] Kam, Badjeck, Teh, Teh, and Tran (2012).
[54] http://www.fao.org/fishery/countrysector/FI-CP_VN/en.
[55] Maximum catch potential (Cheung et al. 2010).
[56] Lehodey et al. (2010). In a 4°C world, conditions for larval spawning in the western Pacific are projected to have deteriorated due to increasing temperatures to the benefit of subtropical regions. Overall adult mortality is projected to increase, leading to a markedly negative trend in biomass by 2100.
[57] Kolstad and Johansson (2011) derived a releationship between diarrhea and warming based on earlier studies (Scenario A1B).
[58] Perch-Nielsen (2009). Assessment allows for adaptive capacity, exposure, and sensitivity in a 2°C warming and 50cm SLR scenario for the period 2041–2070.

Chapter 5

South Asia: Extremes of Water Scarcity and Excess

REGIONAL SUMMARY

In this report, South Asia refers to a region comprising seven countries[82] with a growing population of about 1.6 billion people in 2010, which is projected to rise to over 2.2 billion by 2050. At 4°C global warming, sea level is projected to rise over 100 cm by the 2090s, monsoon rainfall to become more variable with greater frequency of devastating floods and droughts. Glacier melting and snow cover loss could be severe, and unusual heat extremes in the summer months (June, July, and August) are projected to affect 70 percent of the land area. Furthermore, agricultural production is likely to suffer from the combined effects of unstable water supply, the impacts of sea-level rise, and rising temperatures. The region has seen robust economic growth in recent years, yet poverty remains widespread and the combination of these climate impacts could severely affect the rural economy and agriculture. Dense urban populations, meanwhile, would be especially vulnerable to heat extremes, flooding, and disease.

Current Climate Trends and Projected Climate Change to 2100

South Asia has a unique and diverse geography dominated in many ways by the highest mountain range on Earth, the Himalayan mountain range and Tibetan Plateau, giving rise to the great river systems of the Indus, Ganges, and Brahmaputra. The climate of the region is dominated by the monsoon: The largest fraction of precipitation over South Asia occurs during the summer monsoon season. Eighty percent of India's rainfall, for example, occurs in this period. The timely arrival of the summer monsoon, and its regularity, are critical for the rural economy and agriculture in South Asia.

Under future climate change, the frequency of years with above normal monsoon rainfall and of years with extremely deficient rainfall is expected to increase. The Ganges, Indus, and Brahmaputra—are vulnerable to the effects of climate change due to the melting of glaciers and loss of snow cover. The result

[82] Bangladesh, Bhutan, India, the Maldives, Nepal, Pakistan, and Sri Lanka. This follows the SREX regional definition and hence does not include Afghanistan. Some of the studies reviewed in the report however include Afghanistan, and less frequently Iran or Turkey, in their assessment for South Asia.

is a significant risk to stable and reliable water resources for the region, with increases in peak flows associated with the risk of flooding and dry season flow reductions threatening agriculture.

In the past few decades a warming trend has begun to emerge over South Asia, particularly in India, which appears to be consistent with the signal expected from human induced climate change. Recent observations of total rainfall amounts during the monsoon period indicate a decline in rainfall, likely due to the effects of anthropogenic aerosols, particularly black carbon. In addition to these patterns there are observed increases in the frequency of the most extreme precipitation events, as well as increases in the frequency of short drought periods.

Rainfall

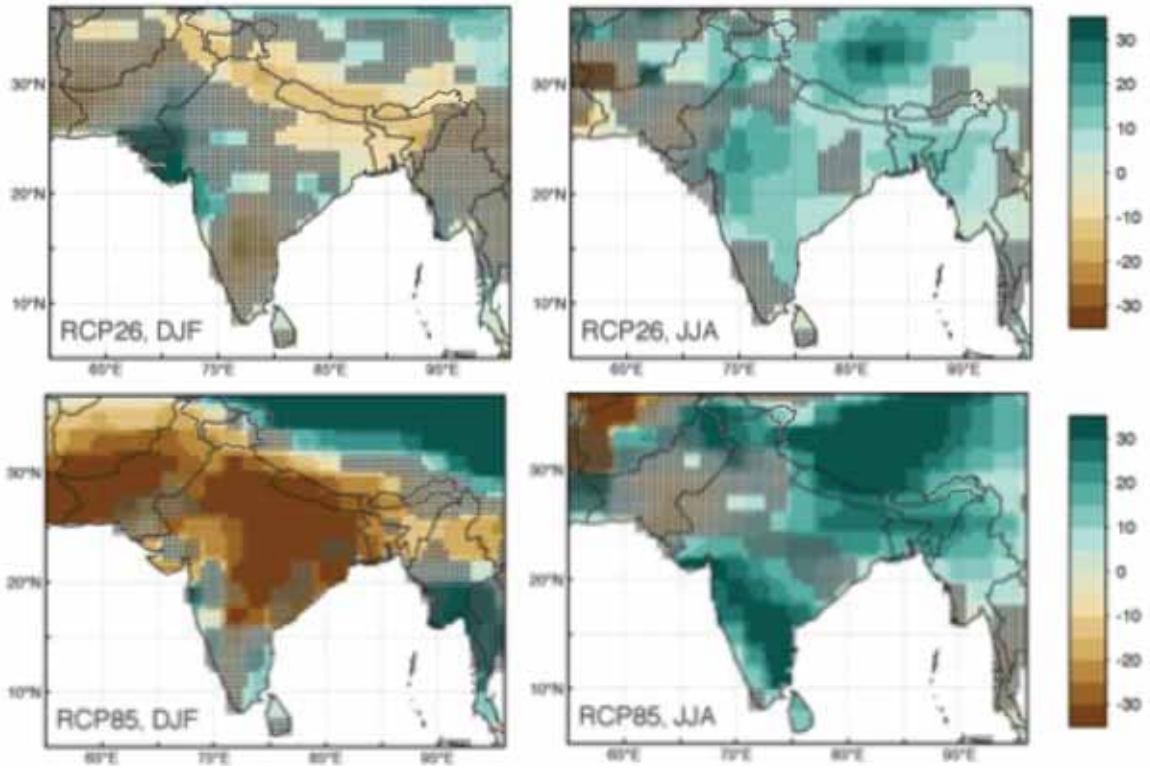
During recent decades, increases in the frequency of the most extreme precipitation events have been observed. Annual precipitation is projected to increase by up to 30 percent in a 4°C world. The seasonal distribution of precipitation is expected to become amplified, with a decrease of up to 30 percent during the dry season and a 30 percent increase during the wet season.

Temperature

In a 4°C world, South Asian summer temperatures are projected to increase by 3°C to nearly 6°C by 2100, with the warming most pronounced in Pakistan. The pattern remains the same in a 2°C world, with warming reaching 2°C in the northwestern parts of the region and 1°C to 2°C in the remaining regions. By the time 1.5°C warming is reached, heat extremes that are unusual or virtually absent in today´s climate in the region are projected to cover 15 percent of land areas in summer.

Under 2°C warming, unusual extreme heat over 20 percent of the land area is projected for Northern Hemisphere summer months, with unprecedented heat extremes affecting about 5 percent of the land area, principally in the south. Under 4°C warming, the west coast and southern India, as well as Bhutan and northern Bangladesh, are projected to shift to new, high-temperature climatic regimes. Unusual heat is projected for 60–80 percent of the Northern Hemisphere summer months in most parts of the region. Some regions are projected to experience unprecedented heat during more than half of the summer months, including Sri Lanka and Bhutan. In the longer term, the exposure of South Asia

Figure 5.1: South Asia Multi-model mean of the percentage change dry-season (DJF, left) and wet-season (JJA, right) precipitation for RCP2.6 (2°C world; top) and RCP8.5 (4°C world; bottom) for South Asia by 2071–2099 relative to 1951–1980



Hatched areas indicate uncertainty regions with 2 out of 5 models disagreeing on the direction of change compared to the remaining 3 models.

Table 5.1: Summary of climate impacts and risks in South Asia[a]

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C[b] (2030s[c])	Around 2°C (2040s)	Around 3°C (2060s)	Around 4°C (2080s)
Regional warming		2011 Indian temperature 9th warmest on record. 2009 warmest at 0.9°C above 1961–90 average		Warm spells lengthen to 20–45 days. Warm nights occur at frequency of 40 percent		Warm spells lengthen to 150–200 days. Warm nights occur at frequency of 85 percent
Heat extremes (in the Northern Hemisphere summer)[d]	Unusual heat extremes	Virtually absent	15 percent of land	20 percent of land	>50 percent of land	>70 percent of land In south almost all summer months unusually hot
	Unprecedented heat extremes	Absent	Virtually absent	<5 percent of land	20 percent of land	>40 percent of land
Precipitation (including the monsoon)		Decline in South Asian monsoon rainfall since the 1950s but increases in frequency of most extreme precipitation events	Change in rainfall uncertain	Change in rainfall uncertain; 20 percent increase of extreme wet day precipitation share of the total annual precipitation[e]	About 5 percent increase in summer (wet season) rainfall	About 10 percent increase in summer (wet season) rainfall. Intra seasonal variability of monsoon rainfall increased, by about 15 percent. 75 percent increase of extreme wet day precipitation share of total annual precipitation[f]
Drought		Increased frequency short droughts			Increased drought over north-western parts of the region, particularly Pakistan	Increased length of dry spells measured by consecutive dry days in eastern India and Bangladesh
Sea-level rise above current:		About 20 cm to 2010	30cm–2040s 50cm–2070 70 cm by 2080–2100	30cm–2040s 50cm–2070 70cm by 2080–2100	30cm–2040s 50cm–2060 90cm by 2080–2100	30cm–2040s 50cm–2060 105cm by 2080–2100, Maldives 10cm higher

[a] A more comprehensive table of impacts and risks for SEA is presented at the end of Chapter 5.
[b] Years indicate the decade during which warming levels are exceeded in a business-as-usual scenario exceeding 4°C by the 2080s.
[c] Years indicate the decade during which warming levels are exceeded in a business-as-usual scenario exceeding 4°C by the 2080s.
[d] Mean across climate model projections is given. Illustrative uncertainty range across the models (minimum to maximum) for 4°C warming are 70–100 percent for unusual extremes, and 30–100 percent for unprecedented extremes. The maximum frequency of heat extreme occurrence in both cases is close to 100 percent, as indicator values saturate at this level.
[e] 50 percent uncertainty range 8–12 percent.
[f] 50 percent uncertainty range 65–85 percent.

to an increase in these extremes could be substantially limited by holding warming below 2°C.

Likely Physical and Biophysical Impacts as a Function of Projected Climate Change

The projected changes in rainfall, temperature, and extreme event frequency and/or intensity would have both direct and indirect impacts on monsoon activity, droughts, glacial loss, snow levels, river flow, ground water resources, and sea-level rise.

Monsoon

While most modeling studies project increases in average annual monsoonal precipitation over decadal timescales, they also project significant increases in inter-annual and intra-seasonal variability.

For global mean warming approaching 4°C, a 10 percent increase in annual mean monsoon intensity and a 15 percent increase in year-to-year variability of Indian summer monsoon precipitation is projected compared to normal levels during the first half of the 20th century. Taken together, these changes imply

that an extreme wet monsoon that currently has a chance of occurring only once in 100 years is projected to occur every 10 years by the end of the century.

A series of unusually intense monsoonal rainfall events in the mountainous catchment of the Indus River was one of the main physical drivers of the devastating Pakistan floods of 2010, which resulted in more than 1,900 casualties and affected more than 20 million people. Farms and key infrastructure, such as bridges, were washed away in the predominantly rural areas affected. The rainfall event itself was only the start of a chain of events that led to prolonged and wide-scale flooding downstream, with many other factors due to human activity. Irrigation dams, barrages, river embankments, and diversions in the inland basins of rivers can seriously exacerbate the risk of flooding downstream from extreme rainfall events higher up in river catchments.

Large uncertainty remains about the behavior of the Indian summer monsoon under global warming. An abrupt change in the monsoon, for example, toward a drier, lower rainfall state, could precipitate a major crisis in South Asia, as evidenced by the anomalous monsoon of 2002, which caused the most serious drought in recent times (with rainfall about 209 percent below the long-term normal and food grain production reductions of about 10–15 percent compared to the average of the preceding decade). Physically plausible mechanisms have been proposed for such a switch, and changes in the tropical atmosphere that could precipitate a transition of the monsoon to a drier state are projected in the present generation of climate models.

Droughts

The projected increase in seasonality of precipitation is associated with an increase in the number of dry days and droughts with adverse consequences for human lives. Droughts are expected to pose an increasing risk in parts of the region, particularly Pakistan, while increasing wetness is projected for southern India. The direction of change is uncertain for northern India. Of the ten most severe drought disasters globally in the last century, measured in terms of the number of people affected, six were in India, affecting up to 300 million people. For example, the Indian droughts of 1987 and 2002/2003 affected more than 50 percent of the crop area in the country and, in 2002, food grain production declined by 29 million tons compared to the previous year. It is estimated that in the states of Jharkhand, Orissa, and Chhattisgarh, major droughts, which occur approximately every five years, negatively impact around 40 percent of agricultural production.

Glacial Loss, Snow Cover Reductions, and River Flow

Over the past century most of the Himalayan glaciers have been retreating. Currently, 750 million people depend on the glacier-fed Indus and Brahmaputra river basins for freshwater resources, and reductions in water availability could significantly reduce the amount of food that can be produced within the river basins. These rivers depend heavily on snow and glacial melt water, which makes them highly susceptible to climate-change-induced glacier and snowmelt. Warming projections of about 2.5°C above pre-industrial levels by the 2050s indicate the risk of substantial reductions in the flow of the Indus and Brahmaputra in summer and late spring, after a period with increased flow. The availability of water for irrigation is very much contingent on these water resources, particularly during the dry seasons.

- An increased river flow in spring is projected due to stronger glacial melt and snowmelt, with less runoff available prior to monsoon onset in late spring and summer.
- For the Indus River Delta, high flow is projected to increase by about 75 percent for warming above 2°C. Higher peak river flows expose a growing number of people inhabiting the densely populated river deltas of the regions to the combined risks of flooding, sea-level rise, and increasing tropical cyclone intensity.

Groundwater Resources

Groundwater resources, which are mainly recharged by precipitation and surface-water, are also expected to be impacted by climate change. South Asia, especially India and Pakistan, are highly sensitive to decreases in groundwater recharge as these countries are already suffering from water scarcity and largely depend on a supply of groundwater for irrigation. In India, for example, 60 percent of irrigation depends on groundwater, while about 15 percent of the country's groundwater tables are overexploited, including the Indus basin. Groundwater resources are particularly important to mitigate droughts and related impacts on agriculture and food security. With increased periods of low water availability and dry spells projected, it is likely that groundwater resources will become even more important for agriculture, leading to greater pressure on resources. Projected increases in the variability and seasonality of monsoon rainfall may affect groundwater recharge during the wet season and lead to increased exploitation during the dry season.

Sea-level Rise

With South Asian coastlines being located close to the equator, projections of local sea-level rise show a greater increase compared to higher latitudes. Sea-level rise is projected to be approximately 100–115 cm by the 2090s in a 4°C world, and 60–80 cm in a 2°C world, by the end of the 21st century relative to 1986–2005, with the highest values (up to 10 cm more) expected for the Maldives. This is generally around 5–10 percent higher than the global mean, and a 50 cm sea-level rise would likely occur by 2060.

Sector-based and Thematic Impacts

Water Resources are already at risk in the densely populated countries of South Asia, according to most studies that assess this risk. One study indicates that for a warming of about 3°C above pre-industrial levels by the 2080s, it is very likely that per capita water availability will decrease by more than 10 percent due to a combination of population increase and climate change in South Asia. Even for 1.5–2°C warming, major investments in water storage capacity would be needed in order to utilize the potential benefits of increased seasonal runoff and compensate for lower dry seasons flows, to allow improved water availability throughout the year.

The quality of freshwater is also expected to suffer from potential climate impacts. Sea-level rise and storm surges in coastal and deltaic regions would lead to saltwater intrusion degrading groundwater quality. Contamination of drinking water by saltwater intrusion may cause an increasing number of diarrhea cases. Cholera outbreaks may also become more frequent as the bacterium that causes cholera, *vibrio cholerae*, survives longer in saline water. About 20 million people in the coastal areas of Bangladesh are already affected by salinity in their drinking water.

Crop Yields are vulnerable to a host of climate-related factors in the region, including seasonal water scarcity, rising temperatures, and salinity intrusion due to sea-level rise. Rising temperatures and changes in rainfall patterns have contributed to reduced relative yields of rice, the most important crop in Asia, especially in rainfed areas. Cultivated crops have been observed to also be sensitive to rising temperatures. One study finds that compared to calculations of potential yields without historic trends of temperature changes since the 1980s, rice and wheat yields have declined by approximately 8 percent for every 1°C increase in average growing-season temperatures. Another study found that the combination of warmer nights and lower precipitation at the end of the growing season has caused a significant loss of rice production in India: yields could have been almost 6-percent higher without the historic change in climatic conditions.

While overall yields have increased over the last several decades, in the last decade worrying signs have emerged of crop yield stagnation on substantial areas of Indian cropland. The projected increase in extreme heat affecting 10 percent of total land area by 2020 and 15 percent by 2030 poses a high risk to crop yields. Crop yields are projected to decrease significantly for warming in the 1.5–2.0°C range; if there is a strong CO_2 fertilization effect, however, the negative effects of warming might be offset in part by low-cost adaptation measures. Above about 2°C warming above pre-industrial levels, crop yields are projected to decrease around 10–30 percent for warming of 3–4.5°C, with the largest reductions in the cases where the CO_2 fertilization effect is weak.

Total Crop Production without climate change is projected to increase significantly (by 60 percent) in the region and be under increased price pressure and a trend factor expressing technological improvements, research and development, extension of markets, and infrastructure. Under 2°C warming by the 2050s, the increase may be reduced by at least 12 percent, requiring more than twice the imports to meet per capita demand than is required without climate change. As a result, per-capita calorie availability is projected to decrease significantly. Decreasing food availability can lead to significant health problems in affected populations, including childhood stunting, which is projected to increase by 35 percent by 2050 compared to a scenario without climate change.

Energy Security is expected to come under increasing pressure from climate-related impacts to water resources. The two dominant forms of power generation in the region are hydropower and thermal power generation (e.g., fossil fuel, nuclear, and concentrated solar power), both of which can be undermined by inadequate water supplies. Thermal power generation may also be affected through pressure placed on cooling systems by increases in air and water temperatures.

Integrated Synthesis of Climate Change Impacts in the South Asia Region

Water resource dynamics: Many of the climate risks and impacts that pose potential threats to populations in the South Asia region can be linked back to changes to the water cycle—extreme rainfall, droughts, and declining snow fall and glacial loss in the Himalayas leading to changes in river flow—combined in the coastal regions with the consequences of sea-level rise and increased tropical cyclone intensity. Increasing seasonality of precipitation as a loss of snow cover is likely to lead to greater levels of flooding, and higher risks of dry periods and droughts. Exacerbating these risks are increases in extreme temperatures, which are already observed to adversely affect crop yields. Should these trends and patterns continue, substantial yield reductions can be expected in the near and midterm. Changes in projected rainfall amounts and geographical distribution are likely to have profound impacts on agriculture, energy, and flood risk.

The region is highly vulnerable even at warming of less than 2°C given the significant areas affected by droughts and flooding at present temperatures. In addition, the projected risks to crop yields and water resources, and sea-level rise reaching 70 cm by the 2070s, are likely to affect large populations.

Deltaic Regions and Coastal Cities are particularly exposed to cascading risks resulting from a combination of climatic changes, including increased temperature, increased river flooding, rising sea levels, and increasingly intense tropical cyclones and their consequences. Deaths in India and Bangladesh currently account for 86 percent of global mortalities from cyclones even though only 15 percent of all tropical cyclones affect this region.

- ***Bangladesh*** emerges as an impact hotspot with increasing and compounding challenges occurring in the same timeframe from extreme river floods, more intense tropical cyclones, rising sea levels, extraordinarily high temperatures, and declining crop yields. Increased river flooding combined with tropical cyclone surges poses a high risk of inundation in areas with the largest shares of poor populations. A 27 cm sea-level rise, projected for the 2040s, in combination with storm surges from an average 10-year return period cyclone, such as Cyclone Sidr, could inundate an area more than 80-percent larger than the area inundated at present by a similar event.
- ***Kolkata*** and ***Mumbai*** are highly vulnerable to the impacts of sea-level rise, tropical cyclones, and riverine flooding. Floods and droughts are associated with health impacts, including diarrheal diseases, which at present are a major cause of child mortality in Asia and the Pacific.

Climate change shocks to seasonal water availability would confront populations with ongoing and multiple challenges to accessing safe drinking water, sufficient water for irrigation, and adequate cooling capacity for thermal power production.

Irrespective of future emission paths, in the next 20 years a several-fold increase in the frequency of unusually hot and extreme summer months can be expected from warming already underway. A substantial increase in excess mortality is expected to be associated with such heat extremes and has been observed in the past.

Increasing risks and impacts from extreme river floods, more intense tropical cyclones, rising sea levels, and extraordinarily high temperatures are projected. Population displacement, which already periodically occurs in flood-prone areas, is likely to continue to result from severe flooding and other extreme events. Agricultural production is likely to suffer from the combined effects of rising temperatures, impacts on seasonal water availability, and the impacts of sea-level rise.

Future economic development and growth will contribute to reducing the vulnerability of South Asia's large and poor populations. Climate change projections indicate, however, that high levels of vulnerability are projected and their societal implications indicate that high levels of vulnerability are likely to remain and persist. Warming is projected to significantly slow the expected reduction in poverty levels. Many of the climate change impacts in the region pose a significant challenge to development, even with relatively modest warming of 1.5–2°C. Major investments in infrastructure, flood defense, and development of high temperature and drought resistant crop cultivars, and major improvements in such sustainability practices as groundwater extraction, would be needed to cope with the projected impacts under this level of warming.

Introduction

This report defines the South Asian region as Bangladesh, Bhutan, India, Nepal, the Maldives, Pakistan, and Sri Lanka. For the projections of temperature and precipitation changes, heat extremes, and sea-level rise presented here, South Asia is defined as ranging from 61.25 to 99.25°E and 2.25 to 30.25°N.[83]

Although economic growth in South Asia has been robust in recent years, poverty remains widespread and the world's largest concentration of poor people reside in the region. The unique geography of the region plays a significant part in shaping the livelihoods of South Asians. Agriculture and the rural economy are largely dependent on the timely arrival of the Asian summer monsoon. The Hindu Kush and Himalaya mountains to the north contain the reach of the monsoon, thereby confining its effects to the subcontinent and giving rise to the great river systems of the Indus and Ganges-Brahmaputra.

The populations of South Asia are already vulnerable to shocks in the hydrological regime. Poverty in the Bay of Bengal region, for example, is already attributed in part to such environmental factors as tropical cyclones and seasonal flooding. Warming toward 4°C, which is expected to magnify these and other stressors, would amplify the challenge of poverty reduction in South Asia (Box 5.1). These risk factors include:

- Increases in temperatures and extremes of heat
- Changes in the monsoon pattern
- Increased intensity of extreme weather events, including flooding and tropical cyclones
- Sea-level rise

These physical impacts and their effects on a number of sectors, including agriculture, water resources, and human health, will be reviewed in this analysis. Not all potential risks and affected sectors are covered here as some (e.g., ecosystem services) fall outside the scope of this report.

Regional Patterns of Climate Change

A warming trend has begun to emerge over South Asia in the last few decades, particularly in India, and appears to be consistent

[83] Impact assessments pertaining to water resources, droughts and health impacts include Afghanistan.

Box 5.1: Observed Vulnerabilities

Observed Vulnerability – Floods

The 2010 flash flood in Pakistan is an example of an extreme event of unprecedented severity and illustrates the challenges South Asia faces (UNISDR 2011). Unusually intense monsoonal rainfall in the mountainous catchment of the Indus River was one of the main physical drivers of the devastating flood (P. Webster, Toma, and Kim 2011). The flood caused more than 1,900 casualties, affected more than 20 million people, and resulted in $9.5 billion in economic damages—the highest number of people affected and the largest price tag ever for a natural disaster in Pakistan (EM-DAT 2013, based on data from 1900–2013). Homes, farms, and such key infrastructure as bridges were washed away in the predominantly rural area affected (UNISDR 2011).

Observed Vulnerability – Droughts

Losses induced by past droughts highlight current South Asian vulnerability to droughts. Of the 10 most severe drought disasters globally in the last century, measured in terms of the number of people affected, six took place in India; these affected up to 300 million people (in 1987 and 2002; 1900–2013 data based on EM-DAT 2013). In India, the droughts of 1987 and 2002–2003 affected more than 50 percent of the crop area in the country (Wassmann, Jagadish, Sumfleth, et al. 2009); in 2002, food grain production declined by 29 million tons compared to the previous year (UNISDR 2011). Major droughts in the states of Jharkhand, Orissa, and Chhattisgarh, which occur approximately every five years, are estimated to affect around 40 percent of rice production, an $800 million loss in value (Wassmann, Jagadish, Sumfleth, et al. 2009).

with the signal expected from human-induced climate change (Kumar et al 2010).

Recent observations of total rainfall amounts during the monsoon period indicate a decline in the last few decades. While some earlier studies find no clear trend in the all-India mean monsoon rainfall (Guhathakurta and Rajeevan 2008; R. Kripalani, Kulkarni, Sabade, and Khandekar 2003),[84] more recent studies indicate a decline of as much as 10 percent in South Asian monsoon rainfall since the 1950s (Bollasina, Ming, and Ramaswamy 2011; Srivastava, Naresh Kumar, and Aggarwal 2010; A. G. Turner and Annamalai 2012; Wang, Liu, Kim, Webster, and Yim 2011).[85] The data also note a downward trend in rainfall during monsoon and post-monsoon seasons in the basins of the Brahmaputra and Barak rivers in the state of Assam in Northeast India for the time period 1901–2010; this trend is most pronounced in the last 30 years (Deka, Mahanta, Pathak, Nath, and Das 2012). While the observed decline is inconsistent with the projected effects of global warming, there are indications that the decline could be due at least in part to the effects of black carbon and other anthropogenic aerosols (A. G. Turner and Annamalai 2012).

Within this overall picture, important changes have been observed in the structure and processes of precipitation events in the monsoon region. Most rainfall during the monsoon period comes from moderate to heavy rainfall events, yet recent studies indicate a decline in the frequency of these events from the 1950s to the present (P. K. Gautam 2012;[86] R. Krishnan et al. 2012), consistent with observations of changes in monsoon physics.[87] These trends are in accordance with very high resolution modeling (20 km resolution) of the future effects of greenhouse gases and aerosols on the Indian monsoon (R. Krishnan et al. 2012).

In addition to these patterns, there are observed increases in the frequency of the most extreme precipitation events (R. Gautam, Hsu, Lau, and Kafatos 2009; P. K. Gautam, 2012) and in the frequency of short drought periods (Deka et al. 2012). Deka et al. (2012) attribute this to a superposition of the effects of global warming on the normal monsoon system. They argue that these changes "indicate a greater degree of likelihood of heavy floods as well as short spell droughts. This is bound to pose major challenges to agriculture, water, and allied sectors in the near future." Over northern India, the 20th century has witnessed a trend toward increasingly frequent extreme rain events attributed to a warming atmosphere (N. Singh and Sontakke 2002; B. N. Goswami, Venugopal, Sengupta, Madhusoodanan, and Xavier 2006; Ajayamohan and Rao 2008).

Extreme rainfall events over India show wide spatial variability, with more extreme events occurring over the west coast and central and northeast India (Pattanaik and Rajeevan 2009). The frequency and intensity of extreme rainfall events over central India show a rising trend under global warming, whereas the frequency of moderate events show a significant decreasing trend (B. N. Goswami, Venugopal, Sengupta, Madhusoodanan, and Xavier 2006).

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84 Even though there is no overall rainfall trend in in India, several smaller regions within the country show significant increasing and decreasing trends (Guhathakurta and Rajeevan 2008; K. R. Kumar, Pant, Parthasarathy, and Sontakke 1992).

85 Although most studies agree on the existence of this decrease, its magnitude and significance are highly dependent on the sub-region on which the analysis is performed and the dataset that is chosen (A. G. Turner and Annamalai 2012).

86 Gridded observational data for Central India show a decrease in moderate (5–100 mm/day) rainfall events.

87 APHRODITE observational dataset shows that the frequency of moderate-to-heavy rainfall events (i.e., local rainfall amounts between the 75th and 95th percentile) during the summer monsoon season has decreased between 1951–2010. For the same time period, parallel changes in the rising branch of the meridional overturning circulation of the South Asian Monsoon from NCEP reanalysis data are observed with a decrease in the variability of the inter-annual vertical velocity.

Projected Temperature Changes

A 2°C world shows substantially lower average warming over the South Asian land area than would occur in a 4°C world. Figure 5.2 shows the projected boreal summer the months of June, July, and August (JJA) warming over the Indian subcontinent for RCP2.6 and RCP8.5 scenarios. Summer warming in India is somewhat less strong than that averaged over the total global land area, with temperatures peaking at about 1.5°C above the 1951–80 baseline by 2050 under RCP2.6. Under RCP8.5, warming increases until the end of the century and monthly Indian summer temperatures reach about 5°C above the 1951–80 baseline by 2100 in the multimodel mean. Geographically, the warming occurs uniformly, though inland regions warm somewhat more in absolute terms (see Figure 5.3). Relative to the local year-to-year natural variability, the pattern is reversed—with coastal regions

Figure 5.2: Temperature projections for South Asian land area for the multi-model mean (thick line) and individual models (thin lines) under scenarios RCP2.6 and RCP8.5 for the months of JJA

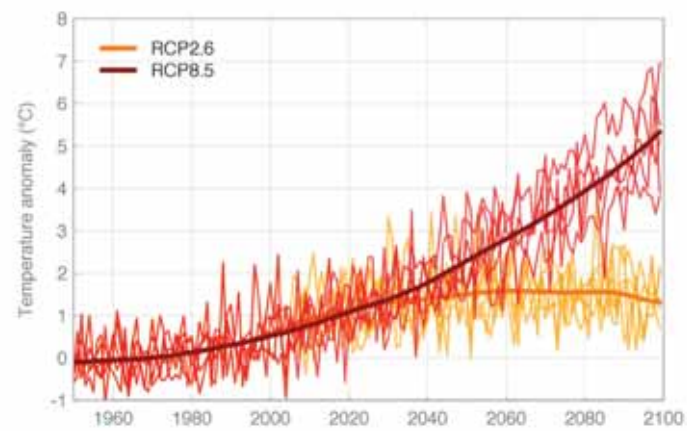
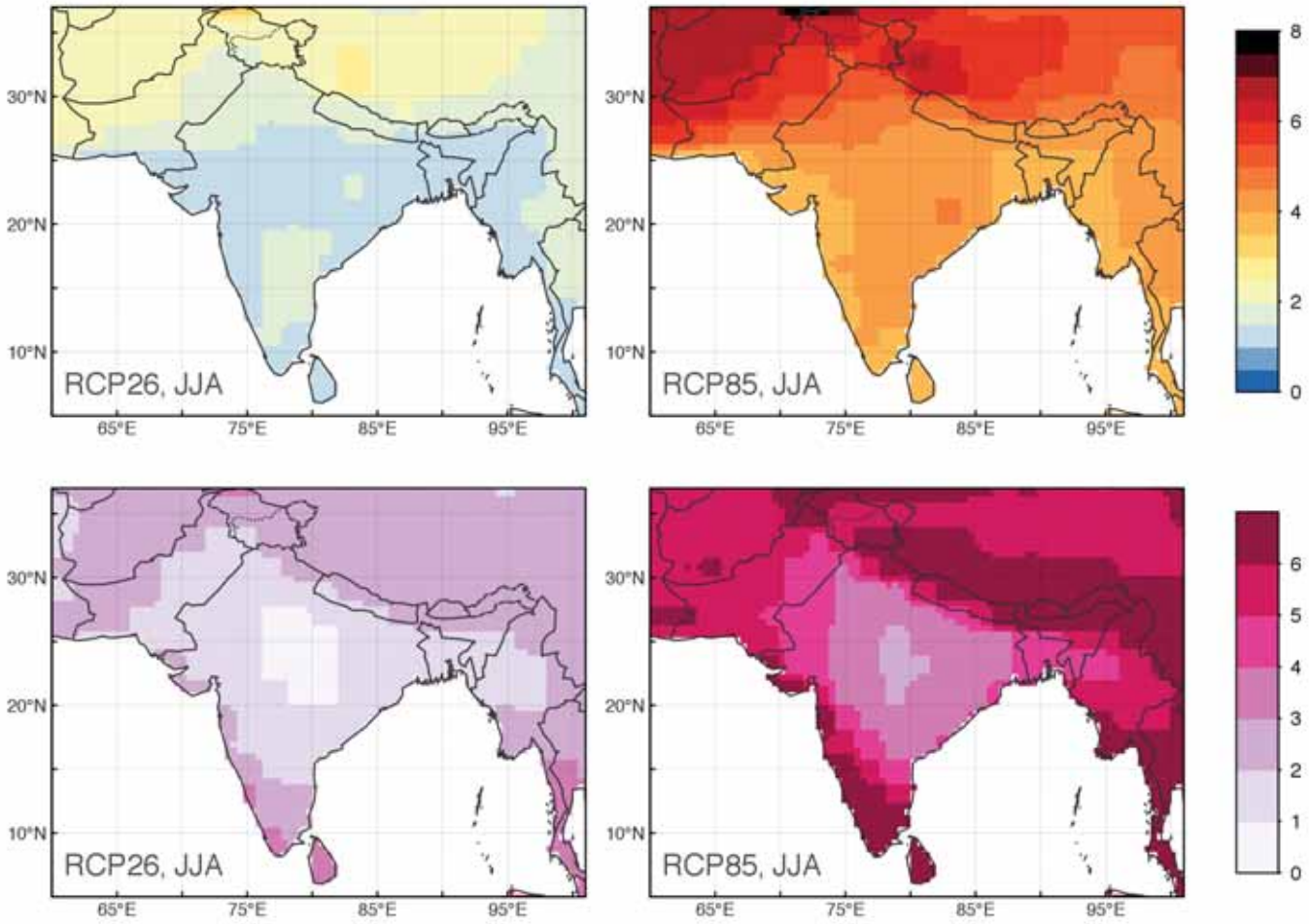


Figure 5.3: Multi-model mean temperature anomaly for RCP2.6 (left) and RCP8.5 (right) for the months of JJA for South Asia. Temperature anomalies in degrees Celsius (top row) are averaged over the time period 2071–99 relative to 1951–80, and normalized by the local standard deviation (bottom row)



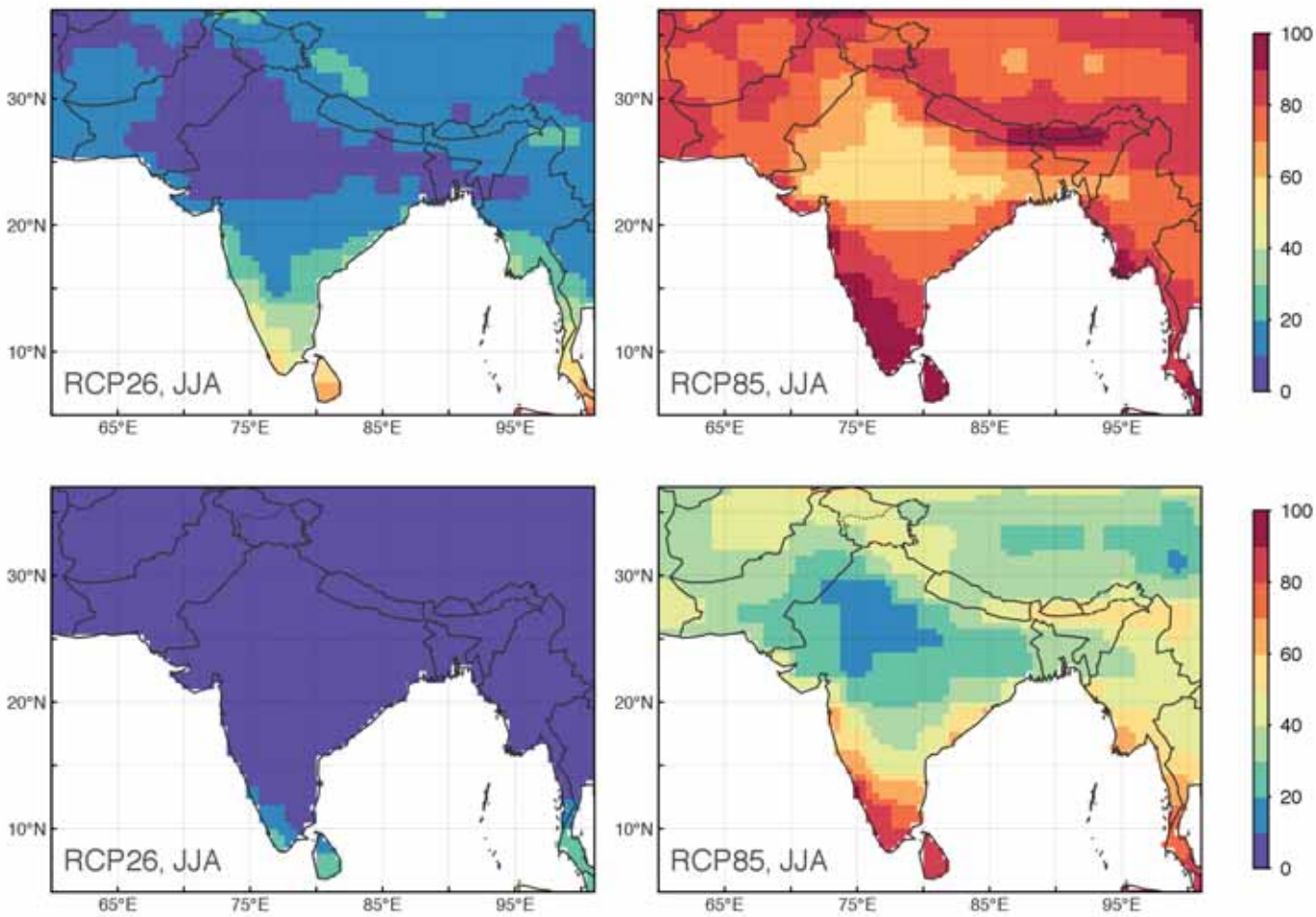
warming more, especially in the southwest (see Figure 5.3). In a 4°C world, the west coast and southern India, as well as Bhutan and northern Bangladesh, shift to new climatic regimes, with the monthly temperature distribution moving 5–6 standard deviations toward warmer values.

These projections are consistent with other assessments based on CMIP3 models. For example, Kumar et al. (2010) project a local warming in India of 2°C by mid-century and 3.5°C above the 1961–90 mean by the end of the 21st century. These local estimates come with considerable uncertainty; there is high confidence, however, that temperature increases will be above any levels experienced in the past 100 years. Using the UK Met Office regional climate model PRECIS, under the SRES-A2 scenario (leading to approximately 4.1°C above pre-industrial levels), Kumar et al. (2010) find local temperature increases exceeding 4°C for northern India.

Projected Changes in Heat Extremes

In a 4°C world, the ISI-MIP multimodel mean shows a strong increase in the frequency of boreal summer months hotter than 5-sigma over the Indian subcontinent, especially in the south and along the coast as well as for Bhutan and parts of Nepal (Figures 5.4 and 5.5). By 2100, there is an approximately 60-percent chance that a summer month will be hotter than 5-sigma (multimodel mean; Figure 5.5), very close to the global average percentage. The limited surface area used for averaging implies that there is larger uncertainty over the timing and magnitude of the increase in frequency of extremely hot months over South Asia compared to that of the global mean. By the end of the 21st century, most summer months in the north of the region (> 50 percent) and almost all summer months in the south (> 90 percent) would be hotter than 3-sigma under RCP8.5 (Figure 5.4).

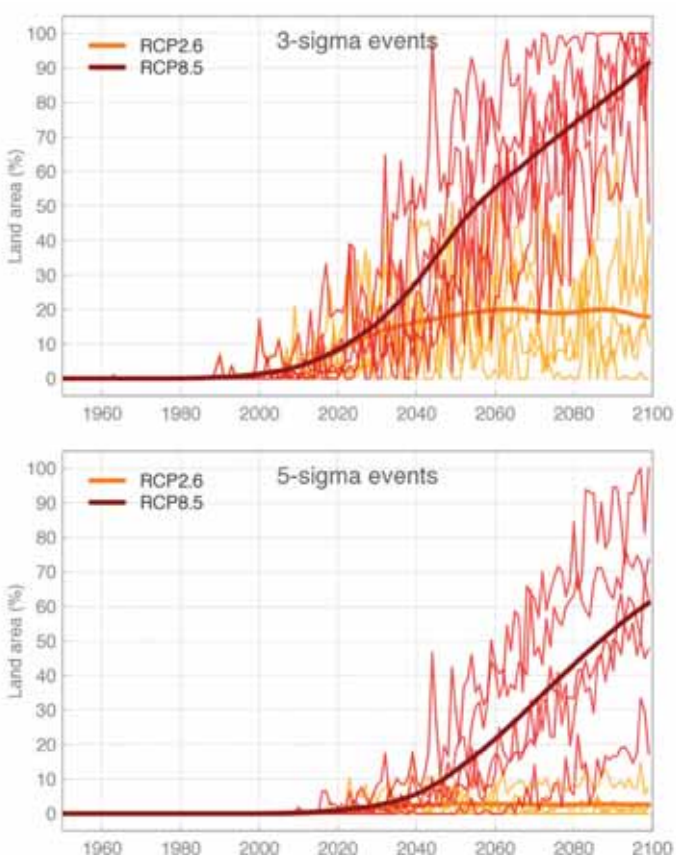
Figure 5.4: Multi-model mean of the percentage of boreal summer months (JJA) in the time period 2071–99 with temperatures greater than 3-sigma (top row) and 5-sigma (bottom row) for scenarios RCP2.6 (left) and RCP8.5 (right) over South Asia



In a 2°C world, most of the high-impact heat extremes projected by RCP8.5 for the end of the century would be avoided. Extremes beyond 5-sigma would still be virtually absent, except for the southernmost tip of India and Sri Lanka (Figure 5.4). The less extreme months (i.e., beyond 3-sigma), however, would increase substantially and cover about 20 percent of the surface area of the Indian subcontinent (Figure 5.5). The increase in frequency of these events would occur in the near term and level off by mid-century. Thus, irrespective of the future emission scenario, the frequency of extreme summer months beyond 3-sigma in the near term would increase several fold. By the second half of the 21st century, mitigation would have a strong effect on the number and intensity of extremes.

For the Indian subcontinent, the multimodel mean of all CMIP5 models projects that warm spells, with consecutive days beyond the 90th percentile, will lengthen to 150–200 days under RCP8.5, but only to 30–45 days under RCP2.6 (Sillmann 2013). By the end of the century, warm nights are expected to occur at a frequency of 85 percent under RCP8.5 and 40 percent under RCP2.6.

Figure 5.5: Multi-model mean (thick line) and individual models (thin lines) of the percentage of South Asian land area warmer than 3-sigma (top) and 5-sigma (bottom) during boreal summer months (JJA) for scenarios RCP2.6 and RCP8.5



Precipitation Projections

A warmer atmosphere carries significantly more water than a cooler one based on thermodynamic considerations. After taking into account energy balance considerations, climate models project an increase in global mean precipitation of about 2 percent per degree of warming.[88]

Model projections in general show an increase in the Indian monsoon rainfall under future emission scenarios of greenhouse gases and aerosols. The latest generation of models (CMIP5) confirms this picture, projecting overall increases of approximately 2.3 percent per degree of warming for summer monsoon rainfall (Menon, Levermann, Schewe, Lehmann, and Frieler 2013). The increase in precipitation simulated by the models is attributed to an increase in moisture availability in a warmer world; it is, somewhat paradoxically, found to be accompanied by a weakening of the monsoonal circulation (Bollasina et al., 2011; R. Krishnan et al. 2012; A. G. Turner and Annamalai 2012), which is explained by energy balance considerations (M. R. Allen and Ingram 2002). Some CMIP5 models show an increase in mean monsoon rainfall of 5–20 percent at the end of the 21st century under a high warming scenario (RCP8.5) compared to the pre-industrial period (N. C. Jourdain, Gupta, Taschetto, et al 2013). This newer generation of models indicates reduced uncertainty compared to CMIP3; however, significant uncertainty remains.[89]

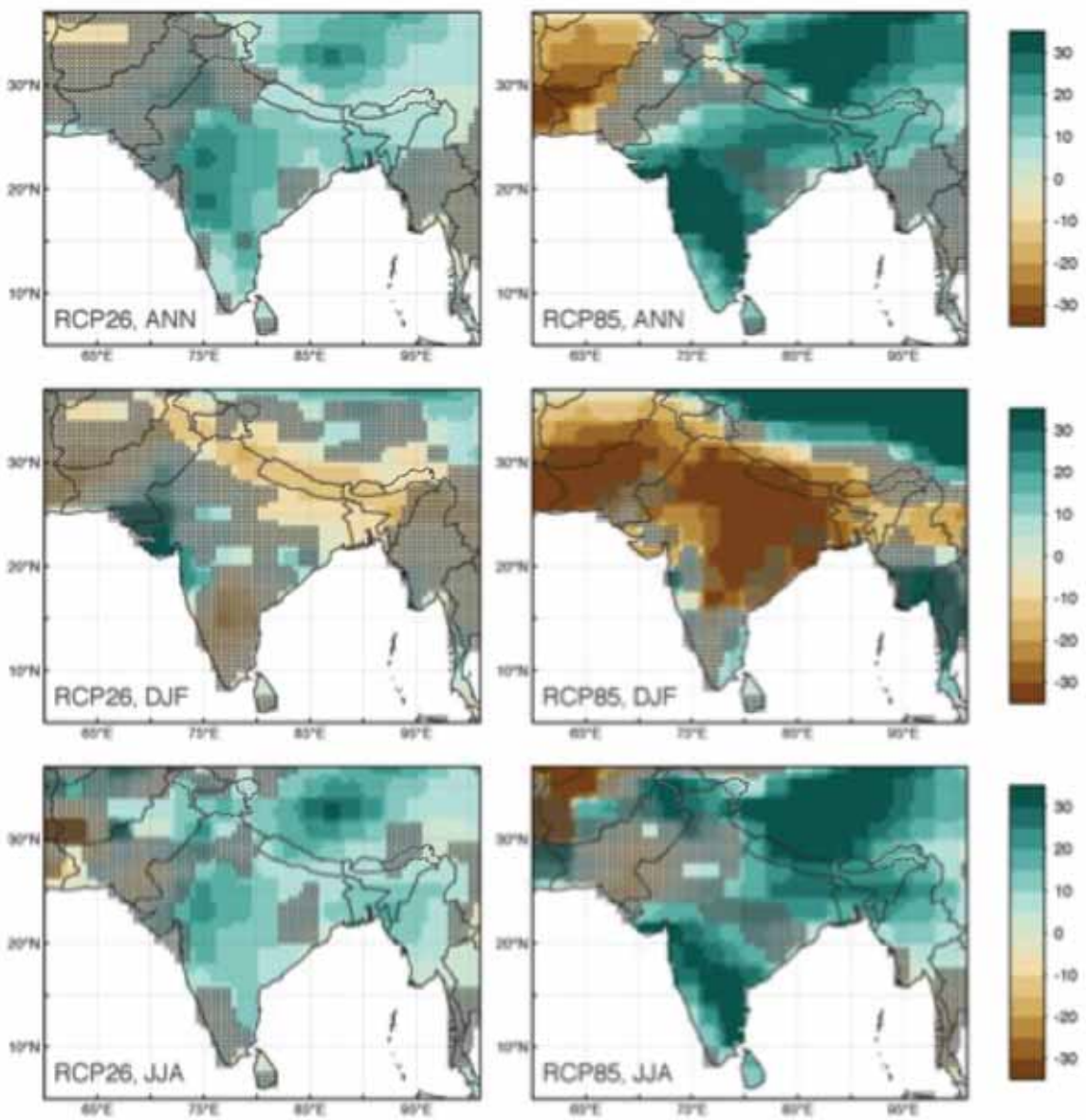
In the 5 GCMs (ISI-MIP models) analyzed for this report, annual mean precipitation increases under both emissions of greenhouse gases and aerosols in the RCP2.6 and RCP8.5 scenarios over most areas of the region. The notable exception is western Pakistan (Figure 5.6). The percentage increase in precipitation is enhanced under RCP8.5, and the region stretching from the northwest coast to the South East coast of peninsular India will experience the highest percentage (~ 30 percent) increase in annual mean rainfall.

It should be noted that the uncertain regions (hatched areas) with inter-model disagreement on the direction of percentage change in precipitation are reduced under the highest concentration RCP8.5 scenario. The percentage change in summer (JJA)

[88] In contrast to the processes behind temperature responses to increased greenhouse gas emissions, which are fairly well understood, projecting the hydrological cycle poses inherent difficulties because of the higher complexity of the physical processes and the scarcity of long-term, high-resolution rainfall observations (M. R. Allen and Ingram 2002).

[89] The projected precipitation from a subset of CMIP-3 models was an overall increase—but with a range of trends, including negative, in monsoon rainfall by 2100 (Turner and Annamalai 2012). The set of four GCMs used by the authors is able to simulate the observed seasonality and intra-annual variability of rainfall as well as the ENSO-ISM teleconnection; it showed substantial decadal variability. This is similar to that observed for the All India Rainfall (AIR) time series. The model ensembles did not replicate phasing, mean, or standard deviation of the AIR curve, however, from which the authors conclude that the decadal-scale variability is largely due to internal variability of the coupled atmosphere-ocean system. The models themselves do not show consistent changes.

Figure 5.6: Multi-model mean of the percentage change in annual (top), dry-season (DJF, middle) and wet-season (JJA, bottom) precipitation for RCP2.6 (left) and RCP8.5 (right) for South Asia by 2071–99 relative to 1951–80



Hatched areas indicate uncertainty regions, with 2 out of 5 models disagreeing on the direction of change compared to the remaining 3 models.

precipitation (i.e., during the wet season) resembles that of the change in annual precipitation. The winter (the months of December, January, February (DJF)) precipitation (Figure 5.6) shows a relative decrease in Pakistan and the central and northern regions of India, whereas the rest of the regions show inter-model uncertainty in the direction of change under the RCP8.5 scenario. This is in agreement with previous studies based on the IPCC AR4 (CMIP3) models (e.g., Chou, Tu, and Tan 2007) which suggest that the wet season gets wetter and the dry season gets drier. Under RCP2.6, the direction of the percentage change in winter rainfall shows large inter-model uncertainty over almost all regions of India.

Increased Variability in the Monsoon System

The largest fraction of precipitation over South Asia occurs during the monsoon season. For example, approximately 80 percent of the rainfall over India occurs during the summer monsoon

(June–September), providing the required amount of water for both rainfed crops and for the irrigated crops which largely depend on surface or groundwater reserves replenished by the monsoon rains (Mall, Singh, Gupta, Srinivasan, and Rathore 2006). The timing of monsoon rainfall is very important for agriculture and water supply, and variability in the monsoon system increases South Asia's risk of flooding and droughts. A decrease in seasonal water availability, together with population increases, may have severe effects on water and food security in this densely populated region (K. K. Kumar et al. 2010).

IPCC AR4 found projected increases in the variability of the monsoon and the seasonality of precipitation; these findings are reinforced by the new CMIP5 model projections. These changes in monsoon variability are expected to pose major challenges that increase with rising levels of warming to human systems that depend on precipitation and river runoff as major sources of freshwater (Box 5.2).

The total amount of rainfall, the length of the monsoon season, and the distribution of rainfall within the season determine the outcome of the monsoon season for the human population dependent on it. For example, the number of rainy days and the intensity of rainfall are key factors (K. K. Kumar et al. 2010). Along with the projected total increase in summer monsoon rainfall, an increase in intra-seasonal variability of approximately 10 percent for a near –4°C world (3.8°C warming in RCP 8.5 for the period 2050–2100) is projected, based on CMIP5 GCMs (Menon, Levermann, and Schewe 2013). The intra-seasonal variability in precipitation, which may lead to floods, can be one of the greatest sources of risk to agriculture and other human activities in South Asia. Sillmann and Kharin (2013a) project, also based on CMIP5 GCMs, that the total annual precipitation on wet days increases significantly over South Asian regions under both high- and low-emission scenarios.

While most modeling studies project average annual mean increased monsoonal precipitation on decadal timescales, they also project significant increases in inter-annual and intra-seasonal variability (Endo, Kitoh, Ose, Mizuta, and Kusunoki 2012; May, 2010; Sabade, Kulkarni, and Kripalani 2010; A. G. Turner and Annamalai 2012; K. K. Kumar et al. 2010):

- The frequency of years with above-normal monsoon rainfall and of years with extremely deficient rainfall is projected to increase in the future (R. H. Kripalani, Oh, Kulkarni, Sabade, and Chaudhari 2007; Endo et al. 2012).
- An increase in the seasonality of rainfall, with more rainfall during the wet season (Fung, Lopez, and New 2011; A. G. Turner and Annamalai 2012), and an increase in the number of dry days (Gornall et al. 2010) and droughts (Aiguo Dai, 2012; D.-W. Kim and Byun 2009).
- An increase in the number of extreme precipitation events (Endo et al. 2012; K. K. Kumar et al. 2010).

Although uncertainty in the effects of global warming on total wet-season rainfall is considerable in the region (see hatched areas in Figure 5.6 JJA), there are particularly large uncertainties in GCM projections of spatial distribution and magnitude of the heaviest extremes of monsoon rainfall (A. G. Turner and Annamalai 2012). The models assessed by Kumar et al. (2010)[90] in general show an increase in the maximum amount of seasonal rainfall for the multimodel ensemble mean around June, July, and August.

There are also a number of simulations assessed in the study by K. K. Kumar et al. (2010) that actually project less rainfall for JJA by 2100. The relative rainfall increase with

Box 5.2: Indian Monsoon: Potential "Tipping Element"

Several mechanisms in the climate system have been identified that when forced by human-induced global warming can lead to relatively rapid, large-scale state shifts, which can lead to non-linear impacts for human systems.[a] Such a "tipping element" of very high relevance for South Asia is a potential abrupt change in the monsoon (Schewe and Levermann 2012) caused by global warming, toward a much drier, lower rainfall state. The emergence of major droughts caused by this would likely precipitate a major crisis in South Asia. Physically plausible mechanisms have been proposed for such a switch and the geological record for the Holocene and last glacial period shows that rainfall in India and China has undergone strong and abrupt changes in the past (Levermann, Schewe, Petoukhov, and Held 2009). Changes in the tropical atmosphere that could precipitate a transition of the monsoon to a drier state are projected in the present generation of climate models and is associated with changes in the El Niño/La Niña-Southern Oscillation (ENSO) (Schewe and Levermann 2012). At this stage such a risk remains speculative—but it clearly demands further research given the significant consequences of such an event. Major droughts in South Asia are associated with large-scale hardship and loss of food production. In India, for example, the droughts in 1987 and 2002/2003 affected more than 50 percent of the crop area in the country and caused major declines in crop production.

[a] Examples of such "tipping elements" are passing of thresholds to irreversible mass loss of the Greenland ice sheet and a dieback of the Amazon rainforest (Lenton, 2011).

[90] Temperature and rainfall characteristics in past and future monsoonal climate are analyzed based on an observational-based, all-India summer monsoon rainfall dataset and the projections made by 22 CMIP3 GCMs. For the baseline runs from 1861–1999, observational and reanalysis data were used to force the models, with the projection period from 2000–2100 for which the SRES A1B scenario was employed (approximately 3.5°C warming above pre-industrial levels).

climate change, which amounts to about 10 percent for the future (2070–98) with respect to the JJA rainfall in the baseline period (1961–90), was accompanied by a 20-percent increase in the "flank periods" of May and October; this could indicate an increase in the length of the monsoon season. The relationship between monsoonal precipitation and ENSO appears to be unchanged for the time periods 2041–60 and 2070–98 with respect to the baseline. This is to some extent ambiguous, as the future expected warming could result in a more permanent El Niño-like state in the Pacific that could, in principle, lead to a decrease in monsoonal rainfall.

Although these results come with a considerable amount of uncertainty, K. K. Kumar et al. (2010) conclude that there are severe risks for critical socioeconomic sectors, including agriculture and health.

Regional Sea-level Rise

As explained in Chapter 2, current sea levels and projections of future sea-level rise are not uniform across the world. South Asian coastlines are situated between approximately 0° and 25° N. Being this close to the equator, projections of local sea-level rise show a stronger increase compared to higher latitudes (see Figure 2.10). For South Asian coastlines, sea-level rise is projected to be approximately 100–110 cm in a 4°C world and 60–80 cm in a 2°C world by the end of the 21st century (relative to 1986–2005). This is generally around 5–10 percent higher than the global mean. Figure 5.7 shows the regional sea-level rise for South Asian coastlines for 2081–2100 under the high emissions scenario RCP8.5 (a 4°C world). Note that these projections include only the effects of human-induced global climate change and not those of local land subsidence due to natural or human influences; these factors need to be accounted for in projecting the local and regional risks, impacts, and consequences of sea-level rise.

Figure 5.8 shows the time series of sea-level rise in a selection of locations in South Asia. These locations are projected to face a sea-level rise around 105 cm (66 percent uncertainty range of 85–125 cm) by 2080–2100. The rise near Kolkata and Dhaka is 5 cm lower, while projections for the Maldives are 10 cm higher. In a 2°C world, the rise is significantly lower for all locations, but still considerable at 70 (60–80) cm. According to the projection in this report, there is a greater than 66-percent chance that regional sea-level rise for these locations will exceed 50 cm above 1986–2005 levels by the 2060s in a 4°C world, and 100 cm by the 2090s; both of these dates are about 10 years before the global mean exceeds these levels. In a 2°C world, a rise of 0.5 meter is likely to be exceeded by about 2070, only 10 years after exceeding this level in a 4°C world. By that time, however, the high and low scenarios diverge rapidly, with one meter rise in a 2°C world not likely to be exceeded until well into the 22nd century.

Figure 5.7: Regional sea-level rise for South Asia in 2081–2100 (relative to 1986–2005) under RCP 8.5

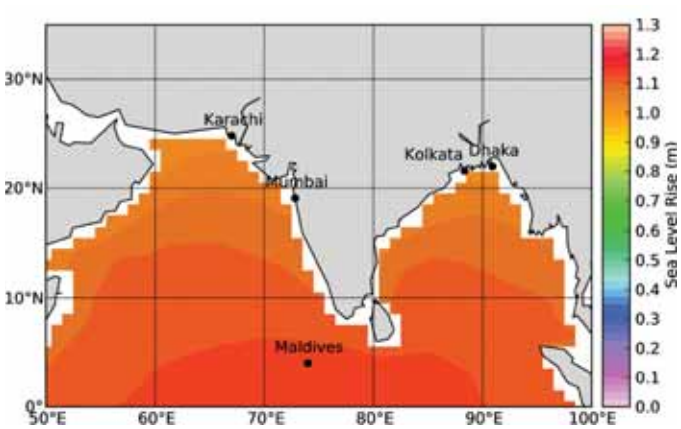
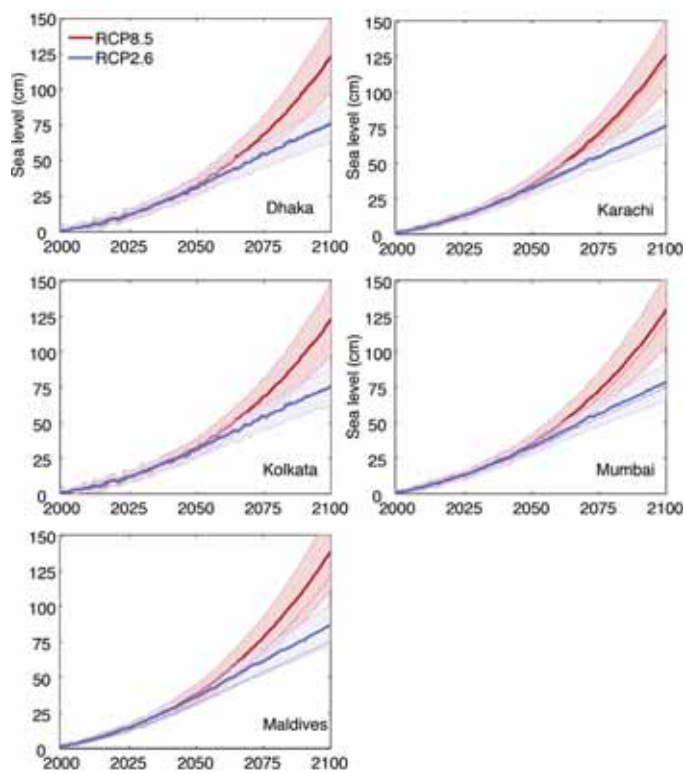


Figure 5.8: Local sea-level rise above the 1986–2005 mean as a result of global climate change (excluding local changes due to land subsidence by nature or human causes)



Shaded areas indicate 66-percent uncertainty range and dashed lines indicate the global mean sea-level rise for comparison.

Water Resources

Apart from the monsoon, the dominant geographical feature of South Asia fundamentally influencing its water hydrography is the Hindu Kush and Himalayan mountain complex. These mountains block the northerly push of the monsoon, confining its precipitation effects to the South Asian subcontinent and providing, with their snow and glacial melt, the primary source of upstream freshwater for many of South Asia's river basins. Climate change impacts on the Himalayan and the Hindu Kush glaciers therefore directly affect the people and economies of the countries of Afghanistan, Bangladesh, Bhutan, India, Nepal, and Pakistan.

These "water towers of Asia" play a dominant role in feeding and regulating the flow of the major river systems of the region: the Indus, the Ganges, and the Brahmaputra. These rivers drain into the coast, with the Ganges and the Brahmaputra carrying huge sediment loads from the Himalayas, creating the densely populated mega-delta that encompasses West Bengal and Bangladesh (see Figures 5.10 and 5.11). Reductions in the glacial mass and snow cover of the Hindu Kush and the Himalayas can have a profound effect on the long-term water availability over much of the subcontinent. Changes in the characteristics of precipitation over the mountains, leading to increasingly intense rainfall, contribute along with other factors to much higher flood risks far downstream and interact adversely with rising sea levels on the coast.

The Indus, the Ganges, and the Brahmaputra basins provide water to approximately 750 million people (209 million, 478 million, and 62 million respectively in the year 2005; Immerzeel et al. 2010). The Ganges basin on the east of the subcontinent has the largest population size and density of the three basins. Both the Indus and the Ganges supply large areas with water for irrigation (144,900m² and 156,300m² respectively), while the 2,880-kilometer Indus River constitutes one of the longest irrigation systems in the world. All three rivers are fed by the Tibetan Plateau and adjacent mountain ranges (Immerzeel, Van Beek, and Bierkens 2010; Uprety and Salman 2011).

In fact, over 50 percent of the world's population lives downstream of the Greater Himalaya region, with snowmelt providing over 40 percent of pre- and early-monsoon discharge in the Greater Himalaya catchments, and more than 65 percent and 30 percent of annual discharge in the Indus and Tsangpo/Brahmaputra catchments, respectively. An increasing occurrence of extremely low snow years and a shift toward extremely high winter/spring runoff and extremely low summer runoff would therefore increase the flood risk during the winter/spring, and decrease the availability of freshwater during the summer (Giorgi et al. 2011).

The Indus and the Brahmaputra basins depend heavily on snow and glacial melt water, which make them extremely susceptible to climate-change-induced glacier melt and snowmelt (Immerzeel, Van Beek, and Bierkens 2010).[91] In fact, most of the Himalayan glaciers, where 80 percent of the moisture is supplied by the summer monsoon, have been retreating over the past century. Where the winter westerly winds are the major source of moisture, some of the glaciers in the northwestern Himalayas and in the Karakoram have remained stable or even advanced (Bolch et al. 2012; Immerzeel et al. 2010).

Projections for the future indicate an overall risk to the flow of these rivers. For the 2045–65 period (global mean warming of 2.3°C above pre-industrial levels), very substantial reductions in the flow of the Indus and Brahmaputra in late spring and summer are projected. These reductions would follow the spring period of increased flow due to melting glaciers and are not compensated by the projected increase in rainfall upstream. The Ganges, due to high annual downstream precipitation during the monsoon season, is less dependent on melt water (Immerzeel et al. 2010).[92]

Although snowfall in the mountainous areas in South Asia may increase (e.g., Immerzeel et al. 2010; Mukhopadhyay 2012), this may in the long run be offset by the decrease in glacial melt water as glaciers retreat due to warming (Immerzeel et al. 2010a). Furthermore, the distribution of the available river melt water runoff within the year may change due to accelerated snowmelt. This is caused by increased spring precipitation (Jeelani, Feddema, Van der Veen, and Stearns 2012), with less runoff available prior to the onset of the monsoon.

More recent research projects a rapid increase in the frequency of low snow years in the coming few decades, with a shift toward high winter and spring runoff and very low summer flows likely well before 2°C warming. These trends are projected to become quite extreme in a 4°C warming scenario (Diffenbaugh, Scherer, and Ashfaq 2012).

Combined with precipitation changes, loss of glacial ice and a changing snowmelt regime could lead to substantial changes in downstream flow. For example, the Brahmaputra River may experience extreme low flow conditions less frequently in the future (Gain,

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[91] Immerzeel et al. (2010) define a Normalized Melt Index (NMI) as a means to assess the relative importance of melt water, as opposed to downstream precipitation (less evaporation), in sustaining the flow of the three river basins. They define it as the volume of upstream melt water discharge divided by the downstream natural discharge, with the natural discharge calculated as the difference between the received precipitation and the natural evaporation in the basin. Changes in river basin runoff in both volume (volumetric discharge) and distribution throughout the year (seasonal distribution) are determined by changes in precipitation, the extent of the snow covered area, and evapotranspiration (Mukhopadhyay 2012).

[92] To project the impacts of climate change on future runoff, Immerzeel et al. (2010) use a hydrological modeling approach and force the model through the output of 5 GCMs run under the A1B scenario for the time period of 2046–65 (global mean warming of 2.3°C above pre-industrial levels). They employ a best-guess glacial melt scenario for the future that assumes linear trends in degree-days and snowfall between the observational period and 2050, where degree-days (here expressed in mm/C) measure snow or ice melt expressed in depth of water for the difference between the base temperature (usually 0°C) and the mean air temperature per day (P. Singh, Kumar, and Arora 2000).

Immerzeel, Sperna Weiland, and Bierkens 2011). There could be a strong increase in peak flow, however, which is associated with flooding risks (Ghosh and Dutta 2012). Combined with projected sea-level rise, this could have serious implications for Bangladesh and other low-lying areas in the region (Gain et al. 2011).

Given the potential impacts across the Northern Hemisphere, this report highlights the likelihood of intensifying hydrologic stress in snow-dependent regions, beginning in the near-term decades when global warming is likely to remain within 2°C of the pre-industrial baseline.

Water Security

Water security is becoming an increasingly important development issue in South Asia due to population growth, urbanization, economic development, and high levels of water withdrawal. The assessment of water security threats is undertaken using differing metrics across the studies, which often makes a comprehensive assessment difficult. In India, for example, gross per capita water availability (including utilizable surface water and replenishable groundwater) is projected to decline from around 1,820m³ per year in 2001 to about 1,140m³ per year in 2050 due to population growth alone (Bates, Kundzewicz, Wu, and Palutikof 2008b; S. K. Gupta and Deshpande 2004). Although this estimate only includes blue water availability (water from rivers and aquifers), it has to be kept in mind that in South Asia, in contrast to Europe or Africa, the consumption of blue water in the agricultural sector exceeds that of green water (precipitation water infiltrating into the soil) (Rockström et al. 2009). Thus, climate change, by changing hydrological patterns and freshwater systems, poses an additional risk to water security (De Fraiture and Wichelns 2010; ESCAP 2011; Green et al. 2011), particularly for the agricultural sector (Sadoff and Muller 2009).

Water demand in agriculture and the competition for water resources are expected to further increase in the future as a side effect of population growth, increasing incomes, changing dietary preferences, and increasing water usage by industrial and urban users. Even without climate change, satisfying future water demand will be a major challenge. Observations and projections point to an increase in seasonality and variability of monsoon precipitation with climate change; this poses additional risks to human systems, including farming practices and irrigation infrastructure that have been highly adapted to the local climate. In fact, extreme departures from locally expected climates that delay the onset of monsoons and extend monsoon breaks may have a much more profound impact on agricultural productivity than changes in absolute water availability or demand (see Chapter 5 on "Agricultural Production").

Present Water Insecurity

Based on several different methods of measuring water security, the densely populated countries of South Asia are already exposed to a significant threat of water insecurity. Taking into account water quality and exposure to climate change and water-related disasters, ESCAP (2011) identifies India, Bangladesh, Pakistan, the Maldives, and Nepal as water hotspots in the Asia-Pacific region.

South Asia's average per capita water availability,[93] defined by the sum of internal renewable water sources and natural incoming flows divided by population size, is less than 2,500m³ annually (ESCAP 2011); this is compared to a worldwide average of almost 7,000m³ per capita per year (World Bank 2010c). In rural areas of India, Bangladesh, Pakistan, Nepal, and Sri Lanka,[94] 10 percent or more of the population still remain without access to an adequate amount of water, even if defined at the relatively low level of 20 liters per capita per day for drinking and other household purposes. Rates of access to sanitation are also low. In the year 2010 in India, only 34 percent of the population had access to sanitation; in Pakistan, that number is 48 percent and in Bangladesh it is 54 percent (2010 data based on World Bank 2013b).

Applying a multi-factorial water security index,[95] Vörösmarty et al. (2010) find that South Asia's present threat index varies regionally between 0.6 and 1, with a very high (0.8–1) threat over central India and Bangladesh on a threat scale of 0 (no apparent threat) to 1 (extremely threatened). Along the mountain ranges of the Western Ghats of South India, in Nepal, in Bhutan, in the northeastern states of India, and in the northeastern part of Afghanistan, the incident threat level is high to very high (0.6–0.8).[96] Another approach, in which a country is considered to be water stressed if less than 1,700m³ river basin runoff per capita is available, also found that South Asia is already a highly water-stressed region (Fung et al. 2011).

Projected Changes in Water Resources and Security

The prognosis for future water security with climate change depends on the complex relationship among population growth, increases in agricultural and economic activity, increases in total precipitation, and the ultimate loss of glacial fed water and snow cover, combined with regional variations and changes in seasonality across South Asia. Projections show that in most cases climate

93 Including Afghanistan, Iran and Turkey.

94 Bhutan and the Maldives have slightly higher levels of access to water.

95 Aggregating data on river flows, using cumulative weights based on expert judgment on 23 factors relating to catchment disturbance, pollution, water resource development, and biotic factors.

96 Insufficient river flow over parts of Pakistan, the southwestern parts of Afghanistan, and the northwestern arid desert regions of India, especially Rajasthan and the Punjab, precludes the investigation of ongoing changes in the water security index (Vörösmarty et al. 2010b). In these areas, water availability is predominantly influenced by snowmelt generated upstream in the Hindu Kush and Himalayas (Barnett and Webber 2010) and, as shown by Immerzeel et al. (2010), climate-change-induced glacier retreat can significantly influence water availability in river basins which heavily depend on snow and glacial melt water.

change aggravates the increasing pressure on water resources due to high rates of population growth and associated demand.

An example of this complexity can be seen in the work of Fung et al. (2011), who project the effects of global warming on river runoff in the Ganges basin.[97] A warming of about 2.7°C above pre-industrial levels is projected to lead to a 20-percent increase in runoff, and a 4.7°C warming to approximately a 50-percent increase. Without taking seasonality into account, the increase in mean annual runoff in a 4°C world is projected to offset increases in water demand due to population growth.[98] With 2°C warming, the total mean increase in annual runoff is not sufficiently large to mitigate the effects of expected population growth in these regions; water stress, therefore, would not be expected to decrease in South Asia.

While an increase in annual runoff sounds promising for a region in which many areas suffer from water scarcity (Bates et al. 2008; Döll 2009; ESCAP 2011), it has to be taken into account that the changes are unevenly distributed across wet and dry seasons. In projections by Fung et al. (2011), annual runoff increases in the wet season while further decreasing in the dry season—with the amplification increasing at higher levels of warming. This increase in seasonality implies severe flooding in high-flow seasons and aggravated water stress in dry months in the absence of large-scale infrastructure construction (Fung et al. 2011; World Bank 2012).

River runoff, however, is just one measure of available water; more complex indexes of water security and availability have also been applied. A recent example is that of Gerten et al. (2011c), who apply the concept of blue water and green water to evaluate the effects of climate change on available water supplies for agriculture and human consumption. They find that a country is water scarce if the availability of blue water used for irrigation and green water used for rainfed agricultural production does not exceed the required amount of water to produce a diet of 3,000 kilocalories per capita per day. For a diet based on 80 percent vegetal and 20 percent animal product-based calories, Gerten et al. (2011c) estimate this amount at 1,075m³ of water per capita per year.

For global warming of approximately 3°C above pre-industrial levels and the SRES A2 population scenario for 2080, Gerten et al. (2011) project that it is very likely (>90 percent confidence) that per capita water availability in South Asia[99] will decrease by more than 10 percent.[100] While the population level plays an important role in these estimates, there is a 10–30 percent likelihood that climate change alone is expected to decrease water availability by more than 10 percent in Pakistan and by 50–70 percent in Afghanistan. The likelihood of water scarcity driven by climate change alone is as high as >90 percent for Pakistan and Nepal and as high as 30–50 percent for India. The likelihood of a country becoming water scarce is shown in Figure 5.9.

Another study examining the effects of climate change on blue and green water availability and sufficiency for food production arrives at broadly similar conclusions. In a scenario of 2°C warming by 2050, Rockström et al. (2009) project food and water requirements in India to exceed green water availability by more than 150 percent, indicating that the country will be highly dependent on blue water (e.g., irrigation water) for agriculture production.[101] At the same time, blue water crowding, defined as persons per flow of blue water, is expected to increase due to population growth. As early as 2050, water availability in Pakistan and Nepal is projected to be too low for self-sufficiency in food production when taking into account a total availability of water below 1300m³ per capita per year as a benchmark for the amount of water required for a balanced diet (Rockström et al. 2009).

The projection of impacts needs to rely on accurate predictions of precipitation and temperature changes made by GCMs (see Chapter 5 on "Regional Patterns of Climate Change"). In addition, the estimation of impacts relies on (and depends on) hydrological models and their accurate representation of river runoff. Furthermore, as the above results demonstrate, water scarcity in the future is also highly dependent on population growth, which poses a large source of uncertainty. Finally, many studies use different metrics to estimate water resource availability and water scarcity, making direct intercomparison difficult. Irrespective of these multiple sources of uncertainty, with a growing population and strong indications of climate-related changes to the water cycle, clear and growing risks to stable and safe freshwater provisions to populations and sectors dependent on freshwater are projected to increase with higher levels of warming.

Projected Changes to River Flow

South Asia has very low levels of water storage capacity per capita, which increases vulnerability to fluctuations in water flows and changing monsoon patterns (Ministry of Environment and Forests 2012; Shah 2009). India, for example, stores less than 250m³ of water per capita (in contrast to countries such as Australia and the U.S., which have a water storage capacity of more than 5,000m³ per capita). There is a large potential in South Asian countries to both utilize existing natural water storage capacity and to construct additional capacity (Ministry of Environment and Forests, 2012). The potential for improvements in irrigation systems, water harvesting

[97] Estimates are based on an application of the climateprediction.net (CPDN). HADCM3 global climate model ensemble runs with the MacPDM global hydrological model and under the SRES A1B climate change scenario, together with the expected UN population division population growth scenario. Warming levels of 2°C and 4°C compared to the 1961–90 baseline were examined. The years by which the temperature increase is expected to occur varies as an ensemble of models was used.

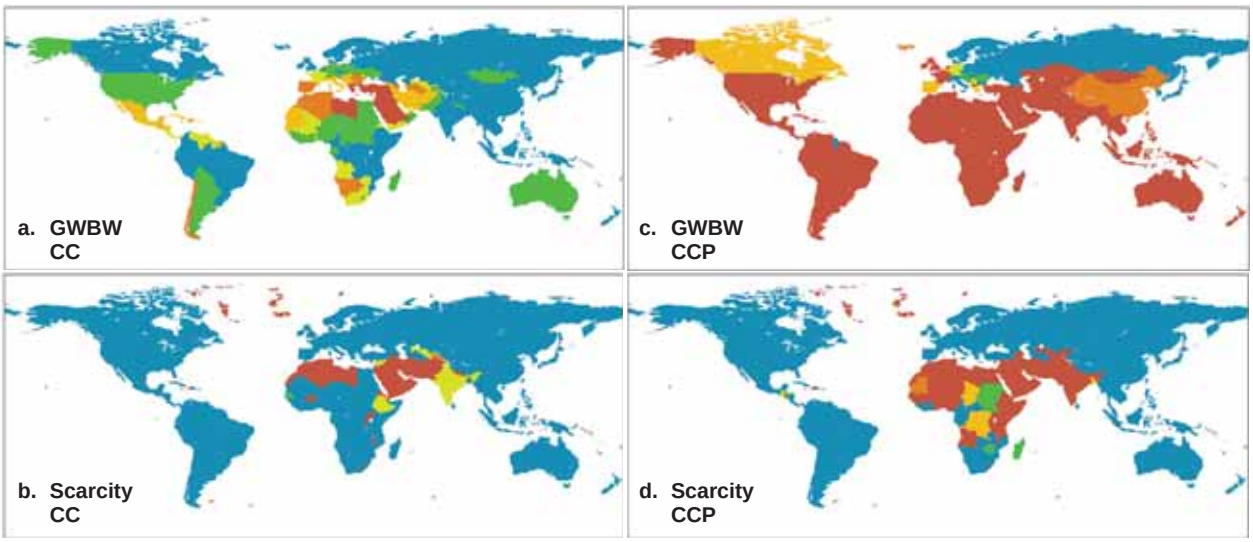
[98] Population projections are based on UN population growth rate projections until 2050 and linear extrapolations for the 2060s.

[99] Except for Sri Lanka; no estimates are reported for the Maldives.

[100] Ensemble of 17 CMIP3 GCMs for SRES A2 and B1 climate and population change scenarios.

[101] Using the LPJmL dynamic vegetation and a water balance model driven by climate output from HadCM$_2$ forced by A2 SRES emission scenario.

Figure 5.9: Likelihood (%) of (a),(c) a 10-percent reduction in green and blue water availability by the 2080s and (b),(d) water scarcity in the 2080s (left) under climate change only (CC; including CO_2 effects) and (right) under additional consideration of population change (CCP)



Note that the positive percentage scale indicates a 10% decrease in water availability. Results are presented for the A2 scenario. These likelihoods were derived from the spread of impacts under all climate models (e.g. 90 percent means that the given impact occurs in 9 out of 10 (~15 out of 17) climate change projections).

Source: Gerten et al. (2011).

From Gerten et al. (2011). Global water availability and requirements for future food production. Journal of Hydrometeorology, 12(5), 885-899. Journal of hydrometeorology by American Meteorological Society. Reproduced with permission of AMERICAN METEOROLOGICAL SOCIETY in the format Republish in a book via Copyright Clearance Center. Further permission required for reuse.

techniques, and water productivity, and more-efficient agricultural water management in general, is also high; such improvements would serve to offset risks from climate variability.

A pronounced amplification of river flows, combined with large changes in the discharge cycle from glaciers and snowpack in the Himalayas, point to substantial risks, not least related to flooding, in the future. River flooding can have far-reaching consequences, directly affecting human lives and causing further cascading impacts on affected businesses, where small-scale enterprises are often the most vulnerable. Asgary, Imtiaz, and Azimi (2012) evaluated the impacts of the 2010 river floods on small and medium enterprises (SME) in Pakistan. The authors first found that 88 percent of the sample business owners had to evacuate their towns due to the flood, therefore causing a major disruption to business. They further found that 47 percent of the businesses had recovered within 1–3 months after the occurrence of the floods; 90 percent had recovered after six months. However, most of the businesses suffered losses and only a few of them were at the same level or wealthier afterwards than prior to the event. The authors further explain that small businesses have a higher probability of being located in hazard-prone areas, occupying unsafe business facilities and lacking the financial and human resources to cope with the consequences of disasters.

The climate model projections discussed in the previous section strongly indicate that there is likely to be a strong increase in seasonal flows due to global warming—on top of likely overall increases in precipitation. These patterns appear differently in different river basins. For example, recent work by Van Vliet et al. (2013) projects changes in low, mean, and high river flows globally and finds pronounced differences between the Indus and the Ganges-Brahmaputra basins.[102] For the Indus, the mean flow is projected to increase by the 2080s for warming levels of around 2–°C by around 65 percent, with low flow increasing by 30 percent and the high flow increasing by 78 percent. For the Ganges-Brahmaputra system, the mean flow increases by only 4 percent, whereas the low flow decreases by 13 percent and the high flow by 5 percent. The changes are amplified with higher levels of warming between the individual scenarios.

Given these large changes in seasonal amplification of river flows and rainfall amounts, it is clear that, even for 2°C warming, major investments in water storage capacity will be needed in order to utilize the potential benefits of increased seasonal runoff for improved water availability throughout the year. At the same time, infrastructure for flood protection has to be built. The required investment in water infrastructure is likely to be larger with a warming of above 4°C compared to a warming of above 2°C (Fung et al. 2011).

[102] Three GCMs forced by the SRES A2 and B1 scenarios with hydrological changes calculated with the VIC (Variable Infiltration Capacity) model.

Cities and Regions at Risk of Flooding

Coastal and deltaic regions are particularly vulnerable to the risks of flooding. Cities in particular agglomerate high numbers of exposed people. A number of physical climatic changes indicate an increased risk of flooding, including more extreme precipitation events, higher peak river flows, accelerated glacial melt, increased intensity of the most extreme tropical cyclones, and sea-level rise. These changes are expected to further increase the number and severity of flood events in the future (Eriksson, Jianchu, and Shrestha 2009; Ministry of Environment and Forests 2012; Mirza 2010). A number of these projected changes are likely to interact, exacerbating damages and risk (e.g., higher peak river flows in low-lying coastal deltas potentially interacting with rising sea levels, extreme tropical cyclones, and associated storm surges). Such events could in turn pose additional threats to agricultural production and human health, as will be discussed in Chapter 5 under "Agricultural Production" and "Human Impacts."

A wide range of flooding events can be influenced or caused by climate change, including flash floods, inland river floods, extreme precipitation-causing landslides, and coastal river flooding, combined with the effects of sea-level rise and storm-surge-induced coastal flooding. In addition to floods and landslides, the Himalayan regions of Nepal, Bhutan, and Tibet are projected to be exposed to an increasing risk of glacial lake outbursts (Bates et al. 2008; Lal 2011; Mirza 2010).[103] The full scope of possible flooding events will not be explored; the focus of this section will instead be on low-lying river delta regions where there is a confluence of risk factors. This does not mean that other kinds of flooding events are not significant—merely that they fall outside the scope of this report.

Climate change is not the only driver of an increasing vulnerability to floods and sea-level rise. Human activities inland (such as upstream damming, irrigation barrages, and diversions) as well as activities on the delta (such as water withdrawal) can significantly affect the rate of aggradation and local subsidence in the delta, thereby influencing its vulnerability to sea-level rise and river floods. Subsurface mining is another driver (Syvitski et al. 2009). Subsidence, meanwhile, exacerbates the consequences of sea-level rise and increases susceptibility to river flooding.

The Current Situation in the Region

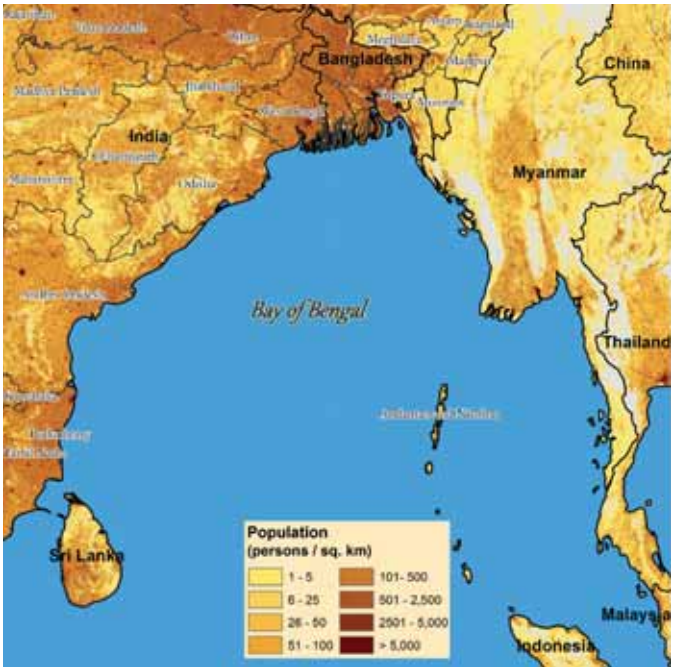
The frequency of extreme floods and the scope of flood-prone areas are increasing, particularly in India, Pakistan, and Bangladesh. Precipitation is the major cause of flooding (Mirza 2010). Since 1980, the risks from flooding have grown due mainly to population and economic growth in coastal regions and low-lying areas. In 2000, approximately 38 million people were exposed to floods in South Asia; almost 45 million were exposed in 2010, accounting for approximately 65 percent of the global population exposed to floods (UNISDR 2011). Figure 5.10 shows the population density in the Bay of Bengal region.

Deltaic regions in particular are vulnerable to more severe flooding, loss of wetlands, and a loss of infrastructure and livelihoods as a consequence of sea-level rise and climate-change-induced extreme events (Ian Douglas 2009; Syvitski et al. 2009; World Bank 2010d). It is important to recognize, however, that river deltas are very dynamic; where the rate of aggradation (inflow of sediment to the delta) exceeds the local rate of sea-level rise (taking into account subsidence caused by other factors), a delta may be stable in the face of rising sea levels. The vulnerability to climate-related impacts in the region is modulated by factors determining the level of sediment inflow. Reductions in sediment inflow have led to an increase in the relative sea-level rise in the deltas; where sediment inflow increases, relative sea-level rise may decrease.

The two major deltas in South Asia are those of the Ganges, Brahmaputra, and Meghna Rivers and of the Indus River:

- The Indus Delta in Pakistan has an area of 4,750 km² below 2 meters above sea level and a population of approximately

Figure 5.10: Population density in the Bay of Bengal region



Source: Based on Landscan Population dataset, 2008, Oakridge National Laboratory (ORNL).

[103] The buildup of melt water behind glacial moraines as glaciers retreat forms lakes; eventually the moraine dams can burst, leading to catastrophic flooding downstream. An increase in the frequency of glacial lake outburst floods has already been observed (Bates et al. 2008).

350,000.[104] The storm-surge areas of the deltas are at present 3,390 km², and the recent area of river flooding is 680 km² (1,700 km² in situ flooding) (Syvitski et al. 2009). The Indus was recently ranked as a delta at greater risk, as the rate of degradation of the delta (including inflow of sediments) no longer exceeds the relative sea-level rise. In the Indus Delta, a sediment reduction of 80 percent has been observed and the observed relative sea-level rise is more than 1.1 mm per year (Syvitski et al. 2009), exacerbating the global sea-level rise of 3.2 mm/yr (Meyssignac and Cazenave 2012).

- The Ganges-Brahmaputra-Meghna Delta encompasses Bangladesh and West Bengal, including the city of Kolkata in India. Within Bangladesh's borders, the area of the delta lying below 2 meters is 6,170 km² and the population at present is more than 22 million. The storm-surge areas of the delta are at present 10.500km², and the recent area of river flooding in the Ganges-Brahmaputra-Meghna Delta is 52,800 km² (42,300 km² in situ flooding) (Syvitski et al. 2009). The Ganges-Brahmaputra Delta was recently ranked as a "delta in peril" due to reduced aggregation and accelerated compaction of the delta. This is expected to lead to a situation where sea-level rise rates are likely to overwhelm the delta. A sediment inflow reduction of 30 percent has been observed in this delta and aggradation no longer exceeds relative sea-level rise, which is particularly high in the Ganges Delta at 8–18 mm per year (Syvitski et al., 2009). Figure 5.11 shows the basins of the Ganges, Brahmaputra, and Meghna Rivers.

Figure 5.11: The Ganges, Brahmaputra, and Meghna basins

Source: Monirul Qader Mirza (2002).

Reprinted from Global Environmental Change, 12, Monirul Qader Mirza, Global warming and changes in the probability of occurrence of floods in Bangladesh and implications, 127-138, Copyright (2002), with permission from Elsevier. Further permission required for reuse.

Projections: Risks to Bangladesh

Bangladesh is one of the most densely populated countries in the world, with a large population living within a few meters of sea level (see Figure 5.10). Flooding of the Ganges-Brahmaputra-Meghna Delta occurs regularly and is part of the annual cycle of agriculture and life in the region.

Up to two-thirds of the land area of Bangladesh is flooded every three to five years, causing substantial damage to infrastructure, livelihoods, and agriculture—and especially to poor households (World Bank 2010d; Monirul Qader Mirza 2002).

Projections consistently show substantial and growing risks for the country, with more climate change and associated increases in river flooding and sea-level rise. According to Mirza (2010), changes in precipitation are projected to result in an increase in the peak discharges of the Ganges, the Brahmaputra, and the Meghna Rivers. Mirza (2010) estimates the flooded area could increase by as much as 29 percent for a 2.5°C increase in warming above pre-industrial levels, with the largest change in flood depth and magnitude expected to occur in up to 2.5°C of warming. At higher levels of warming, the rate of increase in the extent of mean-flooded-area per degree of warming is estimated to be lower (Mirza 2010).

Tropical cyclones also pose a major risk to populations in Bangladesh. For example, Cyclone Sidr exposed 3.45 million Bangladeshis to flooding (World Bank 2010d). In comparison to the no-climate-change baseline scenario, it is projected that an additional 7.8 million people would be affected by flooding higher than one meter in Bangladesh as a consequence of a potential 10-year return cyclone in 2050 (an increase of 107 percent). A total of 9.7 million people (versus the 3.5 million in the baseline scenario) are projected to be exposed to severe inundation of more than 3 meters under this scenario. Agriculture in the region would also be severely affected. In addition, rural communities representing large parts of the population are expected to remain dependent on agriculture despite structural economic changes in the future away from climate-sensitive sectors; this would leave them vulnerable to these climate change impacts. Furthermore, the highest risk of inundation is projected to occur in areas with the largest shares of poor people (World Bank 2010d).

Projections: Risks to Two Indian Cities

The following discussion of the climate-change-related risks to two Indian cities—Mumbai and Kolkata—is intended to be

[104] This estimate accounts for the population of the four Teluka (sub-districts of the Sind Province, based on the 1998 census) within the coastline. Mipur Sakro: 198,852; Keti Bunder: 25,700; Shah Buner: 100,575; Kharo Chann: 25,656. The data can be found at http://www.districtthatta.gos.pk/Taluka%20Administration.htm.

illustrative rather than to provide a comprehensive assessment of risks to urban areas in the region. The focus is on large cities as these represent high agglomerations of assets and people, which however does not imply a relatively higher human resilience in rural areas.

Mumbai

Mumbai, due to its geography, is particularly exposed to both flooding from heavy rainfall during the monsoon and sea-level rise inundation as large parts of the city are built on reclaimed land which lies lower than the high-tide level. Indeed, the city has the largest population exposed to coastal flooding in the world (IPCC 2012) (Box 5.3). The city's drainage system is already inadequate in the face of heavy rainfall, and rapid and unplanned urbanization is likely to further increase the flood risk in Mumbai (Ranger et al. 2011).

The projected increase in heavy precipitation events associated with climate change poses a serious risk to the city—and that does not even take into account the effects of sea-level rise. By the 2080s and with a warming of 3°C to 3.5°C above pre-industrial levels, climate projections indicate a doubling of the likelihood of an extreme event similar to the 2005 floods (and a return period reduced to around 1-in-90 years).[105] Direct economic damages (i.e., the costs of replacing and repairing damaged infrastructure and buildings) of a 1-in-100 year event are estimated to triple in the future compared to the present day and to increase to a total of up to $1.9 billion due to climate change only (without taking population and economic growth into account). Additional indirect economic costs, such as sectoral inflation, job losses, higher public deficit, and financial constraints slowing down the process of reconstruction, are estimated to increase the total economic costs of a 1-in-100 year event to $2.4 billion (Ranger et al. 2011). Without adaptation, population and economic growth would increase the exposure to and damage of flooding events in the future. In terms of adaptation, Ranger et al. (2011) estimate that improved building codes and improving the drainage system in Mumbai could reduce direct economic costs by up to 70 percent.

A limitation of Ranger et al. (2011) is that the study does not include the impacts of sea-level rise—even though it is very plausible that even low levels of sea-level rise would further reduce the effectiveness of drainage systems. This report projects the sea-level rise in Mumbai at around 35 cm by the 2050s under either of the emission pathways leading to the 2°C or 4°C worlds; for the 2° world, a rise of around 60 cm by the 2080s and, for the 4°C world, a rise of close to 80 cm (see Chapter 5 on "Regional Sea-level Rise").

Kolkata

Kolkata is ranked among the top 10 cities in the world in terms of exposure to flooding under climate change projections (IPCC 2012; UN-HABITAT 2010b; World Bank 2011a). The elevation of Kolkata city and the metropolitan area surrounding the city ranges from 1.5–11 meters above sea level (World Bank 2011a). Kolkata is projected to be exposed to increasing precipitation, storm surges, and sea-level rise under climate change scenarios. Roughly a third of the total population of 15.5 million (2010 data; UN-HABITAT 2010) live in slums, which significantly increases the vulnerability of the population to these risk factors. Furthermore, 15 percent of the population live by the Hooghly River and are highly exposed to flooding. Another factor adding to the vulnerability of Kolkata is unplanned and unregulated urbanization; infrastructure development is insufficient and cannot keep pace with current urbanization rates (World Bank 2011a).

A recent study by the World Bank (2011a)[106] on urban flooding as a consequence of climate-change finds that a 100-year return period storm will result in doubling the area flooded by a depth of 0.5–0.75m (i.e. high threat level) under the A1F1 climate change scenario (this scenario considers a projected sea-level rise of 27 cm and a 16 percent increase in precipitation by 2050). This excludes Kolkata city, which is analyzed separately, as the city has sewerage networks in place; these sewerage networks are essentially absent in the peri-urban areas surrounding the city. According

Box 5.3: The 2005 Mumbai Flooding

Severe flooding in 2005 caused 500 deaths and an estimated $1.7 billion in economic damage in Mumbai, the commercial and financial hub of India and the city that generates about five percent of the nation's GDP (Ranger et al. 2011). The flood forced the National Stock Exchange to close, and automated teller machine banking systems throughout large parts of the country stopped working. This demonstrated how critical infrastructure can be affected by extreme events in mega-cities (Intergovernmental Panel on Climate Change 2012).

[105] For these estimates, projections of precipitation are taken from the regional climate model PRECIS. They are driven by the A2 SRES scenario, which projects a 3.6°C mean temperature increase across India compared to the 1961–90 baseline period and a 6.5 percent increase in seasonal mean rainfall by 2080 representing an upper-end estimate of future climate risks (Ranger et al. 2011).

[106] Projections are based on the A1F1 SRES emission scenario leading to a global-mean warming of 2.2°C above pre-industrial levels by 2050, 12 GCMs, and an estimated sea-level rise of 27 cm by 2050. Historical rainfall data for 1976–2001 represent the baseline (no climate change) scenario. Land subsidence was not accounted for in the study. Impacts were analyzed in terms of the projected extent, magnitude, and duration of flooding by deploying a hydrological model, a hydraulic model, and an urban storm drainage model. The population of Kolkata in 2050 was estimated by extrapolation based on the past decadal growth rates adjusted for likely future changes in population growth. A decadal population growth rate of 4 percent was applied. Past average per capita GDP growth rates were used to estimate property and income levels in 2050. The presented estimates are based on 2009 prices and thus do not consider inflation (World Bank 2011a).

to the projections presented in Chapter 5 on "Regional Sea-level Rise", the sea-level rise in Mumbai and Kolkata is expected to reach 25 cm by the 2030s–40s.

In Kolkata city, with a population of approximately five million and a population density almost three times higher than the metropolitan area (the city has a population density of 23,149 persons per km² while the metropolitan area has a population density of only 7,950 people per km²), a flood depth of more than 0.25 meters is expected to affect 41 percent of the city area and about 47 percent of the population in 2050 compared to 39 percent of the city area and 45 percent of the population under the baseline scenario (World Bank 2011a).

In terms of damages in Kolkata city only, which accounts for an area of around 185 km² (the metropolitan area surrounding the city is about 1,851 km²) the World Bank (2011a) study estimates the additional climate-change-related damages from a 100-year return-period flood to be $790 million in 2050 (including damages to residential buildings and other property, income losses, losses in the commercial, industrial, and health care sectors, and damages to roads and the transportation and electricity infrastructures). Due to data constraints, both total damages and the additional losses caused by increased flooding as a consequence of climate change should be viewed as lower-bound estimates (World Bank 2011a).

Given that sea-level rise is projected to increase beyond 25 cm to 50 cm by 2075 (and 75 cm by 2100) in the lower warming scenario of 2°C, these risks are likely to continue to grow with climate change.

Scale of Flooding Risks with Warming, and Sea-level Rise

With a few exceptions, most of the studies reviewed here do not examine how flooding risks change with different levels of climate change and/or sea-level rise. In specific locations, this very much depends on local topographies and geography; on a broader regional and global scale, however, the literature shows that river flooding risks are quite strongly related to the projected level of warming. Recent work by Arnell et al (2013) reinforces earlier work, showing that the proportion of the population prone to river flooding increases rapidly with higher levels of warming. Globally about twice as many people are predicted to be flood prone in 2100 in a 4°C world compared to a 2°C scenario. Arnell and Gosling (2013) find that increases in flooding risk are particularly large over South Asia by the 2050s, both in percentage and absolute terms. Reinforcing this are recent projections of the consequence of snow reductions in the Himalayan region: increasing frequency of extremely low snow years causes extremely high northern hemisphere winter/spring runoff increasing flood risks (Diffenbaugh et al 2012).

The response to coastal flooding caused by sea-level rise tends to be much less pronounced; this is principally because, by 2100, the differences between scenarios are not large when adaptation is assumed (i.e., rising wealth drives increasing levels of coastal protection) (Arnell et al 2013). The full difference in impacts would be felt in following centuries.

For the cases studied here, such as the Indus-Brahmaputra Delta, Bangladesh and the cities, it is plausible that higher rates of sea-level rise and climate change together will lead to greater levels of flooding risk. How these risks change, and likely increase, with high levels of warming and sea-level rise remains to be fully quantified.

Agricultural Production

Agriculture contributes approximately 18 percent to South Asia's GDP (2011 data based on World Bank 2013l); more than 50 percent of the population is employed in the sector (2010 data based on World Bank 2013m) and directly dependent on it. In Bangladesh, for example, rural communities, representing large parts of the population, are expected to remain dependent on agriculture despite structural changes in the economy away from climate-sensitive sectors in the future. As a result, much of the population will remain vulnerable to these climate change impacts (World Bank 2009). Productivity growth in agriculture is thus an important driver of poverty reduction, and it is highly dependent on the hydrological cycle and freshwater availability (Jacoby, Mariano, and Skoufias 2011).

The rice-wheat system in the Indo-Gangetic Plain, which meets the staple food needs of more than 400 million people, is a highly vulnerable regional system. The system, which covers an area of around 13.5 million hectares in Pakistan, India, Bangladesh, and Nepal, provides highly productive land and contributes substantially to the region's food production. Declining soil productivity, groundwater depletion, and declining water availability, as well as increased pest incidence and salinity, already threaten sustainability and food security in the region (Wassmann, Jagadish, Sumfleth, et al. 2009).

Climate change is projected to have a significant and often adverse impact on agricultural production in South Asia, the development of the sector, and the economic benefits derived from it (Nelson et al. 2009). There are a significant number of risks arising from climate-change-related phenomena that need to be considered in assessing the future impacts on the sector (Box 5.4). For example, the upper temperature sensitivity threshold for current cultivars for rice is 35–38°C and for wheat is 30–35°C (Wassmann, Jagadish, Sumfleth, et al. 2009). Future heat extremes may thus pose a significant risk to regional production of these crops. This section will provide a short overview of the major risks to crop and agricultural production in the region before turning to model-based projections of future agricultural output.

Box 5.4: Observed Rice Yield Declines

Observed Rice Yield Decline and Slowdown in Rice Harvest Growth

Using agro-meteorological crop modeling, Pathak et al. (2003) explain the observed rice yield decline in the IGP (1985–2000) as a result of the combined decrease in radiation and increase in minimum temperature.[a] Confirming this, Auffhammer, Ramanathan, and Vincent (2006) apply an agro-economic model over all of India and find that atmospheric aerosols and greenhouse gases, reducing radiation and increasing minimum temperatures, have contributed to the recent slowdown in rice harvest growth.

In more recent work, the effects of changes in monsoon, drought, and temperature have been disentangled. Auffhammer et al. (2011) find that rice yields in India would be 1.7 percent higher on average if the monsoon pattern had not changed since 1960, and an additional four percent higher if two further meteorological changes, warmer nights and less precipitation at the end of the growing season, had not occurred. The individual effect of increasing minimum temperatures is reported at 3.4 percent; this caused more than half of the total yield decline. Accordingly, the results indicate that average yield in India could have been almost six percent higher (75 million tons in absolute terms) without changing climatic conditions and confirm that increasing minimum temperatures have had a greater impact on yield than changing monsoon characteristics. The analysis does not account for adaptive responses by farmers. While controlling for increases of yield due to advances in agricultural technology, the authors assume that the simulated yield reduction is a lower bound estimate (Auffhammer et al. 2011). Auffhammer et al. (2011) further point out that, though their analysis is based only on observational data and not on climate models, the results are consistent with climate model projections—and yield reductions are likely to be larger in the future with projected increasing temperatures and, in some models, a continued weakening of the monsoon (Chapter 5 on "Precipitation Projections").

Wheat Yield Stagnation and High-Temperature Negative Effects

Recent work by Lin and Huybers (2012) shows that wheat crop yields peaked in India and Bangladesh around 2001 and have not increased despite increasing fertilizer applications. Using a crop growth model, Kalra et al. (2008) explain the wheat yield stagnation in most parts of northwest India through the interactions of radiation and temperature change.

Observations of crop responses to extremely high temperatures in northern India indicate a significant and substantial negative effect following exposure to temperatures above 34°C. The authors conclude that present crop models may underestimate by as much as 50 percent the yield loss from local warming of 2°C (David B. Lobell, Sibley, Ivan Ortiz-Monasterio, and Ortiz-Monasterio 2012).

[a] Rice harvests are positively correlated with solar radiation late in the season and negatively correlated with night-time temperature.

The effects of rainfall deficits, extreme rainfall events, and flooding are projected to be felt differently in different parts of South Asia. For examples, Asada and Matsumoto (2009) analyze the effects of variations in rainfall on rice production in the Ganges-Brahmaputra Basin in India and Bangladesh. This is one of the most important regions for rice production in South Asia and is responsible for about 28 percent of the world's total rice production. Their focus is on regional differences between the upper and the lower Ganges and the Brahmaputra Basin. Based on climate and rice production data from 1961–2000, Asada and Matsumoto (2009) apply statistical modeling and find that the effect of changes in rainfall differs among the regions analyzed. While rice production in the upper Ganges Basin is strongly affected by rainfall variation and is vulnerable to rainfall shortages, rice production in the lower Ganges Basin is more strongly affected by floods. In the Brahmaputra Basin, in contrast, the drought effect is stronger than the flood effect as a consequence of increasing rainfall variation, though crops are vulnerable to both droughts and floods. These findings are highly relevant in the context of climate change as they provide a better understanding of regional differences and vulnerabilities to provide a stronger basis for adaptation and other responses (Asada and Matsumoto 2009).

Climatic Risk Factors

Extreme Heat Effects

Heat stress, which can be particularly damaging during some development stages and may occur more frequently with climate change, is not yet widely included in crop models and projections. Lobell et al. (2012) use satellite data to investigate the extreme heat effects on wheat senescence; they find that crop models probably underestimate yield losses for +2°C by as much as 50 percent for some sowing dates. Earlier work by Lobell et al. (2011) shows the sensitivity of rice, and wheat in India to increases in maximum temperature in the growing season. Compared to calculations of potential yields without historic trends of temperature changes since the 1980s, rice and wheat yields have declined by approximately 8 percent for every 1°C increase in average growing-season temperatures (David B Lobell, Schlenker, and Costa-Roberts 2011).

If temperatures increase beyond the upper temperature for crop development (e.g., 25–31°C for rice and 20–25°C for wheat, depending on genotype), rapid decreases in the growth and productivity of crop yields could be expected, with greater temperature increases leading to greater production losses (Wassmann,

Jagadish, Sumfleth, et al. 2009). By analyzing the heat stress in Asian rice production for the period 1950–2000, Wassmann et al. (2009) show that large areas in South Asia already exceed maximum average daytime temperatures of 33°C.

By introducing the response to heat stress within different crop models, A. Challinor, Wheeler, Garforth, Craufurd, and Kassam (2007) simulate significant yield decreases for rice (up to –21 percent under double CO_2) and groundnut (up to –50 percent). Under a doubling of atmospheric CO_2 from the 380 ppm baseline, they show that at low temperature increases (+1°C, +2°C), the CO_2 effect dominates and yields increase; at high temperature increases (+3°C, +4°C), yields decrease.

Areas, where temperature increases are expected to exceed upper limits for crop development in critical stages (i.e., the flowering and the maturity stage) are highly vulnerable to heat-induced yield losses. Aggravating heat stress due to climate change is expected to affect rice crops in Pakistan, dry season crops in Bangladesh, and crops in the Indian States of West Bengal, Bihar, Jharkhand, Orissa, Tamil Nadu, Kerala, and Karnataka. The situation may be aggravated by reduced water availability due to changes in precipitation levels and falling groundwater tables, as well as by droughts, floods, and other extreme events (Wassmann, Jagadish, Sumfleth, et al. 2009).

Water and Groundwater Constraints

Agriculture and the food demands of a growing population are expected to be the major drivers of water usage in the future (De Fraiture and Wichelns 2010; Ian Douglas 2009), demonstrating the direct linkage between water and food security. At present, agriculture accounts for more than 91 percent of the total freshwater withdrawal in South Asia (including Afghanistan); Nepal (98 percent), Pakistan (94 percent), Bhutan (94 percent) and India (90 percent) have particularly high levels of water withdrawal through the agricultural sector (2011 data by World Bank 2013d). Even with improvements in water management and usage, agriculture is expected to remain a major source of water usage (De Fraiture and Wichelns 2010).

Even without climate change, sustainable use and development of groundwater resources remain a major challenge (Green et al. 2011). In India, the "global champion in groundwater irrigation" (Shah 2009), resources are already at critical levels and about 15 percent of the country's groundwater tables are overexploited, meaning that more water is being extracted than the annual recharge capacity (Ministry of Environment and Forests 2012). The Indus Basin belongs to the areas where groundwater extraction exceeds annual replenishment. In addition, groundwater utilization in India is increasing at a rate of 2.5–4 percent (Ministry of Environment and Forests 2012). Year-round irrigation is especially needed for intensifying and diversifying small-scale farming. Without any measures to ensure a more sustainable use of groundwater resources, reductions in agricultural production and in the availability of drinking water are logical consequences—even without climate change (Rodell et al. 2009). Climate change is expected to further aggravate the situation (Döll 2009; Green et al. 2011).

Immerzeel, Van Beek, and Bierkens (2010) demonstrate how changes in water availability in the Indus, Ganges, and Brahmaputra rivers may impact food security. The authors estimate that, with a temperature increase of 2–2.5°C compared to pre-industrial levels, by the 2050s reduced water availability for agricultural production may result in more than 63 million people no longer being able to meet their caloric demand by production in the river basins.

Depending on rainfed agriculture for food production carries high risks, as longer dry spells may result in total crop failure (De Fraiture and Wichelns 2010). In India, for example, more than 60 percent of the crop area is rainfed (e.g., from green water), making it highly vulnerable to climate induced changes in precipitation patterns (Ministry of Environment and Forests 2012). The bulk of rice production in India, however, comes from irrigated agriculture in the Ganges Basin (Eriksson et al. 2009); changes in runoff patterns in the Ganges River system are projected to have adverse effects even on irrigated agriculture.

Based on projections for the 2020s and 2030s for the Ganges, Gornall et al. (2010) provide insight into these risks. Consistent with other studies, they project overall increased precipitation during the wet season for the 2050s compared to 2000,[107] with significantly higher flows in July, August, and September. From these global model simulations, an increase in overall mean annual soil moisture content is expected for 2050 (compared to 1970–2000); the soil is also expected to be subject to drought conditions for an increased length of time. Without adequate water storage facilities, however, the increase of peak monsoon river flow would not be usable for agricultural productivity; increased peak flow may also cause damage to farmland due to river flooding (Gornall et al. 2010).

Other river basins are also projected to suffer surface water shortages. Gupta, Panigrahy, and Paribar (2011) find that Eastern Indian agriculture may be affected due to the shortage of surface water availability in the 2080s as they project a significant reduction in the lower parts of the Ganga, Bahamani-Baitrani, and Subarnrekha rivers and the upper parts of the Mahanadi River.

In addition to the large river systems, groundwater serves as a major source of water, especially for irrigation in South Asia (here referring to India, Pakistan, lower Nepal, Bangladesh, and Sri Lanka) (Shah, 2009). In India, for example, 60 percent of irrigation for agriculture (Green et al. 2011) and 50–80 percent of domestic water use depend on groundwater, and yet 95 percent of total groundwater consumption is used for irrigation (Rodell, Velicogna, and Famiglietti 2009).

[107] SRES A1F scenario leading to a temperature increase of approximately 2.3°C above pre-industrial levels by 2050.

With its impacts on surface water and precipitation levels, climate change would affect groundwater resources (Green et al. 2011). South Asia, and especially India and Pakistan, are highly sensitive to decreases in groundwater recharge as these countries are already suffering from water scarcity and largely depend on water supplied from groundwater (Döll 2009). Groundwater resources are particularly important to mitigate droughts and related impacts on agriculture and food security, and it is likely that groundwater resources will become even more important in the future at times of low surface water availability and dry spells (Döll 2009; Green et al. 2011). To date, climate-related changes in groundwater resources have been relatively small compared to non-climatic forces such as groundwater mining, contamination, and reductions in recharge.

Groundwater recharge is highly dependent on monsoon rainfall, and the changing variability of the monsoon season poses a severe risk to agriculture. Farming systems in South Asia are highly adapted to the local climate, particularly the monsoon. Approximately 80 percent of the rainfall over India alone occurs during the summer monsoon (June-September). This rainfall provides water for the rainfed and irrigated crops that depend largely on surface and groundwater reserves that are replenished by the monsoon rains. Observations indicate the agricultural sector´s vulnerability to changes in monsoon precipitation: with a 19-percent decline in summer monsoon rainfall in 2002, Indian food grain production was reduced by about 18 percent compared to the preceding year (and 10–15 percent compared to the previous decadal average) (Mall et al. 2006).

Observations of agricultural production during ENSO events confirm strong responses to variations in the monsoon regime. ENSO events play a key role in determining agricultural production (Iglesias, Erda, and Rosenzweig 1996). Several studies, using historical data on agricultural statistics and climate indices, have established significant correlations between summer monsoon rainfall anomalies, strongly driven by the ENSO events, and crop production anomalies (e.g., Webster et al. 1998).

Recent statistical analysis by Auffhammer, Ramanathan, and Vincent (2011) also confirm that changes in monsoon rainfall over India, with less frequent but more intense rainfall in the recent past (1966–2002) contributed to reduced rice yields. Droughts have also been found to have more severe impacts than extreme precipitation events (Auffhammer et al. 2011). This decrease in production is due to both direct drought impacts on yields and to the reduction of the planted areas for some water-demanding crops (e.g., rice) as farmers observe that the monsoon may arrive too late (Gadgil and Rupa Kumar 2006).

Salinization

Soil salinity has been hypothesized to be one possible reason for observed yield stagnations (or decreases) in the Indo-Gangetic Plain (Ladha et al. 2003). Climate change is expected to increase the risk of salinity through two mechanisms. First, deltaic regions and wetlands are exposed to the risks of sea-level rise and increased inundation causing salinity intrusion into irrigation systems and groundwater resources. Second, higher temperatures would lead to excessive deposits of salt on the surface, further increasing the percentage of brackish groundwater (Wassmann, Jagadish, Heuer, Ismail, Redonna, et al. 2009). However, similar to diminished groundwater availability, which is largely due to rates of extraction exceeding rates of recharge and is, in this sense, human induced (Bates 2008), groundwater and soil salinization are also caused by the excessive use of groundwater in irrigated agriculture. Salinity stress through brackish groundwater and salt-affected soils reduces crop yields; climate change is expected to aggravate the situation (Wassmann, Jagadish, Heuer, et al., 2009).

Drought

Droughts are an important factor in determining agricultural production and food security. They can also have severe implications for rural livelihoods, migration, and economic losses (Intergovernmental Panel on Climate Change 2012; UNISDR 2011). Evidence indicates that parts of South Asia have become drier since the 1970s (Intergovernmental Panel on Climate Change 2007) in terms of reduced precipitation and increased evaporation due to higher surface temperatures, although the attribution of these changes in dryness has not yet been resolved.

Bangladesh is regularly affected by severe droughts as a result of erratic rainfall and unstable monsoon precipitation. While country-wide droughts occur approximately every five years, local droughts in rainfed agricultural areas, such as the northwest of Bangladesh, occur more regularly and cause yield losses higher than those from flooding and submergence (Wassmann, Jagadish, Sumfleth, et al. 2009).

Droughts can be a result of an overall decline in rainfall in wet or dry season, a shift in the timing of the wet season, as well as a strong local warming that exhausts water bodies and soils by evaporation. Across models, total annual precipitation is projected on average to increase over southern India and decrease over northwestern India, Pakistan, and Afghanistan, while the difference between years might increase due to increased interannual variability of the monsoon (Chapter 5 on "Precipitation Projections"). Some models show a peak in precipitation increase over northern India and Pakistan rather than over southern India (e.g., Taylor et al. 2012). In the dry season, the models generally agree on a projected widespread reduction in precipitation across the region (Chapter 5 on "Precipitation Projections"), which increases the population's dependence on river flow, above ground water storage, and ground water for natural systems during the monsoon season. In a 4°C warming scenario globally, annual mean warming is projected to exceed 4°C in southern India and rise to more than 6°C in Afghanistan (Chapter 5 on "Projected Temperature Changes")—increasing both evaporation and water

requirements of plants for evapotranspiration. Using such projections in precipitation and warming, (Dai 2012) estimates that, for a global mean warming of 3°C by the end of the 21st century, the drought risk expressed by the Palmer Drought Severity Index (PDSI) becomes higher across much of northwestern India, Pakistan, and Afghanistan but becomes lower across southern and eastern India.

It should be noted that such projections are uncertain, not only due to the spread in model projections but also to the choice of drought indicator (Taylor et al. 2012). For example, drought indicators like PDSI include a water balance calculation involving precipitation and evaporation and relate the results to present-day conditions, so that drought risk is presented relative to existing conditions. By contrast, Dai (2012) showed that projected changes in soil-moisture content indicate a drying in northwestern Pakistan, Afghanistan, and the Himalayas—but no significant drying or wetting over most of India.

Flooding and Sea-level Rise

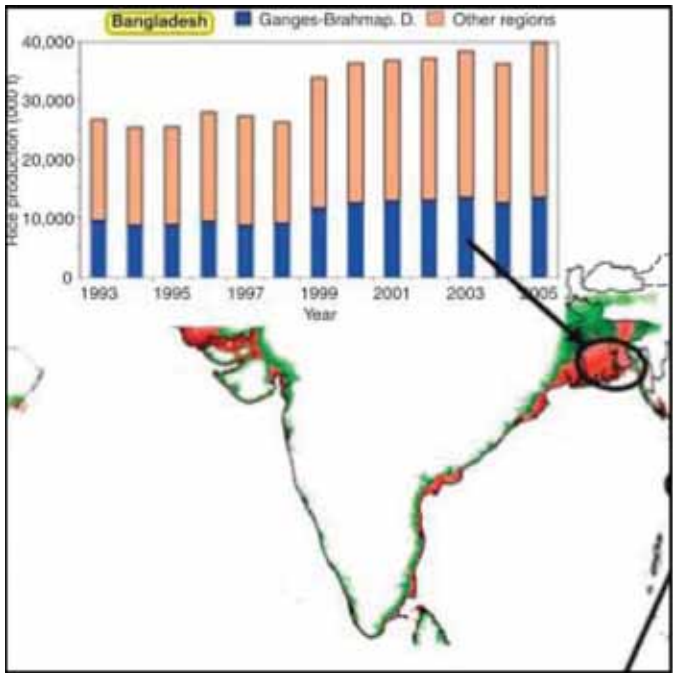
Flooding poses a particular risk to deltaic agricultural production. The rice production of the Ganges-Brahmaputra-Meghna Delta region of Bangladesh, for example, accounts for 34 percent of the national rice production and is used for domestic consumption only. Large parts of the area are less than five meters above sea level and therefore at high risk of sea-level rise (see Figure 5.12). Bangladesh is a rice importer; even today, food shortages are a persistent problem in the country, making it even more vulnerable to production shocks and rising food prices (Douglas 2009; Wassmann, Jagadish, Sumfleth, et al. 2009). Higher flood risk as a consequence of climate change poses a severe threat to the Aman rice crop in Bangladesh, which is one of the three rice crops in Bangladesh that grows in the monsoon season; it accounts for more than half of the national crop (Wassmann, Jagadish, Sumfleth, et al. 2009). Increased flood risk to the Aman and Aus (pre-monsoon) rice crops is likely to interact with other climate change impacts on the Boro (post-monsoon) rice crop production, leading to substantial economic damages (Yu et al. 2010). In this region, large amounts of productive land could be lost to sea-level rise, with 40-percent area losses projected in the southern region of Bangladesh for a 65 cm rise by the 2080s (Yu et al. 2010).

Tropical Cyclone Risks

Tropical cyclones already lead to substantial damage to agricultural production, particularly in the Bay of Bengal region, yet very few assessments of the effects of climate change on agriculture in the region include estimates of the likely effects of increased tropical cyclone intensity.

Tropical cyclones are expected to decrease in frequency and increase in intensity under future climate change (see Chapter 4 on "Tropical Cyclone Risks" for more discussion on tropical cyclones). More intense tropical cyclones, combined with sea-level rise, would increase the depth and risk of inundation from floods and storm surges and reduce the area of arable land (particularly in low-lying deltaic regions) (Box 5.5). In Bangladesh, for example, a projected 27 cm sea-level rise by 2050, combined with a storm surge induced by an average 10-year return-period cyclone such as Sidr, could inundate an area 88-percent larger than the area inundated by current cyclonic storm surges[108] (World Bank 2010d). Under this scenario, for the different crop seasons, the crop areas

Figure 5.12: Low elevation areas in the Ganges-Brahmaputra Delta



Source: Wassmann et al. (2009)

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Box 5.5: The Consequences of Cyclone Sidr

In 2007, category four cyclone Sidr (NASA, 2007) in Bangladesh caused a production loss of 800,000 tons of rice, or about 2 percent of total annual production in 2007 (FAO 2013). It also resulted in $1.7 billion in economic damages. The major damage occurred in the housing sector, followed by agriculture and infrastructure (Wassmann, Jagadish, Sumfleth, et al. 2009; World Bank 2010d).

[108] Based on the assumption that landfall occurs during high-tide and that wind speed increases by 10 percent compared to cyclone Sidr.

exposed to inundation are projected to increase by 19 percent for the Aman crop, by 18 percent for the Aus crop, and by 43 percent for the Boro crop. The projected regional sea-level rise by 2050 is estimated in Chapter 5 on "Regional Patterns of Climate Change" at around 30–35 cm under both the 2°C and 4°C scenarios, with sea levels rising to 80 cm by 2100 in the former scenario and to over a meter in the latter one.

Uncertain CO_2 Fertilization Effect

Despite the different representations of some specific biophysical processes, the simulations generally show that the positive fertilization effect of the increasing atmospheric CO_2 concentration may counteract the negative impacts of increased temperature (e.g., A. J. Challinor & Wheeler 2008). There are, however, regional differences: For the intensive agricultural areas of northwest India, enhanced wheat and rice yields might be expected under climate change, provided that current irrigation can be maintained. Enhanced yields could also be expected for rainfed rice in southwest India if the temperature increase remains limited, as water use efficiency is enhanced under elevated atmospheric CO_2 levels. Uncertainties associated with the representation or parameterization of the CO_2 fertilization effect, however, lead to a large range of results given by different crop models (see Chapter 3 on "Crops" for more discussion on the CO_2 fertilization effect). For example, large parts of South Asia are projected to experience significant declines in crop yield without CO_2 fertilization, while increases are projected when taking the potential CO_2 fertilization effect into account. However, controversy remains as to the strength of the effect, and there is considerable doubt that the full benefits can be obtained (Müller et al. 2010).

Projected Changes in Food Production

The impacts of climate change on crop production in South Asia could be severe. Projections are particularly negative when CO_2 fertilization, of which the actual benefits are still highly uncertain, is not accounted for. Low-cost adaptation measures may mitigate against yield declines up to 2.5°C warming if the CO_2 fertilization effect is taken into account; where the CO_2 fertilization effect is not accounted for, yields show a steady decline.

It is important to recognize that the assessments outlined below do not yet include the known effects of extreme high temperatures on crop production, the effects of extreme rainfall and increased seasonality of the monsoon, lack of needed irrigation water (many assessments assume irrigation will be available when needed), or the effects of sea-level rise and storm surges on loss of land and salinization of groundwater. The evidence from crop yields studies indicates that the CO_2 fertilization effect is likely to be outweighed by the negative effects of higher warming above 2.5°C.

The crop yield review here shows a significant risk, in the absence of a strong CO_2 fertilization effect, of a substantial, increasing negative pressure from present warming levels upward. The rapid increase in the area of South Asia expected to be affected by extreme monthly heat is 10 percent of total land area by 2020 and approximately 15 percent by 2030;[109] combined with evidence of a negative response to increases in maximum temperature in the growing season, this points to further risks to agricultural production in the region.

There are relatively few integrated projections to date of total crop production in South Asia. Most published studies focus on estimating changes in crop yield (that is, yield per unit area) for specific crops in specific regions, and examine the consequences of climate change and various adaptation measures on changes in yield. Although total crop production (for a given area over a given timeframe) is fundamentally influenced by crop yield, other factors (availability of water, soil salinization, land availability, and so forth) play an important role and need to be accounted for.

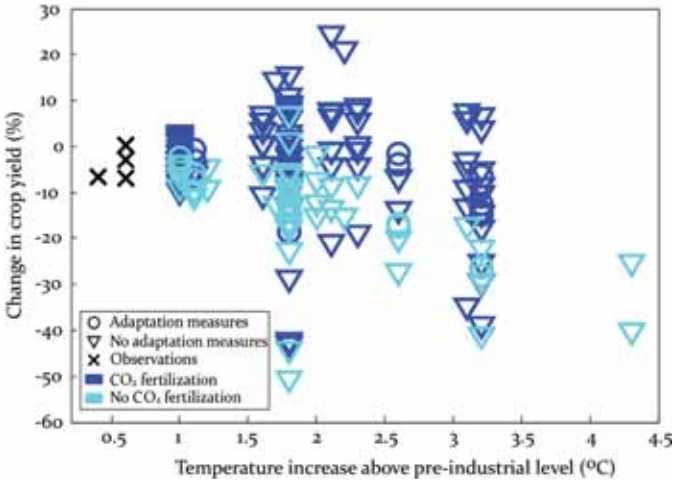
Crop yields in South Asia have improved over time, and it can be expected that future improvements may occur due to technological changes, cultivar breeding and optimization, production efficiencies, and improved farm management practices. A recent global assessment of crop yield trends, however, indicates grounds for concern in South Asia (Lobell, Schlenker, and Costa-Roberts 2011). In India, rice crop yields have been improving on about 63 percent of the cropped area—but not improving on the remainder. For wheat, crop yield is increasing on about 30 percent of the cropped area in India, but not on the rest. In Pakistan, wheat crop yields are improving on about 87 percent of the cropped area. For soybean crops in India, yield improvements are occurring on about half of the area. Maize, not yet a large crop in India, exhibits yields improving on over 60 percent of the cropped area.

Figure 5.13 shows the relationship between global mean temperature and yield changes for most of the crops grown in South Asia. Recent studies show results for different crops (maize, wheat, rice, groundnut, sorghum, and soybean), for different irrigation systems, and for different regions (see Appendix 4 for details). Often the results are presented as a range for different GCM models or for a region or sub-regions. In the following analysis, which is an attempt to identify a common pattern of the effects of CO_2 fertilization and adaptation measures on crop yield, all crops are gathered together without distinction among crop types, irrigation systems, or regions in Asia. In cases in which a study showed a range of GCM models for a specific crop, the average of the models was considered as representative of yield change.

Across the whole warming range considered, there exists a significant relationship between crop yield decrease and temperature increase ($F = 25.3$, $p < 0.001$) regardless of crop type or

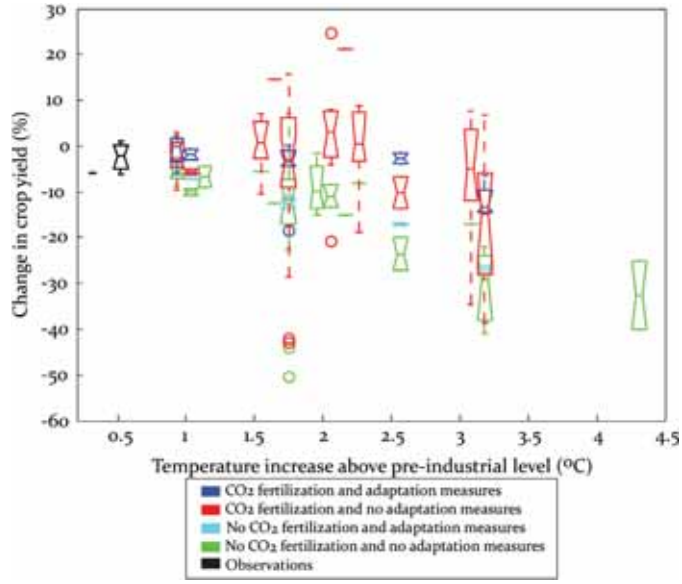
[109] Values for this timeframe are independent of the warming scenario that is projected for both a 2°C and a 4°C world.

Figure 5.13: Scatter plot illustrating the relationship between temperature increase above pre-industrial levels and changes in crop yield



Data points represent different types of crops, in different regions of Asia, considering different irrigation systems and the effects of CO_2 fertilization (dark blue) or not (light blue), and of adaptation measures (circles) or not (triangles).

Figure 5.14: Box plot illustrating the relationship between temperature increase above pre-industrial levels and changes in crop yield



The whiskers are lines extending from each end of the boxes to show the extent of the rest of the data. Outliers are data with values beyond the ends of the whiskers. Overlap of the narrowing around the median (notches) indicates that the difference between the medians is not significant to $p<0.05$.

whether the effects of CO_2 fertilization or adaptation measures are taken into account:

- For warming below about 2.1 degrees above pre-industrial levels, and with cases with and without CO_2 fertilization taken together, there is no longer a significant relationship between warming and yield loss. This suggests that the effects of adaptation measures and CO_2 fertilization are stronger and may compensate for the adverse effects of climate change under 2°C warming.
- If one excludes cases that include CO_2 fertilization, then significant yield losses may occur before 2°C warming.
- With increases in warming about 2°C above pre-industrial levels, crop yields decrease regardless of these potentially positive effects. While CO_2 fertilization partly compensates for the adverse effects of climate change, this compensation appears stronger under temperature increases below 2°C above pre-industrial levels.

The same data as above is shown in Figure 5.14 with statistical relationships. The median estimates of yields indicate that studies with CO_2 fertilization and adaptation measures (dark blue) and CO_2 fertilization without adaptation measures (red) show a fairly flat response to about 2°C warming—and then show a decreasing yield trend. Yields excluding these effects (green and light blue) show a decreasing yield trend with a temperature increase. There is no significant difference between red bars (adding only CO_2 fertilization effects) between 1.2–2.1°C temperature increase levels; this becomes significant at 2.5°C. If the effects of both CO_2 fertilization and adaptation measures are taken into account (dark blue bars), then the medians only differ significantly at the highest level of temperature increase. This suggests that a substantial, realized CO_2 fertilization effect and adaptation measures have positive effects at lower levels of temperature increases but that, at higher temperature increases, this effect is overshadowed by the stronger effects of greater climate change. If there is a strong CO_2 fertilization effect, the effects of warming might be compensated for by low-cost adaptation measures below about 2°C warming, whereas for warming greater than this yield levels are likely to decrease. With increases in warming above about 2°C above pre-industrial levels, crop yields appear likely to decrease regardless of these potentially positive effects.

This overall pattern of increasingly large and likely negative impacts on yields with rising temperatures would have a substantial effect on future crop production.

Lal (2011) estimates the overall consequences for crop production in South Asia. He finds that in the longer term CO_2 fertilization effects would not be able to offset the negative impacts of increases in temperatures beyond 2°C on rice and wheat yields in South Asia.

He estimates that cereal production would decline 4–10 percent under the most conservative climate change projections (a regional warming of 3°C) by the end of this century.

A recent assessment by Nelson et al. (2010) is a fully integrated attempt to estimate the global crop production consequences of climate change; this report draws substantially upon that work. The most important crops in South Asia are rice and wheat, accounting for about 50 percent and 40 percent of production, respectively. Nelson et al. (2009, 2010)[110] estimate the direct effects of climate change (changes in temperature and precipitation for rainfed crops and temperature increases for irrigated crops) on the production of different crops with and without the effect of CO_2 fertilization under a global mean warming of about 1.8°C above pre-industrial levels by 2050. They find that South Asia (including Afghanistan) is affected particularly hard by climate change—especially when the potential benefits of the CO_2 fertilization effect are not included (Nelson et al., 2009, 2010). The authors make the decision in conducting their analysis to show mainly results excluding the CO_2 fertilization effect as "this is the most likely outcome in farmers' fields."

Two climate model projections are applied for the South Asian region in 2050. One of the models (NCAR) projects a substantial (11 percent) increase in precipitation; the other (CSIRO) model projects about a 1.6 percent increase above 2000 levels. The CMIP5 projections reviewed above project about a 2.3 percent increase in precipitation per degree of global mean warming (1.3–3 percent range); hence, more recent projections than those deployed by Nelson et al. (2010) imply a likely total increase of about 4 percent in 2050. In analyzing the results of this work, this report averages the model results; in the case of South Asia there is little overall difference between the models.

Table 5.2 provides a summary of the assessment of the integrated effects of climate change on crop production in South Asia. Without climate change, overall crop production is projected to increase significantly (by about 60 percent) although, in per capita terms, crop production will likely not quite keep pace with projected

[110] The estimates are based on the global agriculture supply and demand model IMPACT 2009, which is linked to the biophysical crop model DSSAT. Climate change projections are based on the NCAR and the CSIRO models and the A2 SRES emissions scenario, leading to a global mean warming of about 2.0°C above pre-industrial levels by 2050 (Nelson et al. 2009, 2010). To capture the uncertainty in the CO_2 fertilization effect, simulations are conducted at two levels of atmospheric CO_2 in 2050: the year 2000 level of 369 ppm, called the no-CO_2fertilization scenario; and the projected level in 2050 for 532 ppm under the SRES A2 scenario, termed the with-CO_2 fertilization scenario.

Table 5.2: Major results from the Nelson et al. (2010) assessment of crop production changes to 2050 under climate change in South Asia

Crops	Crop Production (Year 2000)	Crop as Percentage of Total 2000	Projected Yield Improvements No Climate Change (% p.a.)	Crop Production 2050 No Climate Change	Crop Production 2050 with Climate Change and No CO_2 fertilization Effect	Average Annual Yield Change with Climate Change
Rice (mmt)	120	48%	0.9%	169	145	–0.2%
Wheat (mmt)	97	38%	1.6%	191	103	–1.3%
Maize (mmt)	16	6%	0.6%	19	16	0.1%
Millet (mmt)	11	4%	1.5%	12	11	0.0%
Sorghum (mmt)	8	3%	1.2%	10	8	1.4%
Total (mmt)	252			401	282	
Cereal Availability (kg/capita)	185			174	122	
Daily Per Capita Availability (kcal/capita/day)	2,424			2,660	2,241	
Total Population (million)	1,361			2,306	2,306	
Net Cereal Exports (mmt)	15			–20	–53	
Value of Net Cereal Trade (million $)	$2,589			-$2,238	-$14,827	
Number of Malnourished Children (million)	76			52	59	

Note that crop production in 2050 with climate change and no CO_2 fertilization effect is calculated as an average of the CSIRO and NCAR models used by Nelson et al. (2010) in the study. Projections start from climate conditions, including CO_2 concentration around year 2000. No explicit assumptions are made as to the effects of climate change to year 2000.

population growth. Under climate change, however, and assuming the CO_2 fertilization effect does not increase above present levels, a significant (about one-third) decline in per capita South Asian crop production is projected. With much larger yield reductions projected after 2050 than before (based on the above analysis), it could be expected that this food production deficit could grow further.

In South Asia, with the growth in overall crop production reduced from about 60 percent in the absence of climate change to a little over a 12 percent increase, and with population increasing about 70 percent over the same period, there would be a need for substantial crop imports. Nelson et al. (2010) estimate imports in 2050 to be equivalent to about 20 percent of production in the climate change scenario. Compared to the case without climate change, where about five percent of the assessed cereals would be imported in 2050 under the base scenario (costing over $2 billion per year), import costs would increase to around $15 billion per year.

In addition to the direct impacts of climate change on water and agricultural yield, there are also indirect impacts which have major implications for the food security of the region. These include food price fluctuations and trade and economic adjustments, which may either amplify or reduce the adverse effects of climate change.

Even without climate change, world food prices are expected to increase due to population and income growth as well as a growing demand for biofuels (Nelson et al. 2010). At the global level and with climate change, Nelson et al. (2010) estimate additional world food price increases to range from 32–37 percent for rice and from 94–111 percent for wheat by 2050 (compared to 2000). Adjusting for CO_2 fertilization as a result of climate change, price increases are projected to be 11–17 percent lower for rice, wheat, and maize, and about 60-percent lower for soybeans (Nelson et al. 2010).

While per capita calorie availability would be expected to increase by 9.7 percent in South Asia by 2050 without climate change, it is projected to decline by 7.6 percent below 2000 levels with climate change. Taking CO_2 fertilization into account, the decline would be 4.3 percent compared to calorie availability in 2000, which is still a significant change compared to the no-climate-change scenario. The proportion of malnourished children is expected to be substantially reduced by the 2050s without climate change. However, climate change is likely to partly offset this reduction, as the number of malnourished children is expected to increase by 7 million compared to the case without climate change (Nelson et al. 2010).[111]

Impacts in Bangladesh

While the risks for South Asia emerge as quite serious, the risks and impacts for Bangladesh are arguably amongst the highest in the region. Yu et al. (2010) conducted a comprehensive assessment of future crop performance and consequences of production losses for Bangladesh.

Yu et al. (2010) assess the impacts of climate change on four different crops under 2.1°C, 1.8°C, and 1.6°C temperature increases above pre-industrial levels in 2050.[112] They also take into account soil data, cultivar information, and agricultural management practices in the CERES (Crop Environment Resources Synthesis) model. The study accounts for temperature and precipitation changes, flood damage, and CO_2 fertilization for Aus (rice crop, planted in April), Aman (rice crop, planted in July), Boro (rice crop, planted in December), and wheat. Aman and Boro production areas represent 83 percent of the total cultivated area for these four crops, Aus production areas represent 11.1 percent, and wheat production areas represent 5.9 percent.

Yu et al. (2010) first estimate the impacts of climate change without taking into account the effects of flooding on production. They find that the Aus, Aman, and wheat yields are expected to increase whereas Boro production is expected to decrease as the Boro crop is more reactive to changes in temperature than changes in precipitation. When river and coastal flooding are taken into account, Aus and Aman crop production is expected to decrease. Note that Boro and wheat production are not expected to be affected by river or coastal flooding.

Yu et al. (2010) also evaluate the impact of coastal flooding on the production of rice and wheat in Bangladesh. The authors estimate the effects of floods on production using sea-level rise projections under the scenarios B1 and A2 only. Table 5.3 displays the sea-level rise values under the scenarios B1 and A2 used in this study. Taking into account the number of days of submergence, the relative plant height being submerged, and development stage of the plant (from 10 days after planting to maturity), the authors calculate the flood damage as a percentage of the yield reduction. Values for yield reduction vary from 0 percent when floods submerge the plants to 25–50 percent of the mature plant height for fewer than six days, to 100 percent when floods submerge more than 75 percent of plant height for more than 15 days at any stage of plant development.

Taking into account the impact of changes in temperature and precipitation, the benefits of CO_2 fertilization, mean changes in floods and inundation, and rising sea levels, the authors estimate that climate change will cause an approximately 80-million-ton reduction in rice production from 2005–50, or about 3.9 percent

[111] All estimates presented by Nelson et al. (2010) are based on the global agriculture supply and demand model IMPACT 2009, which is linked to the biophysical crop model DSSAT. Climate change projections are based on the NCAR and CSIRO models and the A2 SRES emissions scenario (global-mean warming of about 1.8°C above pre-industrial levels by 2050 globally). In this study, crop production growth is determined by crop and input prices, exogenous rates of productivity growth and area expansion, investments in irrigation, and water availability. Demand is a function of price, income, and population growth, and is composed of four categories of commodity demand: food, feed, biofuels, feedstock, and other uses.

[112] These temperature increases are based on the IPCC SRES A1B, A2, and B1 scenarios, respectively.

Figure 5.15: Median production change averaged across the climate change scenarios (A1B, A2, and B1) with and without CO_2 fertilization

This figure compares the integrated effects of all factors (climate change, CO_2 fertilization, and planning) for each of the main crop types. Note that for Boro and wheat, flooding does not affect production. These are compared with the cases excluding CO_2 fertilization but including the effects of climate change.

Source: Data from Yu et al. (2010).

Table 5.3: Projected and estimated sea-level rise under B1 and A2 scenarios from Yu et al. (2010), compared to the 2°C and 4°C world projections in this report (see Chapter 5 on "Regional Patterns of Climate Change")

"Warming World"	Scenario/Decade	2030s	2050s	2080s
2°C World	IPCC SRES B1	5cm	8cm	15cm
	RCP2.6	20cm	35cm	55cm
4°C World	IPCC SRES A2	15cm	27cm	62cm
	RCP8.5	20cm	35cm	75cm

annually[113] (World Bank 2010a; Yu et al. 2010). With an annual rice production of 51 million tons (2011 data based on FAO 2013), this amount is almost equivalent to two years of current rice production in Bangladesh. The results should probably be seen as optimistic as the simulations include highly uncertain benefits from CO_2 fertilization (Yu et al. 2010).

Yu et al. (2010) estimate the discounted total economy-wide consequences of climate change at about $120 billion between 2005–50, or $2.68 billion per year. This represents a decline of 5.14 percent in the national GDP. In the scenario with the most severe climate change impacts, however, GDP is expected to decrease by about eight percent during the same period and up to 12.2 percent between 2040–50. They also find that the discounted total losses in agricultural GDP due to the combined impacts of climate change would be approximately $25.8 billion, or $0.57 billion per annum.

The Implications of Declining Food Production for Poverty

The impacts of climate change on food prices, agricultural yields, and production are expected to have direct implications for human well-being. In particular, per capita calorie availability and child

[113] Projected annual reduction losses over the 45-year period range from 4.3 percent under the A2 scenarios to 3.6 percent under the B1 scenarios. GCM uncertainty further widens the range of projections from 2–6.5 percent. The 16 GCMs applied in this study for the two climate scenarios project a median warming of 1.6°C above 1970–99 temperatures (approximately 2°C above pre-industrial levels) and an increase of 4 percent in annual precipitation as well as greater seasonality in Bangladesh by 2050 (World Bank, 2010a).

malnutrition, affecting long-term growth and health, may be severely affected by climate change and its various effects on the agricultural sector (Nelson et al. 2010). Furthermore, uneven distribution of the impacts of climate change is expected to have adverse effects on poverty reduction.

Hertel et al. (2010) show that, by 2030, poverty implications due to rising food price in response to productivity shocks would have the strongest adverse effects on a selected number of social strata. In a low-productivity scenario, described as a world with rapid temperature increases and crops highly sensitive to warming, higher earnings result in declining poverty rates for self-employed agricultural households. This is due to price increases following production shocks. Non-agricultural urban households, in turn, are expected to suffer the most negative impacts of food price increases. As a result, the poverty rate of non-agricultural households in this scenario rises by up to a third in Bangladesh.[114]

Table 5.4: Electricity sources in South Asian countries

Country	Hydroelectricity (% of total)	Thermoelectricity (including coal, oil, natural gas and nuclear power) (% of total)
Bangladesh	3.9	96.0
Bhutan	n.a	n.a
India	11.9	85.5
Maldives	n.a	n.a
Nepal	99.9	0.1
Pakistan	33.7	66.3
Sri Lanka	52.3	47.5

Source: Adapted from" and then go one with World Bank (2013f); World Bank (2013f); World Bank (2013g); World Bank (2013h); World Bank (2013i); World Bank (2013j).

Human Impacts

Populations in the region are expected to experience further repercussions from the climatic risk factors outlined above. The human impacts of climate change will be determined by the socioeconomic context in which they occur. The following sections outline some of these expected implications, drawing attention to how particular groups in society, such as the poor, are the most vulnerable to the threats posed by climate change.

Risks to Energy Supply

Sufficient energy supply is a major precondition for development, and electricity shortages remain a major bottleneck for economic growth in South Asian countries (ADB 2012). A lack of energy, and poor infrastructure in general, deter private investment and limit economic growth (Naswa and Garg 2011). Only 62 percent of the South Asian population (including Afghanistan) has access to electricity, including 62 percent in Pakistan, 66 percent in India, 41 percent in Bangladesh, 43 percent in Nepal, and 77 percent in Sri Lanka; no data are available for Bhutan and the Maldives (2009 data; World Bank 2013e). This indicates that there is still a major gap in electricity supply to households—especially in rural areas.

As Table 5.4 shows, the two main sources of electricity in the region are hydroelectric and thermoelectric power plants. Both sources are expected to be affected by climate change.

The high proportion of electricity generation in South Asia that requires a water supply points to the potential vulnerability of the region's electricity sector to changes in river flow and in water temperature. Hydroelectricity is dependant only on river runoff (Ebinger and Vergara 2011). Thermoelectricity, on the other hand, is influenced by both river runoff and, more generally, the availability and temperature of water resources (Van Vliet et al. 2012).

Hydroelectricity

India is currently planning large investments in hydropower to close its energy gap and to provide the energy required for its targeted 8–9 percent economic growth rate (Planning Commission, 2012a). This is in spite of the potential negative impacts on local communities and river ecosystems (Sadoff and Muller 2009). The major as yet unexploited hydropower potential lies in the Northeast and Himalayan regions. As it is estimated that so far only 32 percent of India's hydropower potential, estimated at 149 GW, is being utilized, India is planning to harness the estimated additional capacity of 98,863 MW in the future (Planning Commission 2012a). Substantial undeveloped potential for hydropower also exists in other South Asian countries (Sadoff and Muller 2009). Nepal, for example, utilizes only approximately 0.75 percent of its estimated hydropower potential (Shrestha and Aryal 2010).

With the projected increasing variability of and long-term decreases in river flow associated with climate change, electricity generation via hydropower systems will become more difficult to forecast. This uncertainty poses a major challenge for the design and operation of hydropower plants. In Sri Lanka, for example, where a large share of the electricity is generated from hydropower, the multipurpose Mahaweli scheme supplies 29 percent of national power generation and 23 percent of irrigation water. A projected decrease in precipitation in the Central Highlands of Sri Lanka may cause competition for water across different sectors (Eriyagama, Smakhtin, Chandrapala, and Fernando 2010).

[114] Hertel et al. (2010) assume an unchanged economy from 2001. Their low-productivity scenario is associated with a 32 percent food price increase.

Increasing siltation of river systems also poses a risk to hydropower. India, for example, has already recorded many cases of malfunctioning power turbines due to high levels of siltation (Naswa and Garg 2011; Planning Commission 2012b). Yet another climate-induced risk for hydropower systems is physical damage due to landslides, floods, flash floods, glacial lake outbursts, and other climate-related natural disasters (Eriksson et al. 2009; Naswa and Garg 2011; Shrestha and Aryal 2010). Nepal (with 2,323 glacial lakes) and Bhutan (with 3,252 glacial lakes) are particularly vulnerable to glacial lake outbursts. The glacial lake flood from the Dig Tsho in Nepal in 1985, for example, destroyed 14 bridges and caused approximately $1.5 million worth of damage to a small hydropower plant (Ebi, Woodruff, Hildebrand, and Corvalan 2007); it also affected a large area of cultivated land, houses, human inhabitants, and livestock (Shrestha and Aryal 2010).

As resources for rebuilding damaged infrastructure tend to be scarce and carry large opportunity costs, climate change may pose an additional risk and, indeed, a possible deterrent to infrastructure development in developing countries (Naswa and Garg 2011).

Thermal Power Generation

The primary source of vulnerability to a thermal power plant from climate change is potential impacts on its cooling system as the full efficiency of a plant depends on a constant supply of fresh water at low temperatures (I. Khan, Chowdhury, Alam, Alam, and Afrin 2012). Decreases in low flow and increases in temperature are the major risk factors to electricity generation (Mcdermott and Nilsen 2011). Heat waves and droughts may decrease the cooling capacity of power plants and reduce power generation (I. Khan et al. 2012).

Studies quantifying the impacts of climate change on thermal power generation in South Asia specifically are not available. However, a study by Van Vliet et al. (2012) evaluates these impacts in 2040 and 2080. They examine the effects of changes in river temperatures and in river flows, and find that the capacity of power plants could decrease 6.3–19 percent in Europe and 4.4–16 percent in the United States over the period 2031–60 for temperature ranges of 1.5–2.5°C. Other climate-related stressors may also affect electricity production in South Asia, including salinity intrusion due to sea-level rise, which can disturb the normal functioning of the cooling system; increasing intensity of tropical cyclones, which can disrupt or damage power plants within coastal areas; and river erosion, which can damage electricity generation infrastructures on the banks of rivers (I. Khan et al. 2012).

Health Risks and Mortality

Climate change is also expected to have major health impacts in South Asia, and it is the poor who are expected be affected most severely. The projected health impacts of climate change in South Asia include malnutrition and such related health disorders as child stunting, an increased prevalence of vector-borne and diarrheal diseases, and an increased number of deaths and injuries as a consequence of extreme weather events (Markandya and Chiabai 2009; Pandey 2010).

Childhood Stunting

Climate change is expected to negatively affect food production (see Chapter 5 on "Agricultural Production"), and may therefore have direct implications for malnutrition and undernutrition—increasing the risk of both poor health and rising death rates (Lloyd, Kovats, and Chalabi 2011). The potential impact of climate change on childhood stunting, an indicator measuring undernourishment, is estimated by Lloyd, Kovats, and Chalabi (2011). At present, more than 31 percent of children under the age of five in South Asia are underweight (2011 data based on World Bank 2013n).

Using estimates of changes in calorie availability attributable to climate change, and particularly to its impact on crop production, Lloyd et al. (2011) estimate that climate change may lead to a 62 percent increase in severe childhood stunting and a 29 percent increase in moderate stunting in South Asia by 2050 for a warming of approximately 2°C above pre-industrial levels.[115] As the model is based on the assumption that within-country food distribution remains at baseline levels, it would appear that better distribution could to some extent mitigate the projected increase in childhood stunting.

Diarrheal and Vector-Borne Diseases

Diarrhea is at present a major cause for child mortality in Asia and the Pacific, with 13.1 percent of all deaths under age five in the region caused by diarrhea (2008 data from ESCAP 2011). Pandey (2010) investigates the impact of climate change on the incidence of diarrheal disease in South Asia and finds a declining trend in the incidence of the disease but an increase of 6 percent by 2030 (and an increase of 1.4 percent by 2050) in the relative risk of disease from the baseline, compared to an average increase across the world of 3 percent in 2030 (and 2 percent in 2050) (Pandey 2010).[116] Noteworthy in this context is the finding by Pandey (2010) that, in the absence of climate change, cases of diarrheal disease in South Asia (including Afghanistan) would decrease earlier, as the expected increase in income would allow South Asian countries to invest in their health services.

[115] The estimates are based on the climate models NCAR and CSIRO, which were forced by the A2 SRES emissions scenario (ca. 1.8°C above pre-industrial by 2050 globally). By 2050, the average increases in maximum temperature over land are projected as 1.9°C with the NCAR and 1.2°C with the CSIRO model, compared to a 1950–2000 reference scenario (Lloyd et al. 2011).

[116] This study is based on two GCMs, NCAR, the colder and drier CSIRO model, and the A2 scenarios (global-mean warming about 1.2°C by 2030 and 1.8°C by 2050 above pre-industrial levels). For establishing the baseline incidence of these diseases (for 2010, 2030, and 2050), the author uses WHO projections. Population estimates are based on UN projections, and GDP estimates are based on an average of integrated models.

Climate change is expected to affect the distribution of malaria in the region, causing it to spread into areas at the margins of the current distribution where colder climates had previously limited transmission of the vector-borne disease (Ebi et al. 2007). Pandey (2010) finds that the relative risk of malaria in South Asia is projected to increase by 5 percent in 2030 (174,000 additional incidents) and 4.3 percent in 2050 (116,000 additional incidents) in the wetter scenario (NCAR). The drier scenario (CSIRO) does not project an increase in risk; this may be because calculations of the relative risk of malaria consider the geographical distribution and not the extended duration of the malarial transmission season (Pandey 2010). As in the case of diarrheal disease, malaria cases are projected to significantly decrease in the absence of climate change (from 4 million cases in 2030 to 3 million cases in 2050).

Salinity intrusion into freshwater resources adds another health risk. About 20 million people in the coastal areas of Bangladesh are already affected by salinity in their drinking water. With rising sea levels and more intense cyclones and storm surges, the contamination of groundwater and surface water is expected to intensify. Contamination of drinking water by saltwater intrusion may cause an increasing number of cases of diarrhea. Cholera outbreaks may also become more frequent as the bacterium that causes cholera, *vibrio cholerae*, survives longer in saline water (A. E. Khan, Xun, Ahsan, and Vineis 2011; A. E. Khan, Ireson, et al. 2011). Salinity is particularly problematic in the dry season, when salinity in rivers and groundwater is significantly higher due to less rain and higher upstream freshwater withdrawal. It is expected to be further aggravated by climate-change-induced sea-level rise, reduced river flow, and decreased dry season rainfall.

A study conducted in the Dacope sub-district in Bangladesh found that the population in the area consumed 5–16g of sodium per day from drinking water alone in the dry season, which is significantly higher than the 2g of dietary sodium intake per day recommended by WHO and FAO. There is strong evidence that higher salt intake causes high blood pressure. Hypertension in pregnancy, which is found to be 12 percent higher in the dry season compared to the wet season in Dacope, also has adverse effects on maternal and fetal health, including impaired liver function, intrauterine growth retardation, and preterm birth (A. E. Khan, Ireson, et al. 2011).

The Effects of Extreme Weather Events

In South Asia, unusually high temperatures pose health threats associated with high mortality. This is particularly so for rural populations, the elderly, and outdoor workers. The most common responses to high average temperatures and consecutive hot days are thirst, dizziness, fatigue, fainting, nausea, vomiting and headaches. If symptoms are unrecognized and untreated, heat exhaustion can cause heatstroke and, in severe cases, death. In Andhra Pradesh, India, for example, heat waves caused 3,000 deaths in 2003 (Ministry of Environment and Forests 2012). In May 2002, temperatures increased to almost 51°C in Andhra Pradesh, leading to more than 1,000 deaths in a single week. This was the highest one-week death toll due to extreme heat in Indian history. In recent years, the death toll as a consequence of heat waves has also increased continuously in the Indian states of Rajasthan, Gujarat, Bihar, and Punjab (Lal 2011).

In their global review, Hajat and Kosatky (2010) find that increasing population density, lower city gross domestic product, and an increasing proportion of people aged 65 or older were all independently linked to increased rates of heat-related mortality. It is also clear that air pollution, which is a considerable problem in South Asia, interacts with high temperatures and heat waves to increase fatalities.

Most studies of heat-related mortality to date have been conducted for cities in developed countries, with relatively few published on developing country cities and regions (Hajat and Kosatky 2010). Cities such as New Delhi, however, exhibit a significant response to warming above identified heat thresholds. One recent review found a 4-percent increase in heat-related mortality per 1°C above the local heat threshold of 20°C (range of 2.8–5.1 °C) (McMichael et al. 2008).

A study by Takahashi, Honda, and Emori (2007) further found that most South Asian countries are likely to experience a very substantial increase in excess mortality due to heat stress by the 2090s, based on a global mean warming for the 2090s of about 3.3°C above pre-industrial levels under the SRES A1B scenario and an estimated increase in the daily maximum temperature change over South Asia in the range of 2–3°C. A more recent assessment, by Sillmann and Kharin (2012), based on the CMIP5 models, projects an annual average maximum daily temperature increase in the summer months of approximately 4–6°C by 2100 for the RCP 8.5 scenario. The implication may be that the level of increased mortality reported by Takahashi et al. (2007) could occur substantially earlier and at a lower level of global mean warming (i.e., closer to 2°C) than estimated. Takahashi et al. (2007) assume constant population densities. A further risk factor for heat mortality is increasing urban population density.

While methodologies for predicting excess heat mortality are still in their infancy, it is clear that even at present population densities large rates of increase can be expected in India and other parts of South Asia. The projections used in this report indicate a substantial increase in the area of South Asia exposed to extreme heat by as early as the 2020s and 2030s (1.5°C warming above pre-industrial levels), which points to a significantly higher risk of heat-related mortality than in the recent past.

The Effects of Tropical Cyclones

Although only 15 percent of all tropical cyclones affect South Asia, India and Bangladesh alone account for 86 percent of global deaths from cyclones. The high mortality risk is mainly due to high

population density in the region (Intergovernmental Panel on Climate Change 2012). Projected casualties for a 10-year return cyclone in 2050 in Bangladesh are estimated to increase to 4,600 casualties (for comparison, Cyclone Sidr caused 3,406 deaths), with as many as 75,000 people projected to be injured (compared to 55,282 as a result of Cyclone Sidr)(World Bank 2010d).[117]

Besides deaths and injuries, the main health effects of floods and cyclones are expected to result from indirect consequences, including disruptions to both the food supply and to access to safe drinking water. An increased intensity of tropical cyclones could therefore pose major stresses on emergency relief and food aid in affected areas.

Population Movement

Migration, often undertaken as short-term labor migration, is a common coping strategy for people living in disaster-affected or degraded areas (World Bank 2010f). (See Chapter 3 on "Population Movement" for more discussion on the mechanisms driving migration.) There is no consensus estimate of future migration patterns resulting from climate-change-related risks, such as extreme weather events and sea-level rise, and most estimates are highly speculative (Gemenne 2011; World Bank 2010g). Nevertheless, the potential for migration, including permanent relocation, is expected to be heightened by climate change, and particularly by sea-level rise and erosion. Inland migration of households and economic activity has already been observed in Bangladesh, where exposed coastal areas are characterized by lower population growth rates than the rest of the country (World Bank 2010d). A sea-level rise of one meter is expected to affect 13 million people in Bangladesh (World Bank 2010d),[118] although this would not necessarily imply that all people affected would be permanently displaced (Gemenne 2011).

Hugo (2011) points out that migration occurs primarily within national borders and that the main driver of migration is demographic change; environmental changes and other economic and social factors often act as contributing causes. In the specific case of flooding, however, environmental change is the predominant cause of migration. Hugo (2011) identifies South Asia as a hotspot for both population growth and future international migration as a consequence of demographic changes, poverty, and the impacts of climate change.

Conflict

Although there is a lack of research on climate change and conflicts, there is some evidence that climate change and related impacts (e.g., water scarcity and food shortages) may increase the likelihood of conflicts (De Stefano et al. 2012; P. K. Gautam 2012).

A reduction in water availability from rivers, for example, could cause resource-related conflicts and thereby further threaten the water security of South Asia (P. K. Gautam 2012). The Indus and the Ganges-Brahmaputra-Meghna Basins are South Asia's major transboundary river basins, and tensions among the riparian countries over water use do occur.

In the context of declining quality and quantity of water supplies in these countries, increasing demand for water is already causing tensions over water sharing (De Stefano et al. 2012; Uprety and Salman 2011). Water management treaties are considered to be potentially helpful in minimizing the risk of the eruption of such conflicts (Bates et al. 2008; ESCAP 2011). There are bilateral water treaties established for the Indus Basin (although Afghanistan, to which 6 percent of the basin belongs, and China, to which 7 percent of the basin belongs, are not signatories), between India and Bangladesh for the Ganges, and between India and Nepal for the most important tributaries of the Ganges; there are, however, no water treaties for the Brahmaputra (Uprety and Salman 2011).

It has been noted that China is absent as a party to the above-mentioned treaties, though it is an important actor in the management of the basins (De Stefano et al. 2012). Although water-sharing treaties may not avert dissension, they often help to solve disagreements in negotiation processes and to stabilize relations (De Stefano et al. 2012).

Uprety and Salman (2011) indicate that sharing and managing water resources in South Asia have become more complex due to the high vulnerability of the region to climate change. Based on the projections for water and food security presented above, it is likely that the risk of conflicts over water resources may increase with the severity of the impacts.

Conclusion

The key impacts that are expected to affect South Asia are summarized in Table 5.5, which shows how the nature and magnitude of impacts vary across different levels of warming.

Many of the climatic risk factors that pose potential threats to the population of the South Asian region are ultimately related to changes in the hydrological regime; these would affect populations via changes to precipitation patterns and river flow. One of the most immediate areas of impact resulting from changes in the

[117] These projections assume no changes in casualty and injury rates compared to Cyclone Sidr.

[118] The World Bank (2010a) estimation of the number of people affected by a one meter sea-level rise in Bangladesh refers to Huq, Ali, and Rahman (1995), an article published in 1995. More recent projections estimate that between 1.5 million people (Dasgupta, Laplante, Meisner, Wheeler, and Yan 2008), and up to 1.540 million people by 2070 could be affected by a one meter sea-level rise and increased storminess in the coastal cities of Dhaka, Chittagong, and Khulna (Brecht, Dasgupta, Laplante, Murray, and Wheeler 2012). With a different methodology, Hanson et al. (2011) find that approximately 17 million people could be exposed to 0.5 meter sea-level rise. More details on the methodologies can be found in Chapter 4 on "Risks to Coastal Cities."

hydrological regime is agriculture, which is highly dependent on the regularity of monsoonal rainfall. Negative effects on crop yields have already been observed in South Asia in recent decades. Should this trend persist, substantial yield reductions can be expected in the near and midterm.

The region's already large population of poor people is particularly vulnerable to disruptions to agriculture, which could undermine livelihoods dependent on the sector and cause food price shocks. These same populations are likely to be faced with challenges on a number of other fronts, including limited access to safe drinking water and to electricity. The proportion of the population with access to electricity is already limited in the region. Efforts to expand power generation capacity could be affected by climate change via changes in water availability, which would affect both hydropower and thermoelectricity, and temperature patterns, which could put pressure on the cooling systems of thermoelectric power plants.

The risks to health associated with inadequate nutrition or unsafe drinking water are significant: childhood stunting, transmission of water-borne diseases, and hypertension and other disorders associated with excess salinity. Inundation of low-lying coastal areas due to sea-level rise may also affect health via saltwater intrusion. Other health threats are also associated with flooding, heat waves, tropical cyclones, and other extreme events. Population displacement, which already periodically occurs in flood-prone areas, is likely to continue to result from severe flooding and other extreme events.

Bangladesh is potentially a hotspot of impacts as it is projected to be confronted by a combination of increasing challenges from extreme river floods, more intense tropical cyclones, rising sea levels, and extraordinary temperatures.

The cumulative threat posed by the risks associated with climate change, often taking the form of excesses or scarcities of water, would substantially weaken the resilience of poor populations in the region. While the vulnerability of South Asia's large and poor populations can be expected to be reduced in the future by economic development and growth, projections indicate that high levels of vulnerability are likely to persist. Many of the climate change impacts in the region, which appear quite severe with relatively modest warming of 1.5–2°C, pose a significant challenge to development. Major investments in infrastructure, flood defense, and the development of high temperature and drought resistant crop cultivars, and major improvements in sustainability practices (e.g., in relation to groundwater extraction), would be needed to cope with the projected impacts under this level of warming.

Table 5.5: Impacts in South Asia

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C (2030s[1])	Around 2°C (2040s)	Around 3°C (2060s)	Around 4°C and Above (2080s)
Regional Warming		2011 annual mean temperature for India was ninth warmest on record (0.4°C above 1961–90 average). 2009 was the warmest since 1901 at 0.9°C above 1961–90 average[2]		Summer warming peaking at about 1.5°C above the 1951–1980 baseline by 2050.[3] Warm spells[4] lengthen to 20–45 days. Warm nights occur at a 40 percent frequency[5]		Summer temperatures reach about 5°C above the 1951–1980 baseline by 2100.[6] Warm spells lengthen to 150–200 days. Warm nights occur at frequency of 85 percent[7]
Heat Extremes	**Unusual Heat Extremes**	Virtually absent	About 15 percent of land boreal summer months (June, July, August) (JJA)	About 20 percent of land boreal summer months (JJA)	>50 percent of land boreal summer months (JJA)	>70 percent of land boreal summer months (JJA); in the south, almost all (>90 percent) summer months are projected to be unusually hot
	Unprecedented Heat Extremes	Absent	Virtually absent	<5 percent of land boreal summer months (JJA), except for the southernmost tip of India and Sri Lanka with 20–30 percent of summer months experiencing unprecedented heat	About 20 percent of land boreal summer months (JJA)	>40 percent of land boreal summer months (JJA)
Precipitation	**Rainfall**	Decline in South Asian monsoon rainfall since the 1950s but increases in frequency of most extreme precipitation events	Change in rainfall uncertain	Change in rainfall highly uncertain	About 5 percent increase in summer (wet season) rainfall[8]	About 10 percent increase in summer (wet season) rainfall.[9] The region stretching from the northwest coast to the southeast coast of peninsular India is projected to experience the highest percentage (~30 percent) increase in annual mean rainfall. Winter (DJF) precipitation shows a relative decrease in the central India and north India regions
	Variability					Intra-seasonal variability of monsoon rainfall increases by a mean of about 10 percent across a set of 10 CMIP5 models.[10]
	Extremes			Median 20 percent increase of extreme wet day precipitation share of the total annual precipitation[11]		Median 75 percent increase of extreme wet day precipitation share of the total annual precipitation
Drought		Increased frequency short droughts			Increased drought over northwestern India, Pakistan, and Afghanistan[12]	Increased length of dry spells measured by consecutive dry days in eastern India and Bangladesh[13]

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Table 5.5: Impacts in South Asia

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C (2030s[1])	Around 2°C (2040s)	Around 3°C (2060s)	Around 4°C and Above (2080s)
Sea-level Rise (above present)		About 21 cm to 2009[14]	30cm–2040s, 50cm–2070 70cm (60–80) cm by 2080–2100[15]	30cm–2040s, 50cm–2070 70cm (60–80) cm by 2080–2100	30cm–2040s, 50cm–2060 85cm (70–100) cm by 2080–2100	30cm–2040s, 50cm–2060 105 cm (66 percent uncertainty range 85–125 cm) by 2080–2100, higher by 5–10 cm around Maldives, Kolkata, and Dhaka (5 cm lower)
Tropical Cyclone Impacts		Category Four Cyclone Sidr in 2004 exposed 3.45 million Bangladeshis to flooding,[16], causing crop losses equal to about 2 percent of the total annual production[17] and economic damages and total losses of $1.7 billion (2.6 percent of GDP)[18]		An additional[19] 7.8 million people would be affected by flooding higher than 100 cm in Bangladesh as a consequence of a 10-year return cyclone in 2050; 9.7 million people (3.5 million people in the baseline scenario) are projected to be exposed to severe inundation of more than 3m under this scenario. More intense tropical cyclones, combined with sea-level rise, would increase the depth and risk of inundation from floods and storm surges. In Bangladesh, a projected 27cm sea-level rise by 2050, combined with a storm surge induced by an average 10-year return-period cyclone such as Sidr, could inundate an area 88 percent larger than the area inundated by current cyclonic storm surges[20]		
Flooding (combined effects of river flooding, sea-level rise and storm surges)	**Bangladesh**			Mirza (2010) estimates the flooded area could increase by as much as 29 percent for a 2.5°C increase in warming above pre-industrial levels, with the largest change in flood depth and magnitude expected to occur up to 2.5°C of warming.[21] Hanson et al (2011) project that 17 million people might be exposed to 0.5m sea-level rise	At higher levels of warming the rate of increase in the extent of mean flooded area per degree of warming is estimated to be lower[22]	A 100cm sea-level rise is expected to affect 1.5–17 million people,13 million in Bangladesh alone[23] Brecht et al. (2012) estimate that by 2070, approximately 1.5 million people in coastal cities would be affected by coastal floods. Dasgupta et al. (2008) also project 1.5 million people affected by floods

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Table 5.5: Impacts in South Asia

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C (2030s[1])	Around 2°C (2040s)	Around 3°C (2060s)	Around 4°C and Above (2080s)
	Kolkata	Kolkata is ranked among the top ten cities in the world in terms of exposure to flooding.[24]	33 percent of the Kolkata metropolitan area is projected to be exposed to an inundation of more than 0.25m in the event of 100-year return-period rainfall patterns by 2050.[25] In Kolkata City, with its much higher population density, the same scenario is projected to affect 41 percent of the area and 47.4 percent of the population in 2050 (compared to 38.5 percent and 44.9 percent under the baseline scenario)			
	Mumbai	Severe flooding in 2005 caused 500 fatalities and an estimated $1.7 billion in economic damage. Mumbai is the commercial and financial hub of India and generates about 5 percent of India's GDP[26]			By the 2080s, the likelihood of a 2005-like extreme event could more than double, and the return period could be reduced to around 1-in–90 years.[27] Direct economic damages, are estimated to triple compared to the present and increase to up to $1,890 million due to climate change only—without taking population and economic growth into account	

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Table 5.5: Impacts in South Asia

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C (2030s[1])	Around 2°C (2040s)	Around 3°C (2060s)	Around 4°C and Above (2080s)
River Runoff	**Indus**			Mean flow increase of about 65 percent by the 2080s, with low flow increasing by 30 percent and the high flow increasing by 78 percent.[28] When reductions in glacial melt are accounted for, very substantial reductions in late spring and summer flow[29] could be likely	Mean flow increase of about 65 percent by the 2080s, with low flow increasing by 30 percent and the high flow increasing by 78 percent.[30] When reductions in glacial melt are accounted for, very substantial reductions in late spring and summer flow[31] could be likely	
	Ganges			20 percent increase in runoff.[32] Mean flow of the Ganges-Brahmaputra increases by only 4 percent, whereas low flow decreases by 13 percent and high flow by 5 percent[33]	20 percent increase in runoff [32]	50 percent increase in runoff[34]
	Brahmaputra			Very substantial reductions in late spring and summer flow.[29] Mean flow of the Ganges-Brahmaputra increases by only 4 percent, whereas the low flow decreases by 13 percent and high flow by 5 percent[35]		May experience extreme low flow conditions less frequently in the future. Significant increase in peak flow is projected[36]
Water Availability	**Overall**	In India, gross per capita water availability (including utilizable surface water and replenishable groundwater) is projected to decline from around 1,820m³ per year in 2001 to about 1,140m³ per year in 2050 due to population growth alone[37]		Food water requirements in India are projected to exceed green water availability by more than 150 percent, indicating the country would be highly dependent on blue water (irrigation water) agriculture production. By 2050, water availability in Pakistan and Nepal is projected to be too low for self-sufficiency in food production.[38] Without adequate water storage facilities, the increase of peak monsoon river flow would not be usable for agricultural productivity; increased peak flow may also cause damage to farmland due to river flooding[39]	It is very likely that per capita water availability in South Asia will decrease by more than 10 percent[40]	

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Table 5.5: Impacts in South Asia

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C (2030s[1])	Around 2°C (2040s)	Around 3°C (2060s)	Around 4°C and Above (2080s)
	Groundwater Recharge	Groundwater resources already under stress[41]	Climate change is projected to further aggravate groundwater stress[42]	Climate change is projected to further aggravate groundwater stress[43]	Climate change is projected to further aggravate groundwater stress[44]	Climate change is projected to further aggravate groundwater stress[45]
Crop Production				Without climate change, overall crop production is projected to increase by about 60 percent. In per capita terms, however, crop production may not quite keep pace with projected population increase. Under climate change, and assuming the CO_2 fertilization effect does not increase above present levels, overall crop production is projected to increase by about 12 percent above 2000 levels, leading to a significant projected decline by about one third in per capita crop production.[46] Reductions in water availability in the Indus, the Ganges, and the Brahmaputra due in part to loss of glacial melt water from the Himalayas, may impact food security. Using a scaling approach, it has been estimated that more than 63 million fewer people can be fed by the river basins due to reduced water availability[47]		

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Table 5.5: Impacts in South Asia

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C (2030s[1])	Around 2°C (2040s)	Around 3°C (2060s)	Around 4°C and Above (2080s)
Yields	**All crops**	Changes in monsoon rainfall over India with less frequent but more intense rainfall in the recent past (1966–2002) have contributed to reduced rice yields,[48] especially in rainfed areas. Droughts were found to have more severe impacts than extreme precipitation events[49]	Review shows that when cases that include CO_2 fertilization are excluded significant yield losses may occur before 2°C warming; if CO_2 fertilization is effective with some adaptation measures, yields remain approximately flat. Data suggests that the effects of adaptation measures and CO_2 fertilization are stronger and may compensate for the adverse effects of climate change under 2°C warming	With increases in warming above about 2°C above pre-industrial levels, crop yields decrease regardless of potentially positive effects. CO_2 fertilization partly compensates for the adverse effects of climate change	With increases in warming above about 2°C above pre-industrial levels, crop yields decrease regardless of potentially positive effects. CO_2 fertilization partly compensates for the adverse effects of climate change	With increases in warming above about 2°C above pre-industrial levels, crop yields decrease regardless of potentially positive effects. CO_2 fertilization partly compensates for the adverse effects of climate change
Health- and Poverty-related Issues	**Malnutrition and Childhood Stunting**	Present baseline is 23 percent of children under 5 moderately stunted, and 19 percent severely stunted[48]		Without climate change, reductions in the percentage of moderately stunted children is projected to reduce to 11 percent, of severely stunted to 3 percent, by 2050. With climate change, these percentages increase to 14.6 percent and about 5 percent respectively[50]		
	Malaria		Relative risk of malaria projected to increase by 5 percent in 2030[51]	Relative risk of malaria projected to increase by 5 percent in 2050[52]		
	Diarrheal Disease		Relative risk of diarrheal disease increases by 6 percent by 2030 compared to the 2010 baseline[53]	Relative risk of diarrheal disease increases by 1.4 percent by 2050 compared to the 2010 baseline[54]		
	Heat Waves Vulnerability	New Delhi exhibits a 4 percent increase in heat-related mortality per 1°C above the local heat threshold of 20°C (range of 2.8–5.1 percent/C[55])			Most South Asian countries are likely to experience a very substantial increase in excess mortality due to heat stress by the 2090s[56]	

Notes to Table 5.5

[1] Years indicate the decade during which warming levels are exceeded in a business-as-usual scenario, not in mitigation scenarios limiting warming to these levels, or below, since in that case the year of exceeding would always be 2100, or not at all.
[2] Blunden, J. and D. S. Arndt (2012).
[3] Under RCP2.6. Regional warming is somewhat less strong than that averaged over the total global land area.
[4] Consecutive days beyond the 90th percentile.
[5] Sillmann and Kharin (2013).
[6] Under RCP8.5. This is consistent with the CMIP3 projections (K. K. Kumar et al. 2010) under the SRES-A2 scenario (leading to 4.1°C above pre-industrial levels), with local temperature increases exceeding 4°C for Northern India.
[7] Sillmann and Kharin (2013).
[8] The latest generation of models (CMIP5) projects an overall increase of approximately 2.3 percent per degree warming for summer monsoon rainfall (Menon et al., 2013)
[9] Menon et al. (2013); Jourdain, Gupta, Taschetto, et al., (2013).
[10] Mean for RCP 8.5 of 10 models that best simulate the monsoon system (Menon et al. 2013).
[11] Sillmann and Kharin (2013).
[12] Dai (2012).
[13] Sillmann and Kharin (2013).
[14] Above 1880 estimated global mean sea level.
[15] For a scenario in which warming peaks above 1.5°C around the 2050s and drops below 1.5°C by 2100. Due to the slow response of oceans and ice sheets, the sea-level response is similar to a 2°C scenario during the 21st century; it deviates from it after 2100.
[16] World Bank (2010a).
[17] FAO (2013).
[18] Wassmann et al. (2009); World Bank (2010a).
[19] In comparison to the no-climate change baseline scenario.
[20] World Bank (2010a). Based on the assumption that landfall occurs during high tide and that wind speed increases by 10 percent compared to Cyclone Sidr.
[21] Mirza (2010).
[22] Mirza (2010).
[23] World Bank (2010b) estimation of 13 million people in Bangladesh affected by 100cm SLR in Bangladesh refers to Huq, Ali, and Rahman (1995), an article published in 1995.
[24] Intergovernmental Panel on Climate Change (2012); UN-HABITAT (2010); World Bank (2011b). Roughly a third of the total population of the metropolitan area of 15.5 million (2010 data; UN-HABITAT 2010) live in slums, which significantly increases the vulnerability of the population to these risk factors.
[25] World Bank (2011b) uses A1F1 scenario for this study, corresponding to a 2.2°C warming by 2050 and 27cm SLR by 2050. Urban flooding as a consequence of climate-change-induced increases in extreme precipitation, sea-level rise, and storm surges. Total losses in 2050 are estimated at $6.8 billion, with residential property and other buildings and the health care sector accounting for the largest damages. Due to data constraints, both total damages and the additional losses due to increased flooding as a consequence of climate change should be viewed as lower-bound estimates (World Bank 2011).
[26] Ranger et al. (2011). The flood forced the National Stock Exchange to close, and automated teller machine banking systems throughout large parts of the whole country stopped working; this demonstrated how critical infrastructure can be affected by extreme events in mega-cities (Intergovernmental Panel on Climate Change 2012).
[27] Ranger et al. (2011). Warming of 3°C to 3.5°C above pre-industrial levels. Additional indirect economic costs, such as sectoral inflation, job losses, higher public deficits, and financial constraints slowing down the process of reconstruction, are estimated to increase the total economic costs of a 1-in-100-year event to $2,435 million.
[28] Van Vliet et al. (2013) for warming of 2.3°C and of 3.2°C.
[29] For the 2045–65 period (global mean warming of 2.3°C above pre-industrial levels). Immerzeel, Van Beek, and Bierkens (2010).
[30] Van Vliet et al. (2013) for warming of 2.3°C and of 3.2°C.
[31] For the 2045–65 period (global mean warming of 2.3°C above pre-industrial levels). Immerzeel et al. (2010).
[32] Fung, Lopez, and New (2011). SRES A1B warming of about 2.7°C above pre-industrial levels.
[33] Van Vliet et al. (2013) for warming of 2.3°C and of 3.2°C.
[34] Fung, Lopez, and New (2011). SRES A1B warming of about 4.7°C above pre-industrial levels.
[35] Van Vliet et al. (2013) for warming of 2.3°C and 3.2°C.
[36] Gain, Immerzeel, Sperna Weiland, and Bierkens (2011). SRES A1B and B2.
[37] Bates, Kundzewicz, Wu, and Palutikof (2008); Gupta and Deshpande (2004).
[38] When taking a total availability of water below 1300m^3 per capita per year as a benchmark for water amount required for a balanced diet.
[39] Gornall et al. (2010). Consistent with others projecting overall increased precipitation during the wet season for the 2050s, with significantly higher flows in July, August, and September than in 2000. An increase in overall mean annual soil moisture content is expected for 2050 (compared to 1970–2000), although the soil is also expected to be subject to drought conditions for an increased length of time.
[40] Gerten et al., (2011). For a global warming of approximately 3°C above pre-industrial and the SRES A2 population scenario for 2080
[41] Rodell, Velicogna, and Famiglietti (2009); Döll (2009); Green et al. (2011).
[42] Döll (2009); Green et al. (2011).
[43] Döll (2009); Green et al. (2011).
[44] Döll (2009); Green et al. (2011).
[45] Döll (2009); Green et al. (2011).
[46] Nelson et al. (2010).
[47] Immerzeel, Van Beek, and Bierkens (2010). Scenario with increase of 2–2.5°C compared to pre-industrial levels by the 2050s.
[48] Auffhammer, Ramanathan, and Vincent (2011).
[49] Auffhammer, Ramanathan, and Vincent (2011).
[50] Lloyd et al. (2011). South Asia by 2050 for a warming of approximately 2°C above pre-industrial levels (SRES A2).
[51] Pandey (2010). 174,000 additional incidents, SRES A2 for 1.2°C warming.
[52] Pandey (2010). 116,000 additional incidents, 1.8°C increase in SRES A2 scenario.
[53] Pandey (2010). 1.2°C increase in the A2 scenario.
[54] Pandey (2010). 1.8°C increase in the A2 scenario.
[55] McMichael et al. (2008).
[56] Takahashi, Honda, and Emori (2007) find this result for global mean warming in the 2090s of about 3.3°C above pre-industrial levels under the SRES A1B scenario, with an estimated increase in the daily maximum temperature change over South Asia in the range of 2 to 3°C.

Chapter 6

Global Projections of Sectoral and Inter-sectoral Impacts and Risks

Climate change may strongly alter the conditions for human and biological systems over the coming decades, as described by the IPCC (2007). Climate effects can amplify each other, greatly increasing exposure and limiting options to respond, making the consistent assessment of parallel multisector impacts particularly important beyond detailed sectoral analyses and sectoral interactions. In recent years the scientific community has made efforts to identify regions, sectors, and systems that may be particularly at risk or exposed to particularly large or prominent climate changes. Often these have been termed "hotspots", although there is no common definition.

This chapter identifies hotspots of coinciding pressures from the agriculture, water, ecosystems, and health (malaria) sectors at different levels of global warming. It does so by synthesizing the findings presented in Piontek et al. (accepted) obtained as part of the ISI-MIP[119] project; that made an initial attempt at defining multisector hotspots or society-relevant sectors simultaneously exposed to risks. It introduces a number of recent attempts to identify different kinds of hotspots to help put the ISI-MIP results into a broader context. These are further complemented by a review of observed vulnerability hotspots to drought and tropical cyclone mortality risk. This review helps gain an appreciation of factors of vulnerability that are not included within the ISI-MIP framework but that are known to pose severe risks in the future under climate change. It also allows the systematic comparison of impacts within a number of sectors for different levels of global warming.

The methodology for multisectoral exposure hotspots for climate projections from ISI-MIP models is first introduced (Chapter 6 on "Multisectoral Exposure Hotspots for Climate Projections from ISI-MIP Models"). Results are then presented for changes to water availability (Chapter 6 on "Water Availability"; based on Schewe, Heinke, Gerten, Haddeland et al.) and biome shifts (Chapter 6 on "Risk of Terrestrial Ecosystem Shifts"; based on Warszawski, Friend, Ostberg, and Frieler n.d.). Furthermore, the ISI-MIP framework allows for a first estimate of cascading interactions between impacts, presented in Chapter 6 on "Crop Production and Sector Interactions" (based on Frieler, Müller, Elliott, Heinke et al. in review). Overlaying impacts across four sectors (agriculture-crop productivity, water resources, ecosystems, and health-malaria) allows for identification of multisectoral hotspots (Chapter 6 on "Regions Vulnerable to Multisector Pressures" based on Piontek et al.), denoting vulnerability to impacts within these sectors. In order to capture vulnerability to further impacts, hotspots of observed tropical cyclone mortality complement the sectoral assessment. Finally, non-linear and cascading impacts are discussed (Chapter 6 on "Non-linear and Cascading Impacts").

Multisectoral Exposure Hotspots for Climate Projections from ISI-MIP Models

The following analysis relies on biophysical climate change impacts and examines the uncertainty across different climate and impact models. It complements previous studies on hotspots based on pure climate indicators, such as temperature and precipitation and their variability, or with single models. The impacts in the

[119] Note that the studies referenced—Warszawski et al., Frieler et al. Schewe et al., —are in review and results may be subject to change.

four sectors taken into account here represent important risk multipliers for human development (UNDP 2007). It is likely that overlapping effects increase risk as well as the challenge presented for adaptation, especially in regions with low adaptive capacity. Furthermore, impact interactions may amplify each impact (see Chapter 6 on "Crop Production and Sector Interactions"), which is not captured in the following analysis.

Hotspots are understood to be areas in which impacts in multiple sectors fall outside their respective historical range—resulting in significant multisectoral pressure at the regional level. Significant pressure in this context means conditions being altered so much that today's extremes become the norm. Figure 6.1 shows the steps for identifying multisectoral hotspots.[120]

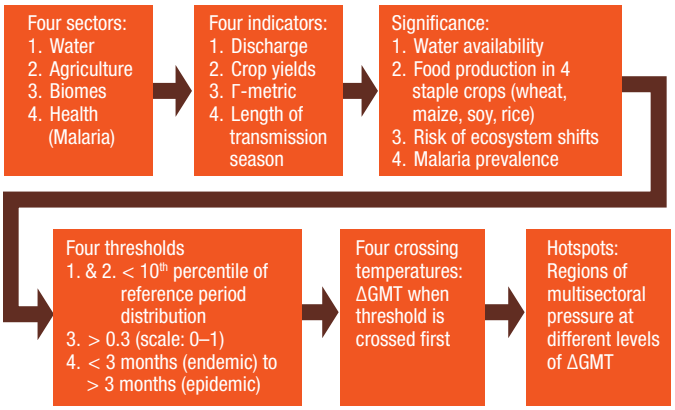
For each sector, a representative indicator with societal relevance is selected, together with a corresponding threshold for significant change, owing to the structural differences between the sectors. The focus is on changes resulting in additional stress for human and biological systems as the basis for analyses of vulnerability, leaving aside any positive effects climate change may have.

Emerging Hotspots in a 4°C World

The overall image that emerges from the hotspots assessments is a world in which no region would be immune to climate impacts in a 4°C world but some regions and people would be affected in a disproportionately greater manner.

While the depicted pattern of vulnerability hotspots often depends on the metric chosen to measure the impact exposure, it is important to remember that the impacts are not projected to increase in isolation from one another. As a result, maps of exposure and vulnerability hotspots (e.g., Figure 6.8) should be understood as complementary to each other—and certainly not exhaustive.

Figure 6.1: The method to derive multisectoral impact hotspots. ΔGMT refers to change in global mean temperature and G refers to the gamma-metric as described in Appendix 3



It is important to note that hotspot mapping based on projections inherit the uncertainty from the climate or impact modeling exercise and are subject to the same limitations as the projections themselves. Thus, in the agricultural sector, sensitivity thresholds of crops are mostly not included, leading to a potentially overly optimistic result. The uncertainty of the CO_2 fertilization effect further obscures any clarity in the global image.

Further research is therefore needed to better understand the consequences of overlapping sectoral and other impacts. Particular attention will need to be drawn to potential interactions between impacts, as well as on including more relevant sectors and tying analyses in with comprehensive vulnerability analyses. While further research can reduce uncertainty, it should be clear that uncertainty will never be eradicated.

Water Availability

Freshwater resources are of critical importance for human livelihoods. For the three regions analyzed in this report, large quantities—between 85–95 percent of the total freshwater withdrawal (World Bank, 2013a)—are required for agriculture, while a lesser share (1–4 percent) is currently required for industrial purposes such as generating hydropower and cooling thermoelectric power plants (Kummu, Ward, De Moel, and Varis, 2010; Wallace 2000). Freshwater availability is a major limiting factor to food production and economic prosperity in many regions of the world (OKI et al. 2001; Rijsberman 2006).

In the framework of ISI-MIP, a set of 11 global hydrological models (GHMs), forced by five global climate models (General Circulation Models [GCMs]), was used to simulate changes in freshwater resources under climate change and population change scenarios. This allows for an estimate of the effects of climate change on water scarcity at a global scale and enables the assessment of the degree of confidence in these estimates based on the spread in results across both hydrological models and climate models.

Whether water is considered to be scarce in a given region is determined by the amount of available water resources and by the population's demand for water. Water demand depends on many factors that may differ from region to region, such as economic structure and land-use patterns, available technology and infrastructure, and lifestyles (Rijsberman 2006). Most importantly, it depends directly on the size of the regional population—more people need more water. Given the current rates of population growth around the world, and the fact that this growth is projected to continue for the better part of the 21st century, water scarcity will increase almost inevitably simply because of population changes (Alcamo, Flörke, and Märker 2007; N. W. Arnell 2004; C.

[120] See Appendix 3 for further information on methodology.

J. Vorosmarty 2000). Thus, when assessing the effect of climate change on water scarcity, one has to realize that climate change does not act on a stationary problem but on a trajectory of rapidly changing boundary conditions.

Water Availability in Food Producing Units

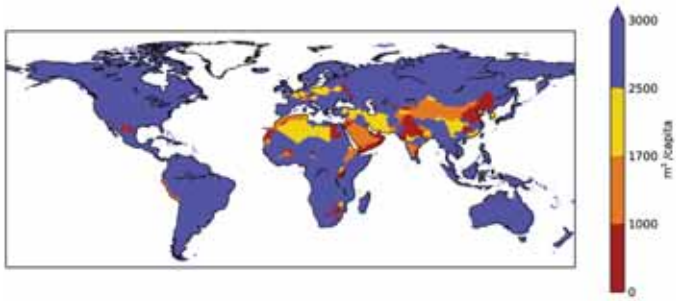
The relative changes in water availability reflect adaptation challenges that may arise in the affected regions. Such challenges will be harder to tackle if a region is affected by water shortages in an absolute sense. A widely used, simplified indicator of water scarcity is the amount of available water resources divided by the population in a given country (or region)—the so-called "water crowding index" (M. Falkenmark et al. 2007; Malin Falkenmark, Lundqvist, and Widstrand 1989). To estimate water resources per country, simply summing up discharge would lead to individual water units being counted multiple times. Using runoff, on the other hand, would not account for flows of water between countries within a river basin. Here, runoff in each basin is redistributed according to the pattern of discharge in the basin (Gerten et al. 2011). The resulting "blue water" resource can then be aggregated over a country or region.

To capture the baseline for future changes, the multi-model median of present-day availability of blue-water resources is shown in Figure 6.2, aggregated at the scale of food-producing units (FPU; intersection of major river basins and geopolitical units). Results given in this section are based on Schewe et al., in review. Importantly, the scale of aggregation influences the resulting water scarcity estimate considerably. For example, if water resources are aggregated at the scale of food productivity units, one FPU within a larger country may fall below a given water scarcity threshold, while another does not. The same country as a whole, on the other hand, may not appear water scarce if a lack of water resources in one part of the country is balanced by abundant resources in another. Thus, global estimates of present-day water scarcity are usually higher when resources are aggregated on smaller scales (for example, FPUs) rather than on a country-wide scale.

It is difficult to determine which scale is more appropriate to assess actual water stress. While FPUs give a more detailed picture and can highlight important differences within larger countries, the country scale takes into account the transport of food (and thus "virtual water") from agricultural areas to population centers within a country, and may be deemed more realistic in many cases. Nonetheless, assessments of water availability should be viewed as approximations.

Results show that corresponding to the regional distribution of changes in water discharge, climate change is projected to diminish per-capita water availability in large parts of North, South, and Central America as well as in the Mediterranean, Middle East, western and southern Africa, and Australia (Figure 6.3, left panel). In a 4°C world, the decreases exceed 50 percent in many FPUs by the end of the century, compared to decreases of 10–20 percent under 2°C warming. The effects of projected population changes are even larger than those of climate change, and the combination of both leaves much of the world threatened by a severe reduction in water availability (Figure 6.3, right panel). Moreover, the spread across the multi-model ensemble is large; thus, more negative outcomes than reflected in the multi-model mean cannot be excluded.

Figure 6.2: Multi-model median of present-day (1980–2010) availability of blue-water resources per capita in food producing units (FPU)



The color scale corresponds to the FAO categories of water scarcity (below 1,000 m³/capita, red), water stress (orange), and water resources vulnerability (yellow).

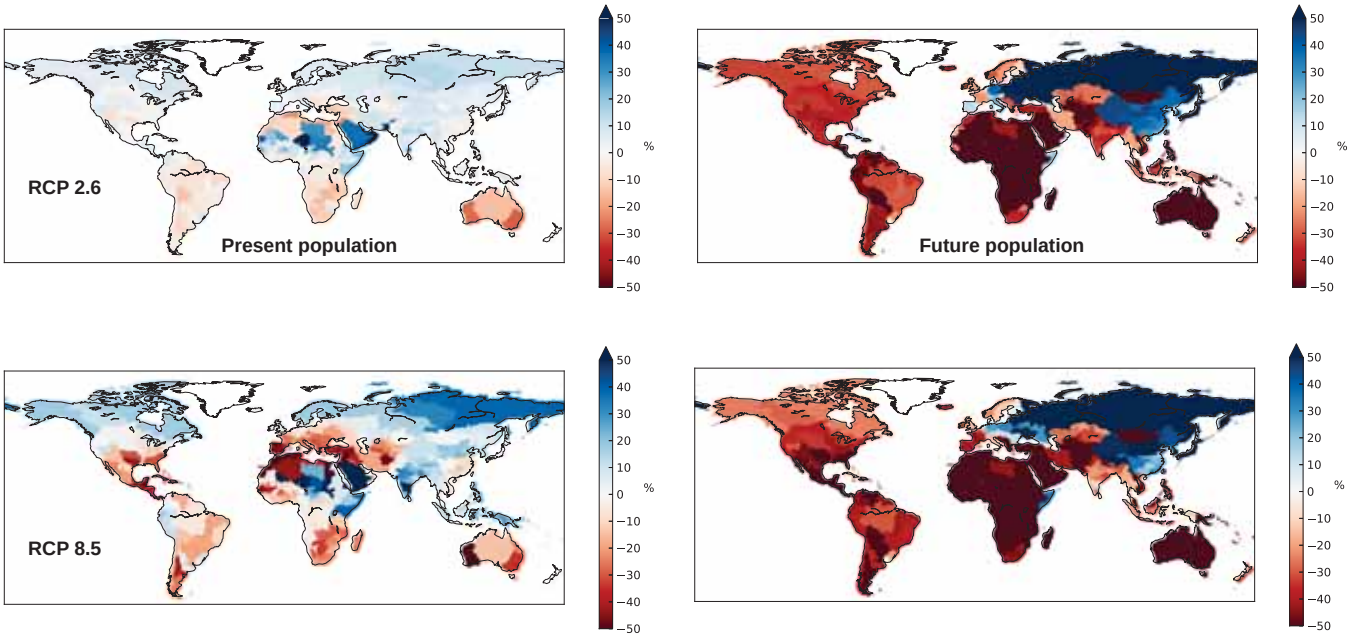
These results illustrate that the effect of climate change on water resources are regionally heterogeneous. Some countries are expected to benefit from more abundant resources even after other countries have become water-scarce because of shrinking resources.

In terms of the regions reviewed in this report, these results broadly show:

- **Sub-Saharan Africa:** In the absence of population increase, increased projected rainfall in East Africa would increase the level of water availability, whereas in much of southern Africa water availability per capita would decrease, with the patterns increasing in strength with high levels of warming. With high levels of warming, West Africa would also show a decrease in water availability per capita. With projected population increase, climate change reduces water resources per capita (compared to the recent 20-year period) over most of Africa in the order of 40–50 percent under both a 1.8°C and a 3.8°C warming scenario by 2069–99.

- **South Asia:** Consistent with the expected increase in precipitation with warming and assuming a constant population, the level of water availability per capita would increase in South Asia. With the projected population increase factored in, however, a large decrease in water availability per capita in the order of 20–30 percent is estimated under a 1.8°C warming by 2069–99. A higher level of warming is projected to further

Figure 6.3: Multi-model median of the relative change in blue-water resources per capita, in 2069–99 relative to 1980–2010, for RCP2.6 (top) and RCP8.5 (bottom)



In the left-hand side panels, population is assumed to remain constant at present-day (year 2000) levels, while in the right-hand side panels it is assumed to change according to the SSP2 population scenario, which projects global population to peak near 10 billion just before the end of the century and includes changes in the regional distribution of population.

increase average precipitation, and the decrease in water availability per capita would be reduced to 10 to 20 percent over much of South Asia.

- **South East Asia:** A very similar broad pattern to that described in South Asia is exhibited in the results shown here. Under a constant population, climate change is expected to increase the average annual water availability per capita. Population growth, however, puts water resources under pressure, decreasing water availability per capita by up to 50 percent by the end of the century.

Review of Climate Model Projections for Water Availability

The ISI-MIP results shown above apply a range of CMIP5 GCMs and a set of hydrology models to produce the model intercomparison and median results (Schewe et al. in review.). Recent work based on the earlier generation of climate models (CMIP3) and one hydrology model[121] shows similar overall results for the three regions (Arnell 2013).

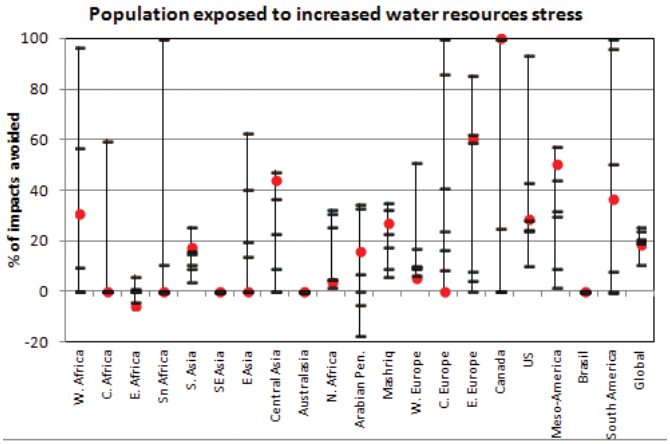
Of interest here are the levels of impacts and different levels of warming. This work examines the change in population exposed to increased water resources stress (using 1,000 m³ of water per capita threshold) between a warming of just above 2°C and scenarios reaching between 4°C and 5.6°C by 2100. In this work, the SRES A1B population scenario was assumed, which has quite different and lower regional population numbers compared to the SSP2 population scenario used in the ISI-MIP analysis.[122]

Figure 6.4 shows the level of impact avoided due to limiting warming to under 2°C compared to a warming of 4–5.6°C by 2100 by indicating the percentage of the population that would be spared the exposure to increased stress on water resources. Compared to many other regions, the level of avoided impact in South Asia is relatively low (in the order of 15–20 percent). South East Asia shows very little, if any, avoided impacts against this metric. Similarly, for East Africa, where increased rainfall is projected, there are very few, if any, avoided impacts. For West Africa, where models diverge substantially, the median of avoided impacts is in the order of 50 percent, with a very wide range. In Southern Africa, where the CMIP5 models seem to agree on a reduction in rainfall, the CMIP3 models show a range from 0–100 percent

[121] HADCM3, HadGEM1, ECHAM5, IPSL_CM4, CCSM3.1 (T47), CGCM3.1 (T63), and CSIRO_MK3.0, and MacPDM hydrology model. Precipitation for the different scenarios was pattern scaled.

[122] In the SRES A1B population scenario, global population peaks at 8.7 billion in 2050 and then decreases to about 7 billion in 2100 (equal to 2010 global population).

Figure 6.4: The percentage of impacts under a 4 to 5.6°C warming avoided by limiting warming to just over 2°C by 2100 for population exposed to increased water stress (water availability below 1000 m³ per capita)



Red dots show impacts avoided under HADCM3 GCM, the range from all seven GCMs shown by seven of the vertical black lines and the horizontal black tick marks indicate the other six models.

Source: N. W. Arnell et al. (2013).

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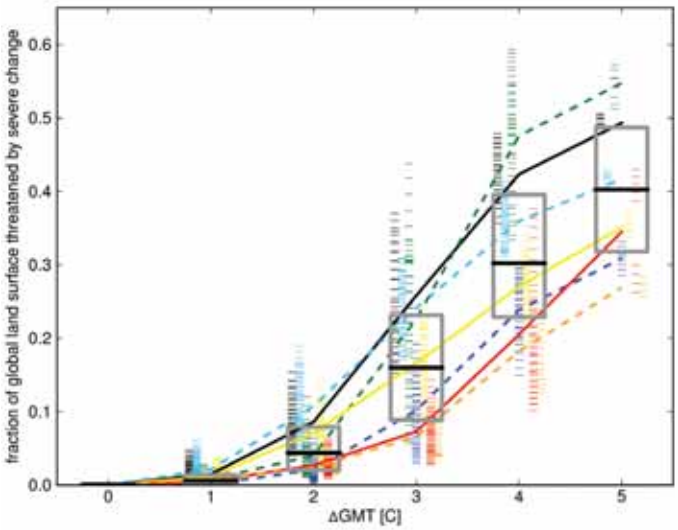
Figure 6.5: Fraction of land surface at risk of severe ecosystem change as a function of global mean temperature change for all ecosystems models, global climate models, and emissions scenarios



The colors represent the different ecosystems models, which are also horizontally separated for clarity. Results are collated in unit-degree bins, where the temperature for a given year is the average over a 30-year window centered on that year. A black horizontal line denotes the median in each bin. The grey boxes span the 25th and 75th percentiles across the entire ensemble. The short, horizontal stripes represent individual (annual) data points; the curves connect the mean value per ecosystem model in each bin. The solid (dashed) curves are for models with (without) dynamic vegetation composition changes. It is important to note that changes are compared to the present baseline.

in avoided impacts. At the global level, limiting warming to 2°C reduces the global population exposed to 20 percent.

Risk of Terrestrial Ecosystem Shifts

Climate change in the 21st century poses a large risk of change to the Earth's ecosystems: Shifting climatic boundaries trigger changes to the biogeochemical functions and structures of ecosystems. Such changing conditions would render it difficult for local plant and animal species to survive in their current habitat.

The extent to which ecosystems will be affected by future climate change depends on relative and absolute changes in the local carbon and water cycles, which partly control the composition of vegetation. Such shifts are likely to imply far-reaching transformations in the underlying system characteristics, such as species composition (Heyder, Schaphoff, Gerten, and Lucht 2011) and relationships among plants, herbivores, and pollinators (Mooney et al. 2009); they are thus essential to understanding what constitutes "dangerous levels of global warming" with respect to ecosystems. Feedback effects can further amplify these changes, both by contributing directly to greenhouse gas emissions (Finzi et al. 2011) and through accelerated shifts in productivity and decomposition resulting from species loss (Hooper et al. 2012).

A unified metric—which aggregates information about changes to the carbon stocks and fluxes, and to the water cycle and vegetation composition across the global land surface—is used to quantify the magnitude and uncertainty in the risk of these ecosystem changes (with respect to 1980–2010 conditions) occurring at different levels of global warming since pre-industrial times. The metric uses changes in vegetation composition as an indicator of risk to underlying plant and consumer communities. Both local (relative) and global (absolute) changes in biogeochemical fluxes and stocks contribute to the metric, as well as changes in the variability of carbon and water fluxes and stocks as an indicator of ecosystem vulnerability. The metric projects a risk of severe change for terrestrial ecosystems when very severe change is experienced in at least one of the metric components, or moderate to severe change in all of them. Marine ecosystems, which are not taken into account here, are further outlined in Chapter 4 on "Coastal and Marine Ecosystems."

[123] Three of the seven models consider dynamic changes to vegetation composition, and all models only consider natural vegetation, ignoring human-induced land-use and land-cover changes. The response of models in terms of the unified metric is shown to be reasonably predicted by changes in global mean temperatures. Note that the ecosystems changes are with respect to 1980–2010 conditions.

The fraction of the global land surface at risk of severe ecosystem change is shown in Figure 6.5 for all seven models as a function of global mean temperature change above pre-industrial levels.[123] Under 2°C warming, 3–7 percent of the Earth's land surface is projected to be at risk of severe ecosystem change, although there is limited agreement among the models on which geographical regions face the highest risk of change. The extent of regions at risk of severe ecosystem change is projected to rise with changes in temperature, reaching a median value of 30 percent of the land surface under 4°C warming and increasing approximately four-fold between 2°C and 3°C. The regions projected to face the highest risk of severe ecosystem changes by 4°C include the tundra and shrub lands of the Tibetan Plateau, the grasslands of eastern India, the boreal forests of northern Canada and Russia, the savannah region in the Horn of Africa, and the Amazon rainforest.

In some regions, projections of ecosystem changes vary greatly across models, with the uncertainty arising mostly from the ecosystem models themselves rather than from differences in the projections of the future climate. Global aggregations, such as reported here, should be treated cautiously, as they can obscure the fact that these arise from significantly different spatial distributions of change. Nonetheless, clear risks of biome shifts emerge when looking at the global picture, which can serve as a backdrop for more detailed assessments.

Review of Climate Model Projections for Terrestrial Ecosystem Shifts

Projections of risk of biome changes in the Amazon by a majority of the ecosystem models in the ISI-MIP study (Warszawski et al. n.d.) arise in most cases because of increases in biomass over this region. This is in agreement with studies considering 22 GCMs from the CMIP3 database with a single ecosystem model (not used in ISI-MIP), which projected biomass increases by 2100 between 14–35 percent over 1980 levels (Huntingford et al. 2013). When considering only projections in the reduction in areal extent of the climatological niche for humid tropical forests, up to 75 percent (climate model mean is 10 percent) of the Amazon is at risk (Zelazowski, Malhi, Huntingford, Sitch, and Fisher 2011). Such discrepancies between ecosystem models and climatological projections are already present in the historical data, in particular with respect to the mechanisms governing tree mortality resulting from drought and extreme heat. For example, observations in the Amazon forest link severe drought to extensive increases in tree mortality and subsequent biomass loss (C. D. Allen et al. 2010). Even in regions not normally considered to be water limited, observed increases in tree mortality suggest a link to global temperature rises because of climate change (Allen et al. 2010; Van Mantgem et al. 2009).

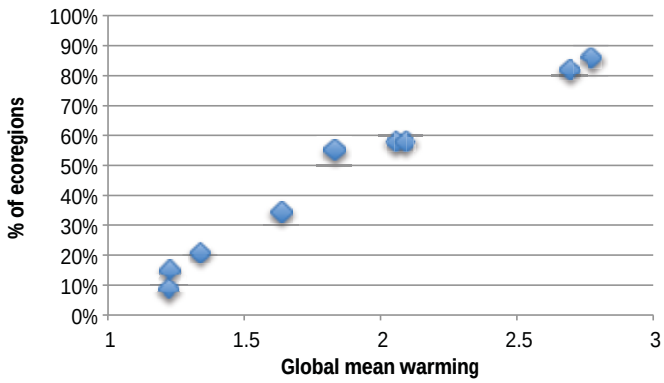
More generally, the recent emergence of a pattern of drought and heat-induced tree mortality, together with high fire occurrence and reduced resistance to pests globally points to a risk that is not presently included in ecosystem models. These observations point to potential for more rapid ecosystem changes than presently projected in many regions (C. D. Allen et al. 2010). The loss and or transformation of ecosystems would affect the services that they provide to society, including provisioning (food and timber) and such support services as soil and nutrient cycling, regulation of water and atmospheric properties, and cultural values (Anderegg, Kane, and Anderegg 2012).

The projected rate of ecosystem change is large in many cases compared to the ability of species and systems to migrate (Loarie et al. 2009). One measure of this, which has been termed the "velocity of climate change," represents the local horizontal velocity of an ecosystem across the Earth´s surface needed to maintain constant conditions suitable for that ecosystem. For the tropical and subtropical grasslands, savannahs, and shrub lands which are characteristic of much of Sub-Saharan Africa (see also Chapter 3 on "Projected Ecosystem Changes"), an average velocity of 0.7 km per year is projected under approximately 3.6°C warming by 2100. For the tropical and subtropical broadleaved forest ecosystems characteristic of much of South and South East Asia, the average velocity is about 0.3 km per year, but with a wide range (Loarie et al. 2009). Under this level of warming, the global mean velocity of all ecosystems is about 0.4 km per year; whereas for a lower level of warming of approximately 2.6°C by 2100, this rate of change is reduced to about 0.3 km per year. As horizontal changes are measured, relatively slow velocity is measured in mountainous regions in contrast to flatter areas. For some species, however, such shifts may not be possible, putting them at risk of extinction (La Sorte and Jetz 2010).

Under future warming, regions are expected to be subject to extreme or unprecedented heat extremes (see also Chapter 2 on "Projected Changes in Heat Extremes"). (Beaumont et al. (2011) measure the extent to which eco-regions, which have been classified as exceptional in terms of biodiversity, are expected to be exposed to extreme temperatures. They find that, by 2100, 86 percent of terrestrial and 83 percent of freshwater eco-regions are projected to experience extreme temperatures on a regular basis, to which they are not adapted (see Figure 6.6).

In conclusion, the state-of-the-art models of global ecosystems project an increasing risk of severe terrestrial ecosystem change with increasing global mean temperature. The area affected increases rapidly with warming. The affected surface increases almost four-fold between warming levels of 2°C and 3°C. The most extensively affected regions lie in the northern latitudes, where current climate conditions would find no analogue in a warmer world. These changes, resulting in shifts in the variability and mean values of carbon and water stock and fluxes and, in some cases, vegetation composition, would pose a major challenge to the survival of plant and animal species in their current habitat.

Figure 6.6: The proportion of eco-regions projected to regularly experience monthly climatic conditions that were considered extreme in the period 1961–90



Source: based on (Beaumont et al. 2011)

Crop Production and Sector Interactions

Population increases and diet changes because of economic development are expected to impose large pressures on the world's food production system. Meeting future demand for food requires substantially improving yields globally as well as coping with pressures from climate change, including changes in water availability.

There are many uncertainties in projecting both future crop yields and total production. One of the important unresolved issues is the CO_2 fertilization effect on crops. As atmospheric CO_2 concentrations rise, the CO_2 fertilization effect may increase the rate of photosynthesis and water use efficiency of plants, thereby producing increases in grain mass and number; this may offset to some extent the negative impacts of climate change (see Laux et al. 2010 and Liu et al. 2008). Projections of crop yield and total crop production vary quite significantly depending on whether the potential CO_2 fertilization effect is accounted for. As is shown in the work of Müller, Bondeau, Popp, and Waha (2010), the sign of crop yield changes (that is, whether they are positive or negative) with climate change may be determined by the presence or absence of the CO_2 fertilization effect. Their work estimates the effects of climate change with and without CO_2 fertilization on major crops (wheat, rice, maize, millet, field pea, sugar beet, sweet potato, soybean, groundnut, sunflower, and rapeseed) in different regions.[124]

Uncertainty surrounding the CO_2 fertilization effect remains, however, meaning that the extent to which the CO_2 fertilization effect could counteract potential crop yield reductions associated with climatic impacts is uncertain. This is problematic for risk assessments in the agricultural sector. When compared with the results from the free-air CO_2 enrichment (FACE) experiments, the fertilization effects used in various models appear to be overestimated (e.g., P. Krishnan, Swain, Chandra Bhaskar, Nayak, and Dash 2007; Long et al. 2005). Further, the C4 crops, including maize, sorghum, and pearl millet—among the dominant crops in Africa—are not as sensitive to elevated carbon dioxide as the C3 crops.[125] Consequently, the benefits for many of the staple crops of Sub-Saharan Africa are not expected to be as positive (Roudier et al. 2011). A recent review of the experimental evidence for CO_2 fertilization indicates that there may be a tendency in crop models to overestimate the benefits for C4 crops, which appear more likely to benefit in times of drought (Leakey 2009).

Although, in CO_2 fertilization experiments, the grain mass, or grain number of C3 crops generally increases, the protein concentration of grains decreases, particularly in wheat, barley, rice, and potatoes (e.g., Taub, Miller, & Allen, 2008). In other words, under sustained CO_2 fertilization the nutritional value of grain per unit of mass decreases. A recent statistical meta-analysis (Pleijel and Uddling 2012) of 57 CO_2 fertilization experiments on wheat shows that if other limiting factors prevent CO_2 fertilization from enhancing grain mass, or number, the diluting effect of enhanced CO_2 on protein content still operates, hence effectively decreasing the total nutritional value of wheat harvests.

The IPCC AR4 found that in the tropical regions a warming of 1–2 °C locally could have significant negative yield impacts on major cereal crops, whereas in the higher latitudes in temperate regions there could be small positive benefits on rainfed crop yields for a 1–3 °C local warming. Research published since has tended to confirm the picture of a significant negative yield potential in the tropical regions, with observed negative effects of climate change on crops in South Asia (David B. Lobell, Sibley, and Ivan Ortiz-Monasterio 2012), Africa (David B Lobell, Bänziger, Magorokosho, and Vivek 2011; Schlenker and Lobell 2010) and the United States (Schlenker and Roberts 2009) and concerns that yield benefits may not materialize in temperate regions (Asseng, Foster, and Turner 2011). In particular, the effects of high temperature on crop yields have become more evident, as has the understanding that the projected global warming over the 21st century is likely to lead to growing seasonal temperatures exceeding the hottest presently on record. Battisti and Naylor (2009) argue that these factors indicate a significant risk that stress on crops and livestock

[124] For their projections, the authors apply three SRES scenarios (A1B, A2, and B1 leading to a global-mean warming of 2.1 °C, 1.8 °C, and 1.6 °C above pre-industrial levels by 2050) and five GCMs, and compare the period 1996–2005 to 2046–55.

[125] C3 plants include more than 85 percent of plants on Earth (e.g. most trees, wheat, and rice) and respond well to moist conditions and to additional carbon dioxide in the atmosphere. C4 plants (for example, sugarcane) are more efficient in water and energy use and out perform C3 plants in hot and dry conditions. C3 and C4 plants differ in the way they assimilate CO_2 into their system to perform photosynthesis. During the first steps in CO_2 assimilation, C3 plants form a pair of three carbon-atom molecules. C4 plants, on the other hand, initially form four carbon-atom molecules.

production will become global in character, making it extremely challenging to balance growing food demand.

The scope of the potential risk can be seen in the results of a recent projection of global average crop yields for maize, soya bean, and wheat by 2050 (Deryng, Sacks, Barford, and Ramankutty 2011). Including adaptation measures, the range of reductions for maize is –6 to –18 percent, for soya bean is –12 to –26 percent, and for spring wheat is –4 to –10 percent, excluding the CO_2 fertilization effect. Losses are larger when adaptation options are not included.

A recent review of the literature by J. Knox, Hess, Daccache, and Wheeler (2012) indicates significant risks of yield reductions in Africa, with the mean changes being –17 percent for wheat, –5 percent for maize, –15 percent for sorghum, and –10 percent for millet. For South Asia, mean production is –16 percent for maize and –11 percent for sorghum. Knox et al. (2012) find no mean change in the literature for rice. However, analysis by Masutomi, Takahashi, Harasawa, and Matsuoka (2009) points to mean changes in Asia for rice yields of between –5 and –9 percent in the 2050s without CO_2 fertilization and between +0.5 and –1.5 percent with CO_2 fertilization.

To cope with the scale of these challenges (even if they are significantly less than shown here) would require substantial increases in crop productivity and yield potential. The recent trend for crop yields, however, shows a worrying pattern where substantial areas of crop-growing regions exhibit either no improvement, stagnation, or collapses in yield. Ray, Ramankutty, Mueller, West, and Foley (2012) show that 24–39 percent of maize, rice, wheat, and soya growing areas exhibited these problems. The top three global rice producers—China, India, and Indonesia—have substantial areas of cropland that are not exhibiting yield gains. The same applies to wheat in China, India, and the United States. Ray et al. (2012) argue that China and India are now "hotspots of yield stagnation," with more than a third of their major crop-producing regions not experiencing yield improvements.

Within ISI-MIP, climate-change-induced pressure on global wheat, maize, rice, and soy production was analyzed on the basis of simulations by seven global crop models assuming fixed present day irrigation and land-use patterns (Portmann, Siebert, & Döll, 2010). In a first step, runoff projections of 11 hydrological models were integrated to estimate the limits of production increases allowing for extra irrigation but accounting for limited availability of renewable irrigation water. In a second step, illustrative future land-use patterns, provided by the agro-economic land-use model MAgPIE (Lotze-Campen et al., 2008; Schmitz et al., 2012), were used to illustrate the negative side effects of the increase in crop production on natural vegetation and carbon sinks due to land use changes. To this end, simulations by seven global biogeochemical models were integrated. Given this context, the urgency of a multi-model assessment with regard to projections of global crop production is evident and has been addressed by the Agricultural Model Intercomparison and Improvement Project (AgMIP; Rosenzweig et al. 2013), with results that will be forthcoming. Similarly, cross-sectoral assessments are needed, as potential sectoral interactions can be expected.

Potential impact cascades are found that underline the critical importance of cross-sectoral linkages when evaluating climate change impacts and possible adaptation options. The combination of yield projections and biogeochemical and hydrological simulations driven by the same climate projections provides a first understanding of such interactions that need to be taken into account in a comprehensive assessment of impacts at different levels of warming. The impacts, which would not occur in isolation, are likely to amplify one another.

Regions Vulnerable to Multisector Pressures

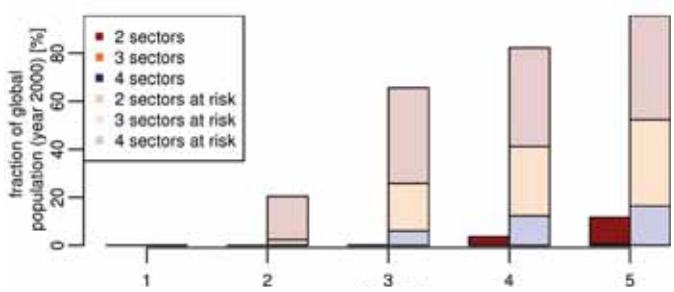
At 4°C above pre-industrial levels, the exposure to multisectoral climate change impacts starts to emerge under the robustness criteria. This means that the sectoral thresholds for severe changes have been crossed at lower levels of global mean temperature. At 5°C above pre-industrial levels, approximately 11 percent of the global population (based on the 2000 population distribution[126]) is projected to be exposed to severe changes in conditions resulting from climate change in at least two sectors (Figure 6.7, bright colored bars).

At the global mean temperature levels in this study, no robust overlap of the four sectors is seen. The fraction of the population affected in the risk analysis is much higher, going up to 80 percent at 4°C above pre-industrial levels, with the effects starting at 2°C (Figure 6.7, light colored bars). There is a clear risk of an overlap of all four sectors.

Multisectoral pressure hotspots are mapped based on pure climate exposure (Figure 6.8, left panel) as well as on a simple measure for vulnerability based on the number of sectors affected and the degree of human development (Figure 6.8, right panel). The grey-colored areas in the left panel are areas at risk. The southern Amazon Basin, southern Europe, eastern Africa, and the north of South Asia are high-exposure hotspots. The Amazon and the East African highlands are particularly notable because of their exposure to three overlapping sectors. Small regions in Central America and western Africa are also affected. The area at risk covers most of the inhabited area, highlighting how common overlapping impacts could be and, therefore, their importance for possible adaptation strategies.

[126] The gridded population distribution for 2000 is based on UNPWWW data (UNDESA 2010), scaled up to match the country totals of the Socio-Economic Pathways database (http://secure.iiasa.ac.at/web-apps/ene/SspDb) using the NASA GPWv3 2010 gridded dataset (http://sedac.ciesin.columbia.edu/data/collection/gpw-v3).

Figure 6.7: Fraction of global population (based on year 2000 population distribution), which is affected by multiple pressures at a given level of GMT change above pre-industrial levels



The bright-colored bars are based on the conservative robust estimates, the light-colored bars on the risk analysis with low likelihood.

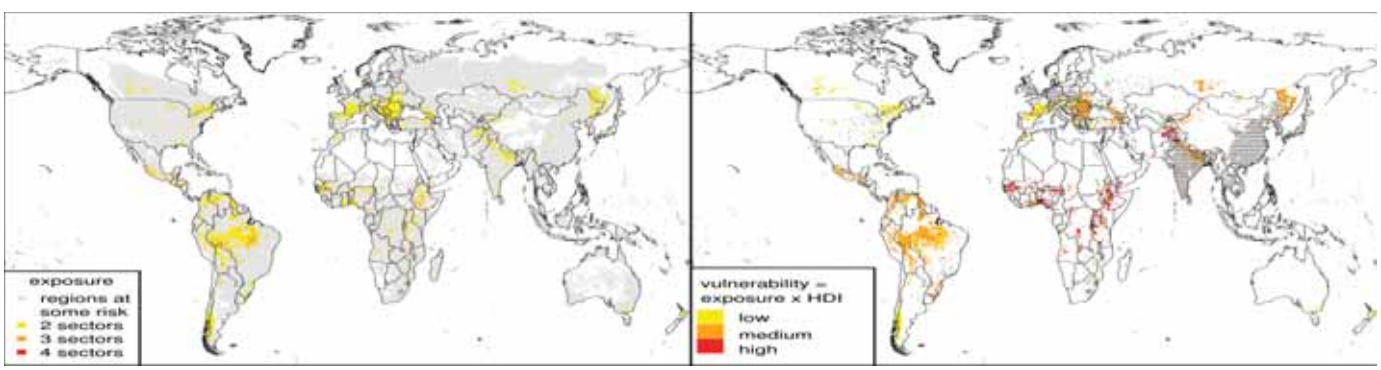
To get a simplified measure for vulnerability, the number of overlapping exposed sectors is combined with the level of human development as provided by the Human Development Index (UNDP 2002), which is a simple proxy for adaptive capacity (Figure 6.8). Based on that vulnerability measure, all regions in Sub-Saharan Africa affected by multisectoral pressures clearly stand out as the most vulnerable areas (Figure 6.8, right panel). Latin America, South Asia, and Eastern Europe are also vulnerable. Weighing it with population density would paint a slightly different picture (hatched regions in the lower panels of Figure 6.8, based on year 2000 population), with large numbers of people potentially affected by multiple pressures in Europe and India. Of note, the vulnerable regions extend over developing, emerging, and developed economic areas.

These results are very conservative. While the thresholds are defined based on historical observations within each sector, the interactions between impacts in each sector are not taken into account. Furthermore, the probability of overlap between the sectors is restricted by the choice of sectors. Agricultural impacts are only taken into account in currently harvested areas and malaria impacts are very limited spatially. Taking into account extreme events would possibly lead to the emergence of a very different hotspot picture. Therefore, what follows is a discussion on the state of knowledge on vulnerability to a subset of extreme events.

Regions with Greater Levels of Aggregate Climate Change

Climate change occurs in many different ways. Increases in mean temperature or changes in annual precipitation as well as seasonal changes, changes in variability, and changes in the frequency of

Figure 6.8: Maps of exposure (left panel) and vulnerability (right panel, defined as the overlap of exposure and human development level as shown in the table) to parallel multisectoral pressures in 2100



Vulnerability = exposure x human development level		Level of human development		
		Low	Medium	High
# of overlapping sectors	2	Medium	Low	Low
	3	High	Medium	Low
	4	High	High	Medium

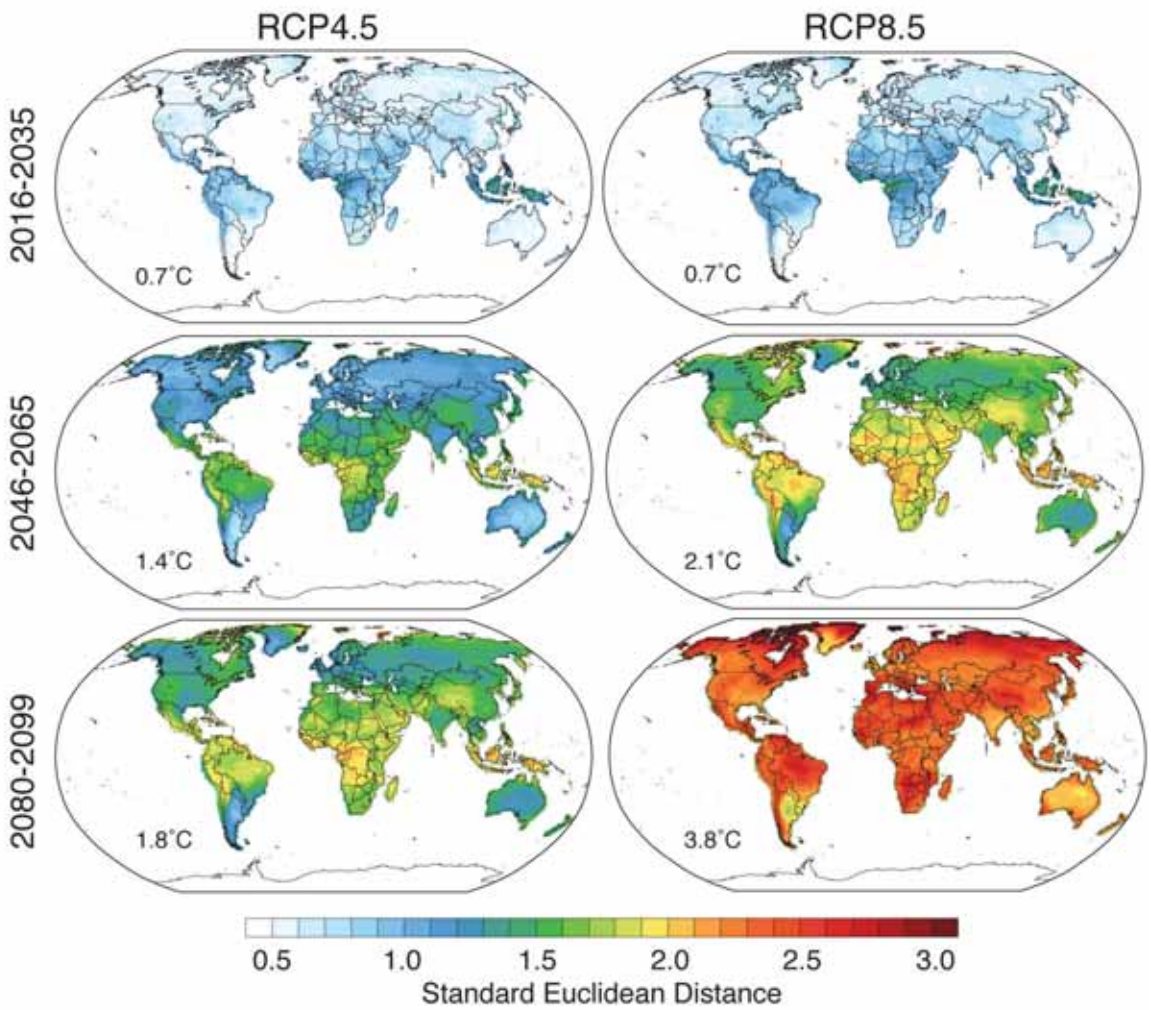
Grey regions in the left panel show areas at risk of multisectoral pressure, if conservative assumptions are relaxed (see Appendix 3 for Method). Vulnerability (right) is a combination of number of sectors affected and level of human development as measured by the year 2000 Human Development Index (UNDP 2002). Hatched regions are regions with very high population density (year 2000), which is expected to act as an additional pressure.

certain kinds of extremes all affect the way in which impacts are expected to unfold and be felt. A region with the largest change in average annual temperature may not be the one with the most overall impact, or the annual average temperature change may not be as significant as other effects, such as seasonal changes. To capture this complexity, Diffenbaugh and Giorgi (2012) used the new CMIP5 global climate models, applying seven climate indicators from each of the four seasons to generate a 28-dimensional measure of climate change.[127]

The picture that emerges is of an increasingly strong change of climatic variables with greater levels of global mean warming. The greater global warming is, the larger the difference between the present climate and the aggregated climate change metric—in other words, the larger the overall effects of climate change (Figure 6.9). This analysis indicates a strong intensification of climate change at levels of warming above 2°C above pre-industrial

[127] Diffenbaugh and Giorgi (2012) considered land grid points north of 60° southern latitude. To calculate the change in each climate indicator, each one is first normalized to the maximum global absolute value in the 2080–99 period for the highest scenario (RCP 8.5), and then the standard Euclidean distance between each of the 28 dimensions and the base period is calculated.

Figure 6.9: Relative level of aggregate climate change between the 1986–2005 base period and three different 20 year periods in the 21st-century



The three different 20 year periods in the 21st-century are the 2020s (1.5°C above pre-industrial levels), 2050s (2.2–2.9°C above pre-industrial levels), and 2090s (2.6–4.6°C above pre-industrial levels) under two different RCP scenarios. To convert the temperatures given in the maps to global mean warming above pre-industrial levels, add 0.8°C.

Source: Diffenbaugh and Giorgi (2012).

Reprinted from Springer, Climatic Change Letters, 114 (3-4), 2012, 813-822, Climate change hotspots in the CMIP5 global climate model ensemble, Diffenbaugh N.S., & Giorgi F., Figure 1, with kind permission from Springer Science and Business Media B.V. Further permission required for reuse.

levels. It is also clear that some regions begin to show strong signs of overall change at lower levels of global mean warming than others. In terms of the regions studied in this report, much of Africa stands out: West Africa, the Sahel, and Southern Africa emerge consistently with relatively high levels of aggregate climate change. South Asia and South East Asia show moderate to high levels of climate change above 1.5°C compared to more northerly and southerly regions.

Vulnerability Hotspots for Wheat and Maize

Fraser et al. (2012) identify hotspots for wheat and maize based on a comparison of regions subject to increasing exposure to yield decreases that are predicted to experience declining adaptive capacity. Where these regions overlap, a hotspot is identified for the time period studied: the 2050s and 2080s. They identify five wheat hotspots (southeastern United States, southeastern South America, northeast Mediterranean region, and parts of central Asia). For maize, three hotspots are found: southeastern South America, parts of southern Africa, and the northeastern Mediterranean. This study uses only one climate model and one hydrology model, limiting the ability to understand the uncertainty of climate model and hydrology model projections in identifying regions at risk. It should be noted that maize is particularly important in Southern Africa.

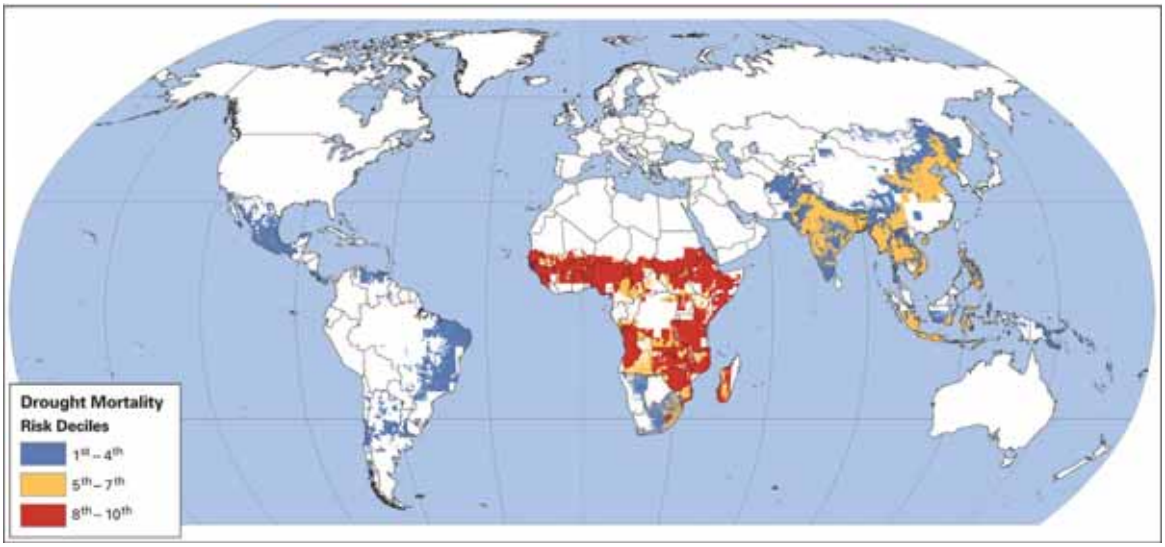
Vulnerability Hotspots for Drought and Tropical Cyclones

Droughts and tropical cyclones have been among the most severe physical risk factors that are projected to increase with climate change, and the severity and distribution of these impacts may change in the future. Looking at impacts from past occurrences illustrates regional vulnerabilities that could be amplified with increasing exposure in the future.

Vulnerability hotspots related to droughts have in the past been highest in Sub-Saharan Africa, with exceptions in southern Africa (Figure 6.10). Much of South Asia and South East Asia also show high levels of vulnerability. It should be noted that the analysis is based only on drought-related mortality. Impacts on agricultural productivity (as have been observed during the Russian drought in 2010 and the American (U.S.) drought in 2012) are not included here.

Taking into account observed vulnerability to tropical cyclones, the East and South East Asian coasts, as well as the eastern North American and Central American coasts, emerge as vulnerability hotspots (Figure 6.11). Madagascar and the densely populated deltaic regions of India and Bangladesh, as well as parts of the Pakistan coast, mark areas of extreme vulnerability. As noted before, the hotspots are based on observed events.

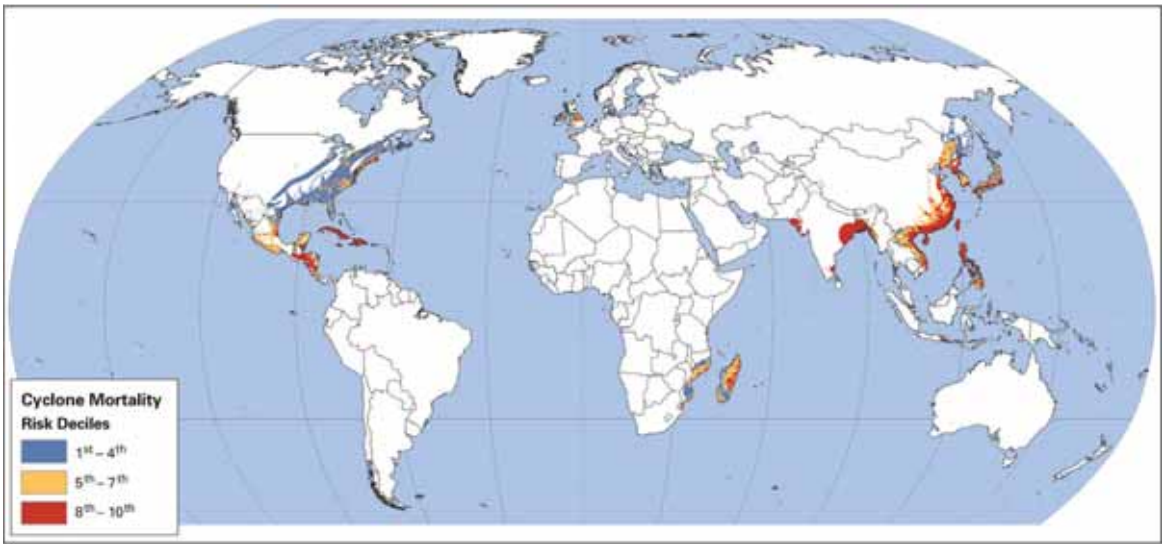
Figure 6.10: Hotspots of drought mortality risk, based on past observations. Regions marked in red (8th–10th deciles) mark the 30 percent of land area that is most severely impacted



Risks are shown for year 2000 population levels (with exposure probabilities average over 1981–2000.) White areas are masked due to low population density or no significant impact observed.

Source: Dilley et al. (2005).

Figure 6.11: Hotspots of cyclone mortality risk, based on past observations. Regions marked in red (8th–10th deciles) mark the 30 percent of land area that is most severely impacted



Risks are shown for year 2000 population levels (with exposure probabilities average over 1981–2000.) White areas are masked due to low population density or no significant impact observed.

Source: Dilley et al. (2005).

Implications for Poverty

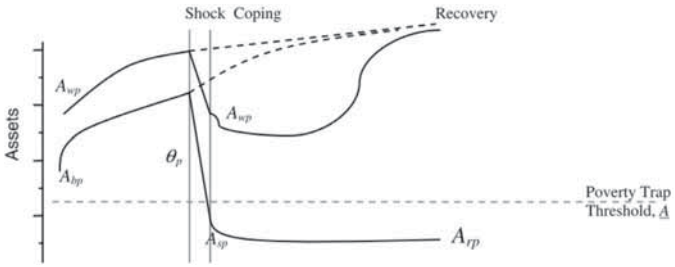
Climate impacts can have negative effects on poverty reduction. While the population´s vulnerability is determined by socioeconomic factors, increased exposure to climate impacts can have adverse consequences for these very factors. It has been observed that natural disasters, such as droughts, floods, or cyclones, have direct and indirect impacts on household poverty—and in some cases could even lead households into poverty traps.

A study assessing the impacts of a three-year long drought in Ethiopia (1998–2000) and category 5 Hurricane Mitch in Honduras found that these shocks have enduring effects on poor households' assets and recovery (Carter, Little, Mogues, and Negatu 2007). The authors observed a critical differential impact of cyclones on poorer households (representing a quartile of the population). Before the occurrence of the disasters, it was assessed that these poor households accumulated assets faster than rich households. As a consequence, this faster accumulation led to a convergent growth path between poorer and richer households. The authors found, however, that both slow and sudden onset disasters slowed down poor households' capacity to accumulate assets.

Figure 6.12 illustrates the impacts of such shocks as cyclones and droughts on the assets of two categories of households (rich and poor). This simplified model only illustrates how climate-induced shocks could drive households into poverty traps.

Because of the consequences of the shocks, assets at the household level significantly decrease; they later increase during the recovery period. For the poorer households, the decrease in assets has the potential to lead them below the poverty trap threshold, preventing households from recovering from the disaster. This figure only gives a schematic representation, however, of the potential impacts of natural disasters on rich and poor households.

Figure 6.12: Asset shocks and poverty traps



Awp represents the assets owned by the rich household; Abp, Asp, and Arp represent the assets owned by the poor households, before the shock (Abp), after the shock (Asp), and after the recovery period (Arp).

Source: Carter et al. (2007).

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Hallegatte and Przyluski (2010) find that these poverty traps at the household level induced by natural disasters could lead to poverty traps at the macroeconomic level. Poor countries' limited capacity to rebuild after disasters, long reconstruction periods, the relatively large economic costs of natural disasters, reduced accumulation of capital and infrastructure, and reduced economic development contribute to amplifying the consequences of these natural disasters. From a long-term perspective, this loop reduces the capacity of a country to cope with the consequences of a disaster. Furthermore, this feedback loop reduces the capacity of developing countries to benefit from natural disasters through the accelerated replacement of capital (Hallegatte and Dumas 2009) after the occurrence of disaster as the damages from the disaster exceed their capacity for reconstruction.

Non-linear and Cascading Impacts

In this report the risks of climate change for a number of major sectors were examined within three regions at different levels of global mean warming. While the attempt was made to draw connections between sectors, the literature does not yet permit a comprehensive assessment of the quantitative magnitude of these risks to elucidate risks of multiple and/or cascading impacts which occur on a similar timescale in the same geographical locations. Nevertheless, one of the first studies of these risks indicates that the proportion of the global population at risk from simultaneous, multiple sectoral impacts increases rapidly with warming. By the time warming reaches 4°C, more than 80 percent of the global population is projected to be exposed to these kinds of risks (see Chapter 6 on "Regions Vulnerable to Multisector Pressures"). While adaptation measures may reduce some of these risks and/or impacts, it is also clear that adaptation measures required would need to be substantial, aggressive and beyond the scale of anything presently contemplated, and occur simultaneously across multiple sectors to significantly limit these damages.

There is also limited literature on non-linear effects and risks. Potential tipping points and non-linearities due to the interactions of impacts are mostly not yet included in available literature. The tentative assessment presented here indicates the risk of such interactions playing out in the focus regions of this report and suggests a need for further research in this field.

In some cases of non-linear behavior observed in certain sectors, such as high-temperature thresholds for crop production, response options are not readily available. For example crop cultivars do not presently exist for the high temperatures projected at this level of warming in current crop growing regions in the tropics and mid-latitudes.

To point the way to future work assessing the full range of risks, it is useful to conclude this report with a brief set of examples that illustrate the risk of non-linear and cascading impacts occurring around the world. The physical mechanisms and thresholds associated with these risks are uncertain, but have been clearly identified in the scientific literature.

Non-Linear Responses of the Earth System

- **Sea-level rise.** In this report the focus has been on sea-level rise of up to a meter in the 21st-century. This excluded an assessment of faster rates, and of longer term, multi-meter sea-level rise increases and what this might mean for the regions studied. Disintegration of the West Antarctic ice sheet could raise sea levels by 4–5 m over a number of centuries, and there is already evidence that the ice sheet is responding rapidly to a warming ocean and climate. Complete loss of the Greenland ice sheet over many centuries to millennia would raise sea levels by 6–7 m. A recent analysis estimates the warming threshold for the Greenland Ice Sheet to irreversibly lose mass at 1.6°C global-mean temperature increase above pre-industrial levels (range of 0.8°C – 3.2°C). Already the damages projected for a 0.5 metre and 1 metre sea level rise in the three regions are very substantial and very few studies have examined the consequences of two, three or 5 m sea-level rise over several centuries. Those that are based on such assessments, however, show dramatic problems. In this report Bangladesh was identified as a region facing multiple simultaneous impacts for large vulnerable populations, due to the combined effects of river floods, storm surges, extreme heat and sea-level rises of up to a meter. Multi-meter sea level rise would compound these risks and could pose an existential risk to the country in coming centuries.
- **Coral reefs.** Recent studies suggest that with CO_2 concentrations corresponding to 2°C warming, the conditions that allow coral reefs to flourish will cease to exist. This indicates a risk of an abrupt transition, within a few decades, from rich coral reef ecosystems to much simpler, less productive and less diverse systems. These changes would lead to major threats to human livelihoods and economic activities dependent upon these rich marine ecosystems, in turn leading to the feedbacks in social systems exacerbating risks and pressures in urban areas.
- **Ecosystems in Sub-Saharan Africa.** The complex interplay of plant species in the African savannas and their different sensitivities to fire regimes and changes in atmospheric CO_2 concentrations implies a potential tipping point from a C4 (grass) to a C3 (woody plants) dominated state at the local scale. Such a transition to a much less productive state, exacerbated by already substantial pressures on natural systems in Africa, would place enormous, negative pressure on many species and threaten human livelihoods in the region.
- **The Indian monsoon.** Physically plausible mechanisms have been proposed for a switch in the Indian monsoon, and changes

in the tropical atmosphere that could precipitate a transition of the monsoon to a drier state are projected in the present generation of climate models. An abrupt change in the monsoon, towards a drier, lower rainfall state, could precipitate a major crisis in South Asia, as evidenced by the anomalous monsoon of 2002, which caused the most serious drought in recent times, with rainfall about 19 percent below the long term normal, and food grain production reductions of about 10–15 percent compared to the average of the preceding decade.

Non-linearity due to Threshold Behavior and Interactions

- **Crop yields.** Non-linear reductions in crop yields have been observed once high temperature thresholds are crossed for many major crops including rice, wheat and maize in many regions. Within the three regions studied temperatures already approach upper limits in important food growing regions. Present crop models have not yet fully integrated the consequences of these responses into projections, nor are high-temperature, drought resistant crop cultivars available at present. When these regional risks are put into the context of probable global crop production risks due to high temperatures and drought, it is clear that qualitatively new risks to regional and global food security may be faced in the future that are little understood, or quantified.
- **Aquaculture in South East Asia.** Temperature tolerance thresholds have been identified for important aquaculture species farmed in South East Asia. More frequent temperatures above the tolerance range would create non-optimum culture conditions for these species and are expected to decrease aquaculture yields. Such damages are expected to be contemporaneous in time with saltwater intrusion losses and inundation of important rice growing regions in, for example Vietnam, as well as loss of marine natural resources (Coral reefs and pelagic fisheries) upon which people depend for food, livelihoods and tourism income.
- **Livestock production in Sub-Saharan Africa,** particularly in the case of small-scale livestock keeping in dryland areas, is under pressure from multiple stressors. Heat and water stress, reduced quantity and quality of forage and increasing prevalence of diseases have direct impacts on livestock. Changes in the natural environment due to processes of desertification and woody plant encroachment may further limit the carrying capacity of the land. Traditional responses are narrowed where diversification to crop farming may no longer be viable and mobility to seek out water and forage is restricted by institutional factors. These stress factors compound one another, placing a significantly greater pressure on affected farmers than if impacts were felt in isolation.

Cascading Impacts

A framing question for this report was the consequence for development of climate change. What emerges from the analyses conducted here and the reviewed literature is a wide range of

Box 6.1: Emerging Vulnerability Clusters: the Urban Poor

The picture that emerges from the three regional analyses is of new clusters of vulnerability appearing in urban areas as urbanization rates increase. Although the urbanization trend is driven by a host of factors, climate change is becoming an increasingly significant driver as it places livelihoods in rural areas under mounting pressure.

However, there are risks associated with the observed and projected urbanization trends. The location of many cities in coastal areas further means that a large and growing number of people are exposed to the impacts of sea-level rise. Similarly, health impacts of heat waves are reportedly high in cities, where the built environment amplifies the warming effect.

Many impacts are expected to disproportionately affect the urban poor. The concentration of large populations in informal settlements, where basic services and infrastructure tend to be lacking, is a considerable source of vulnerability. In such areas, people are highly exposed to extreme weather events, such as storms and flooding. Furthermore, informal settlements often provide conditions particularly conducive to the transmission of the vector and water borne diseases that are projected to become more prevalent with climate change. The urban poor, as net buyers of food, have also been identified as the group most vulnerable to increases of food prices following production shocks and declines.

There are multiple co-benefits to be gained from urban planning which takes into account the risks projected to accompany climate change. Urban areas account for the largest proportions of global greenhouse gas emissions (UN Habitat, 2011) and hence a great potential exists in these areas for mitigation of climate change. Similarly, careful urban planning can strongly increase human resilience to the impacts of climate change. Efficient provision of basic services, which is central to meeting human development needs in urban areas, will assist large communities to cope with the adverse effects associated with rising atmospheric CO_2 concentrations.

Thus, while cities currently often concentrate vulnerability, future patterns of urbanization provide the opportunity to significantly increase the resilience of urban populations.

risks. One cluster of impacts that needs to be highlighted is the risk of negative feedbacks on poverty from climate shocks on poor countries, leading to the potential for climate driven poverty traps migration (see Box 6.1). Recent observational evidence indicates that the poor countries that are most vulnerable to increases in temperature show the least resilience to shocks of extremes. The impacts of a three year long drought in Ethiopia (1998 2000), for example or the Category Five Hurricane Mitch in Honduras have been observed to have long-lasting effects on poverty. These climate-related extreme events and natural disasters can overwhelm a poor country's ability to recover economically, reducing the accumulation of capital and infrastructure, leading to a negative economic feedback. This would reduce the capacity of developing countries to economically benefit from natural disasters through more rapid replacement of capital as the reconstruction capacity is exceeded by the disaster damages.

Increases in climatic extremes of all kinds are projected for the three regions studied: increased tropical cyclone intensity in South East Asia, extreme heat waves and heat intensity in all regions, increased drought in many regions, an increased risk of flooding and consequent damages on agriculture and infrastructure in many regions. Few studies have really integrated these risks into projections of future economic growth and development for these regions.

The analyses presented in this report show that there are substantial risks to human development in the three regions assessed and a consideration of the risks of non-linearity and cascading impacts tends to amplify this picture. Impacts have already begun to occur and in many cases are projected to be severe under 1.5–2°C warming, depending upon the sector and the region. As warming approaches 4°C, very severe impacts are projected, affecting ever larger shares of the global population. Critically the risk of transgressing thresholds and tipping points within sectors and on vital human support systems increases rapidly with higher levels of warming. While limiting warming to 1.5 to 2°C does not eliminate risk and damage to many sectors and regions, it does create breathing space for adaptation measures to limit damage and for populations to learn to cope with the significant, inevitable damage that would occur even at this level of change.

Appendixes

Appendix 1

Background Material on the Likelihood of a 4°C and a 2°C World

4°C - Business-As-Usual Emission Estimates

Recent independent estimates by an international consortium of eight Integrated Assessment Modeling (IAM) research groups investigated how the world can be expected to evolve under a wide variety of climate policies (Kriegler et al. 2013; Riahi et al. 2013; Schaeffer et al. 2013). One of the scenarios investigated is known as the "business-as-usual" (BAU) pathway. In this scenario, which is characterized by a lack of strong climate policies throughout the 21st century, GDP (Kriegler et al. 2013) and population projections (UN 2010) continue to drive energy demand. Global energy intensity roughly follows historical rates of improvements because of the lack of targeted policies. Accordingly, greenhouse gas emissions continue to rise in the estimates of each respective research group and follow an intermediate-to-high BAU path compared to the earlier literature (Nakicenovic and Swart 2000; IPCC 2007a; Rogelj et al. 2011; Riahi et al. 2012).

Recently, questions have been raised in the scientific literature about the validity of the high fossil fuel production outlooks required for such high-emissions BAU scenarios (e.g., Höök et al. 2010). While these critiques, which infer a possible global peak in fossil fuel availability, are not irrelevant, they mainly result from a different interpretation of the availability of fossil fuels from "reserves," "estimated ultimately recoverable resources," and additional "unconventional" resources. The recent Global Energy Assessment (Rogner et al. 2012) provides a discussion of this issue and a detailed assessment of fossil fuel resources. It concludes that enough fossil fuels will be available to satisfy future demand and to continue on a very high emissions pathway (see the GEA-Supply baseline in Riahi et al. 2012). This is in line with the RCP8.5 scenario used in this report (see Box I below), which forms a basis for some of the impacts studies in the rest of this report.

Temperature Changes Implied by Business-As-Usual Emissions Estimates

To compute the global mean temperature increase implied by the business-as-usual scenarios discussed above and in Box A1.1, the authors run a reduced-complexity carbon cycle and climate model in a probabilistic setup, which closely represents the uncertainty assessments of the earth system's response to increasing emissions.

Figure A1.1 below shows global mean temperature projections above pre-industrial levels. In the left panel, the "best-estimate"[128] projections (lines) are put in the context of carbon-cycle and climate-system uncertainties (shaded areas). According to the RCP8.5 scenario, the best-estimate warming is approximately 5.2°C by 2100. There is a 66 percent likelihood[129] that emissions consistent with RCP8.5 lead to a warming of 4.2–6.5°C, and a remaining 33 percent chance that warming would be either lower than 4.2°C or higher than 6.5°C by 2100.

The eight BAU scenarios generated by the international IAM research groups included here are on average slightly lower than RCP8.5, with some scenarios above it. On average,

[128] In this report, the authors speak of "best-estimate" to indicate the median estimate, or projection, within an uncertainty distribution, that is, there is a 50-percent probability that values lie below and an equal 50-percent probability that values lie above the "best-estimate."

[129] A probability of greater than 66 percent is labeled "likely" in IPCC's uncertainty guidelines (Mastrandrea et al. 2010) adopted here.

these scenarios lead to warming projections close to those of RCP8.5 and a medium chance that end-of-century temperature rise exceeds 4°C (see Figure A1.1, right-hand panel). Across all these scenarios, the median projections reach a warming of 4.7°C above pre-industrial levels by 2100.[130] This level is achieved 10 years earlier in RCP8.5.

By contrast, the *CAT reference scenario* (see Box A1.1), used in this report to derive the *CAT Current Pledges* scenario (Climate Analytics et al. 2011), results in warming below the BAU median across the IAM models, with only about 15 percent of climate projections using the IAM results lying below the *CAT Reference BAU*[131] (see Figure A.1, right-hand panel).

Thus, the most recent generation of energy-economic models estimate emissions in the absence of further substantial policy

[130] Note the uncertainty ranges in Figure 2.4: among the various other BAU scenarios, about 30 percent reach a warming higher than RCP8.5 by 2100 (compare light-red shaded with black line).

[131] The lower emissions in the CAT Reference BAU scenario compared to the recent BAU literature scenarios is explained by the fact that the CAT Reference BAU includes more of the effects of currently implemented energy policies than the BAU scenarios from the literature. This also explains why the reduction in future warming is stronger between the multi-model Reference and Current Pledge scenarios than in the CAT cases, since some policies required to achieve current pledges are already included in the CAT Reference BAU (Figure 2.4).

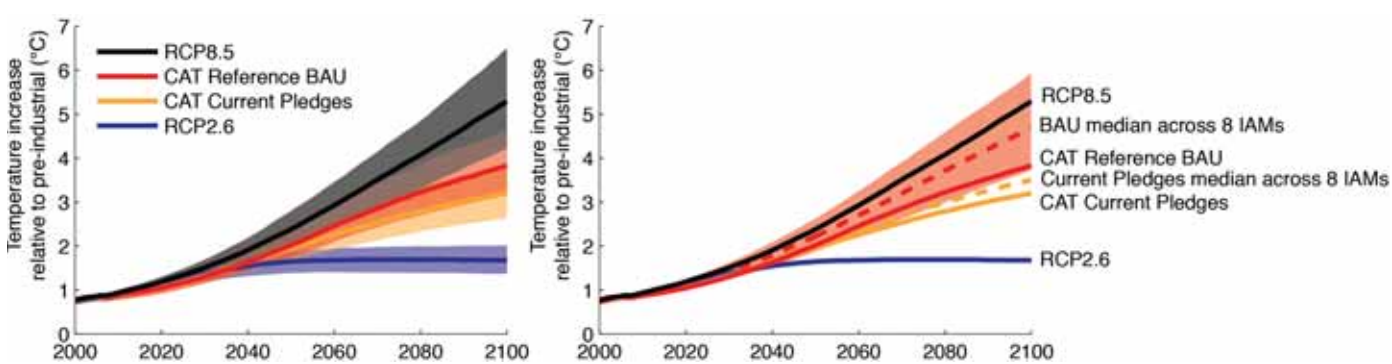
Box A1.1 Emission Scenarios in this Report

To frame its assessment, this report uses four main scenarios that span the range between a lausible high emissions future—leading to end-of-century warming exceeding 4°C with a high robability (ca. 85 percent)—and a feasible low emissions path, likely keeping temperature rise to below 2°C (ca. 85 percent probability).

a. *RCP8.5*: A no-climate-policy baseline with comparatively high greenhouse gas emissions (Riahi et al. 2011), which is used by many studies that are being assessed for the upcoming IPCC Fifth Assessment Report (AR5). This scenario is also the underlying high emissions scenario for impacts assessed in other parts of this report. In this report, the authors refer to the RCP8.5 as a 4°C world.
b. CAT Reference BAU: A lower reference BAU scenario that includes existing climate olicies, but not pledged emission reductions, as estimated by Climate Action Tracker (Climate Analytics et al. 2011).
c. CAT Current Pledges: A scenario also incorporating reductions currently pledged internationally by countries, as assessed by the Climate Action Tracker (Climate Analytics et al. 2011).
d. RCP2.6: A scenario that is representative of the literature on mitigation scenarios aiming to limit the increase of global mean temperature to 2°C (Van Vuuren et al. 2011). Similar to RCP8.5, this emissions path is used by many studies that are being assessed for AR5 and is the underlying low emissions scenario for impacts assessed in other parts of this report. In this report, the authors refer to the RCP2.6 as a 2°C world.

Without predicting what the future will bring, these scenarios are representations of distinct groups of plausible and possible futures that society can decide to work toward. As such,

Figure A1.1 Projections for surface-air temperature increase. The left-hand panel shows probabilistic projections by the SCM (see Box A.1.2)



Lines show "best-estimate" (median) projections for each emission scenario, while shaded areas indicate the 66 percent uncertainty range. The shaded ranges represent the uncertainties in how emissions are translated into atmospheric concentrations (carbon cycle uncertainty) and how the climate system responds to these increased concentrations (climate system uncertainty). The right-hand panel shows projections of temperature increase for the scenarios assessed in this report in the context of BAU projections from the recent Integrated Assessment Model (IAM) literature discussed in the text. The light-red shaded area indicates the 66 percent uncertainty range around the median (red dashed line) of BAU projections from 10 IAMs.

action (business as usual), with the median projections reaching a warming of 4.7°C above pre-industrial levels by 2100—with a 40-percent chance of exceeding 5°C.

Probabilities

From a risk assessment point of view, the probability that specific levels of warming are exceeded in the course of the 21st century is of particular interest. The probabilistic uncertainty ranges of the Simple Climate Model (SCM; see Box A 1.2) projections in this report, as well as the spread in results of complex Atmosphere Ocean General Circulation Models (AOGCMs), provide valuable information for this. For the four emission scenarios, Figure A1.2 shows the gradually increasing probability of exceeding warming levels of 3°C and 4°C. 4°C is "likely" (with a greater than 66-percent chance) exceeded around 2080 for *RCP8.5*. Consistent with the SCM, 80 percent of the AOGCMs project warming higher than 4°C by the 2080–2100 period. For other scenarios, lower probabilities of exceeding 4°C are found.

Figure A1.2 also shows that the *CAT Reference BAU* results in a 40-percent probability of exceeding 4°C by the end of the century, and still increasing thereafter. Recalling that the *CAT Reference BAU* is situated at the low end of most recent reference BAU estimates from the literature and that real-world global CO_2 emissions continue to track along a high emission pathway (Peters et al. 2013), the authors conclude that in the absence of greenhouse gas mitigation efforts during the century, the likelihood is considerable that the world will be 4°C warmer by the end of the century.

The results presented above are consistent with recently published literature. Newly published assessments of the recent trends in the world's energy system by the International Energy Agency in its World Energy Outlook 2012 indicate global mean warming above pre-industrial levels would approach 3.8°C by 2100. In this assessment, there is a 40-percent chance of warming exceeding 4°C by 2100 and a 10-percent chance of warming exceeding 5°C. The updated UNEP Emissions Gap Assessment, released at the Climate Convention Conference in Doha in December 2013, found that present emission trends and pledges[132] are consistent with emission pathways that reach warming in the range of 3–5°C by 2100, with global emissions estimated for 2020 closest to levels consistent with a 3.5–4°C pathway.

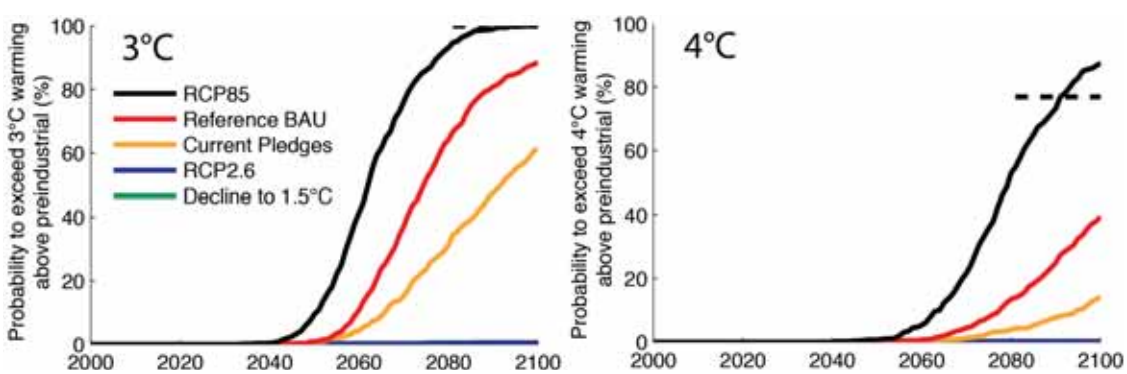
Can Warming Be Held Below 2°C?

The previous section explained why it is still plausible that a high-carbon emissions future could lead to a considerable probability that warming exceeds 4°C by the end of the century. The question that now arises is whether the significant reduction in greenhouse gas emissions required to hold the global temperature increase to below 2°C is feasible. This section discusses some of the latest scientific insights related to keeping warming to low levels.

First of all, most recent results with state-of-the-art AOGCMs and SCMs show that under reference emissions temperatures can exceed 2°C as early as the 2040s, but can also be held to below 2°C relative to pre-industrial levels with a high probability if emissions are reduced significantly (see Box A1.2, Figures A1.1, A1.2, and A1.3). This shows that, from a geophysical point of view, limiting temperature increase to below 2°C is still possible. Other assessments that take into account a large set of scenarios from the literature come to the same conclusion with

[132] "Unconditional pledges, strict rules" case.

Figure A1.2 The probability that temperature increase exceeds 3°C or 4°C above pre-industrial levels projected by a simple coupled carbon cycle/climate model (SCM, see Box III)



The dashed line indicates the percentage of complex Atmosphere Ocean General Circulation Models (AOGCMs) and Earth-System Models (ESMs) as reported by the CMIP5 program that exceeds these temperature thresholds around the year 2090 for the RCP8.5 scenario (zero for RCP2.6).

Box A1.2 Climate Projections and the Simple Climate Model (SCM)

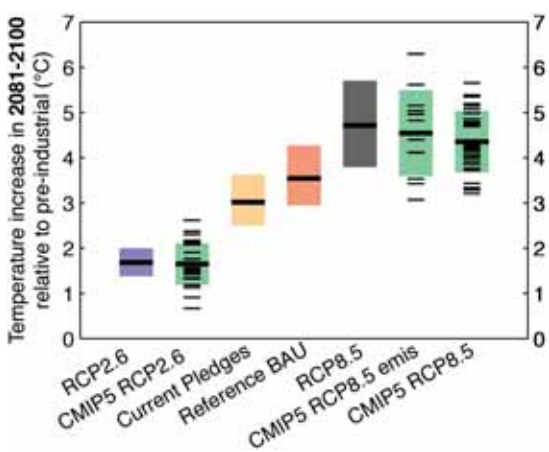
This report uses the reduced-complexity carbon cycle and climate model MAGICC (Meinshausen et al. 2011a, 2011b) to compute estimates of atmospheric greenhouse gas concentrations and their climatic outcomes. MAGICC is the primary simple climate model that has been used in past IPCC Assessment Reports and has been applied, further developed, and scientifically scrutinized for over two decades (Wigley and Raper 1987, 1992, 2001, 2005). MAGICC is a simple climate model (SCM) that can closely emulate the large-scale behavior of much more complex state-of-the-art Atmosphere Ocean General Circulation Models (AOGCMs) for a large range of scenarios.

AOGCMs and Earth-System Models (ESMs, AOGCMs with a coupled carbon cycle), are used to compute geographically explicit projections of a wide range of climate variables, such as temperature near the surface as well as higher up in the atmosphere or down in the ocean, precipitation, winds, ocean currents, and so on. Because these models are very complex and operate on high spatial resolution and small time steps, only a handful of emission scenarios can be run. For the IPCC's upcoming Fifth Assessment Report (AR5), the Coupled Model Intercomparison Project-Phase 5 (CMIP5 Taylor et al. 2012) has collected AOGCM and ESM output for the four new IPCC scenarios (RCPs—Vuuren et al. 2011). These results form an important basis for the climate impact projections presented in much of this report. A subset of five models from the CMIP5 project underlies the temperature and precipitation projections in the report.

The SCM MAGICC is used, however, to compute the global mean response of the carbon cycle and climate system for other scenarios in this report. It is no substitute for AOGCMs, but provides a tool to make synthesized knowledge obtained with AOGCMs available for large scenario numbers and at low computational cost.

Because of uncertainties in the carbon cycle and climate response of the earth system to increasing greenhouse gases, there is a range in the expected temperature outcome (see Figure SPM.5 in IPCC 2007). To sample this uncertainty, the SCM MAGICC has here been used in a probabilistic setup that, by running 600 simulations per scenarios, can closely match the assessment of carbon cycle and climate uncertainties in the IPCC AR4 (Meinshausen et al. 2009). Furthermore, the temperature simulations are also constrained by observations of hemispherical temperatures and heat uptake. Detailed background to the model structure is provided by Meinshausen and Raper et al. (2011a). Figure A1.3 shows the consistency of the global mean temperature response of the SCM with the state-of-the-art AOGCMs of the Coupled Model Intercomparison Project-Phase 5 (CMIP5 Taylor et al. 2012) for both the lowest (RCP2.6) and the highest (RCP8.5) scenario (see also Box A1.1).

Figure A1.3 Projected global-mean temperature increase relative to pre-industrial levels in 2081–2100 for the main scenarios used in this report (see Box A1.1)



The SCM projections (blue, orange, red, and grey ranges) are compared to simulations by complex AOGCMs and Earth-System Models (ESMs) as reported by the CMIP5 project. Only for the RCP2.6 and RCP8.5 scenarios, comparison data are available from CMIP5. For GCMs and ESMs, the black line indicates the mean across all models that ran a particular scenario, thin black lines individual model results, and the green shaded area a standard deviation above and below the mean. The complex models were driven by prescribed greenhouse gas concentrations, except for the"RCP8.5 emis" scenario, for which models were driven by emissions. This scenario leads to somewhat higher warming because of feedbacks in the carbon cycle, which is also the case for all of the SCM scenarios. Note that the CMIP5 model ensemble was not designed to span the entire range of uncertainties (cf., Tebaldi and Knutti 2007), yet shows projections for RCP8.5 ranging from as low as 3°C to as high as 6.2°C because of structural differences in the models.

an SCM (Van Vuuren et al. 2008; Rogelj et al. 2011; UNEP 2012). The one overarching feature of these scenarios is that they limit the cumulative amount of global greenhouse gas emissions to a given emissions budget (Meinshausen et al 2009); to not exceed this budget, emissions start declining by 2020 in most of these scenarios (Rogelj et al. 2011).

International climate policy has until now not managed to curb global greenhouse gas emissions on such a declining path, and recent inventories show emissions steadily on the rise (Peters et al. 2013). However, recent high emission trends do not imply high emissions forever (van Vuuren and Riahi 2008). Several studies show that effective climate policies can substantially influence the trend and bring emissions onto a feasible path in line with a high probability of limiting warming to below 2°C even after low short-term ambition (e.g., OECD 2012; Rogelj et al. 2012a; UNEP 2012; van Vliet et al. 2012; Rogelj et al. 2013). Choosing such a path would however imply higher overall costs, higher technological dependency, and higher risks of missing the climate objective (Rogelj et al. 2012a; UNEP 2012). The Global Energy Assessment (Riahi et al. 2012) and other studies (Rogelj et al. 2012a, 2013) also highlight the importance of demand-side efficiency improvements to increase the chances of limiting warming to below 2°C across the board.

The available scientific literature makes a strong case that achieving deep emissions reductions over the long term is feasible

Figure A1.4 As Figure A1.2 for the probability that temperature increase exceeds 1.5 and 2°C

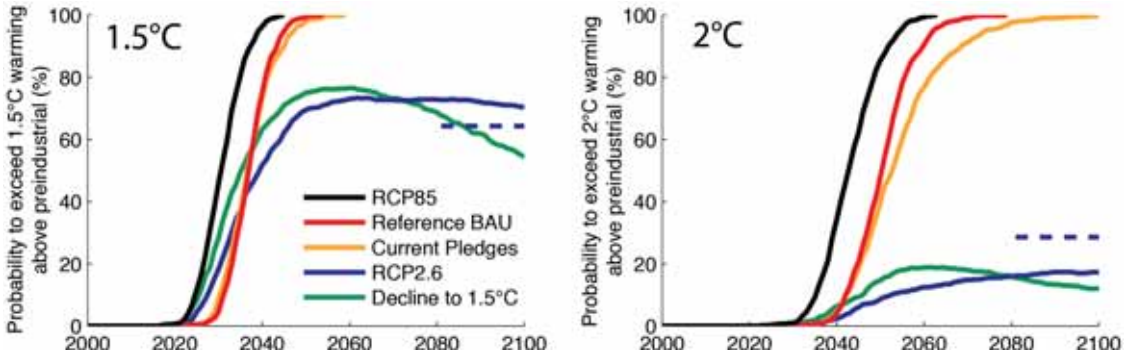


Figure A1.4: As Figure A1.2 for the probability that temperature increase exceeds 1.5 and 2°C. Although 1.5°C is likely to be exceeded even in RCP2.6, the probability is on a downward path by 2100. Still, stronger mitigation efforts than identified in RCP2.6 (see Rogelj et al. 2013) are needed to further bring down the probability of exceeding 1.5°C to below 50 percent by 2100.

(Clarke et al. 2009; Fischedick et al. 2011; Riahi et al. 2012); recent studies also show the possibility together with the consequences of delaying action (den Elzen et al. 2010; OECD 2012; Rogelj et al. 2012a, 2013; van Vliet et al. 2012).

Appendix 2

Methods for Temperature, Precipitation, Heat Wave, and Aridity Projections

Bias Correction for Subset of CMIP5 GCMs as Used Within the ISI-MIP Framework and for Temperature, Precipitation, and Heat Wave Projections in this Report

The temperature, precipitation, and heat wave projections were based on the ISI-MIP global climate database, using the historical (20th century) period and future scenarios RCP2.6 and RCP8.5. The ISI-MIP database consists of 5 CMIP5 global climate models (gfdl-esm2m, hadgem2-es, ipsl-cm5a-lr, miroc-esm-chem, noresm1-m), which were bias-corrected, such that the models reproduce historically observed mean temperature and precipitation and their year-to-year variability. The statistical bias correction algorithm as used by WaterMIP/WATCH has been applied to correct temperature and precipitation values. The correction factors were derived over a construction period of 40 years, where the GCM outputs are compared to the observation-based WATCH forcing data. For each month, a regression was performed on the ranked data sets. Subsequently, the derived monthly correction factors were interpolated toward daily ones. The correction factors were then applied to the projected GCM data (Warszawski et al. in preparation)

Heat Wave Analysis

For each of the ISI-MIP bias-corrected CMIP5 simulation runs, the authors determined the local monthly standard deviation due to natural variability over the 20th century for each individual month. To do so, they first used a singular spectrum analysis to extract the long-term non-linear warming trend (that is, the climatological warming signal). Next, they detrended the 20th century monthly time series by subtracting the long-term trend, which provides the monthly year-to-year variability. From this detrended signal, monthly standard deviations were calculated, which were then averaged seasonally. In the present analysis, the authors employ the standard deviation calculated for the last half of the 20th century (1951–2010); they found, however, that this estimate is robust with respect to different time periods.

Aridity Index and Potential Evaporation

$$AI = \frac{Pr}{ET_0}$$

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

With ET_0 in mm day^{-1}, R_n the net radiation at the crop surface [MJ m^{-2} day^{-1}], G the soil heat flux density [MJ m^{-2} day^{-1}], T the mean air temperature at 2 m height [°C], u_2 the wind speed at 2m height [m s^{-1}], e_s the saturation vapor pressure [kPa], e_a the actual vapour pressure [kPa], Δ the slope of the vapor pressure curve [kPa °C–1] and γ psychrometric constant [kPa °C–1].

The authors calculate monthly ET_0 values for each grid point using climatological input from the ISI-MIP database for both the historic period and future scenarios.

Box A2.1 Overview Table of ISI-MIP Models

Sector	Model abbreviation	Full Model name	References to model
Water/Agriculture/ Ecosystems	LPJmL	Lund-Potsdam-Jena managed Land Dynamic Global Vegetation and Water Balance Model	Bondeau, A., Smith, P., Zaehle, S., Schaphoff, S., Lucht, W., Cramer, W., Gerten, D., Lotze-Campen, H., Müller, C., Reichstein, M., Smith, B. 2007. Modelling the role of agriculture for the 20th century global terrestrial carbon balance. *Global Change Biology* 13, 679–706. Rost, S., Gerten, D., Bondeau, A., Lucht, W., Rohwer, J., Schaphoff, S. 2008: Agricultural green and blue water consumption and its influence on the global water system. *Water Resources Research* 44, W09405, doi:10.1029/2007WR006331.
Water/Ecosystems	ORCHIDEE	N.A.	Krinner, G., N. Viovy, N. de Noblet-Ducoudré, J. Ogée, J. Polcher, P. Friedlingstein, P. Ciais, S. Sitch, and I. C. Prentice (2005), A dynamic global vegetation model for studies of the coupled atmosphere-biosphere system, Global Biogeochem. Cycles, 19, GB1015, doi:10.1029/2003GB002199. Piao, S., P. Friedlingstein, P. Ciais, N. de Nolbet-Ducoudré, D. Labat and S. Zaehle (2007) Changes in climate and land use have a larger direct impact than rising CO_2 on global river runoff trends. Proc Natl Acad Sci USA 104:15242–15247.
	JULES	Joint UK Land Environment Simulator	Best, M. J., Pryor, M., Clark, D. B., Rooney, G. G., Essery, R. L. H., Ménard, C. B., Edwards, J. M., Hendry, M. A., Porson, A., Gedney, N., Mercado, L. M., Sitch, S., Blyth, E., Boucher, O., Cox, P. M., Grimmond, C. S. B., and Harding, R. J.: The Joint UK Land Environment Simulator (JULES), model description – Part 1: Energy and water fluxes, Geosci. Model Dev., 4, 677–699, doi:10.5194/gmd–4-677-2011, 2011. Clark, D. B., Mercado, L. M., Sitch, S., Jones, C. D., Gedney, N., Best, M. J., Pryor, M., Rooney, G. G., Essery, R. L. H., Blyth, E., Boucher, O., Harding, R. J., Huntingford, C., and Cox, P. M.: The Joint UK Land Environment Simulator (JULES), model description – Part 2: Carbon fluxes and vegetation dynamics, Geosci. Model Dev., 4, 701–722, doi:10.5194/gmd-4-701-2011, 2011.
Water	VIC	Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model	Lohmann, D., E. Raschke, B. Nijssen and D. P. Lettenmaier, 1998: Regional scale hydrology: I. Formulation of the VIC-2L model coupled to a routing model, Hydrol. Sci. J., 43(1), 131–141. Liang, X., Lettennmaier, D. P., Wood, E. F., and Burges, S. J., 1994, A simple hydrologically based model of land surface water and energy fluxes for general circulation models, *J. Geophys. Res.*, 99(D7), 14,415– 14,428 (Nosoc runs/results, Pressoc runs/results) Haddeland, I., T. Skaugen, and D.P. Lettenmaier, 2006, Anthropogenic impacts on continental surface water fluxes, *Geophys. Res. Lett.*, 33(8), Art. No. L08406, doi:10.1029/2006GL026047 (Pressoc runs/results)
	H08	N.A.	Hanasaki, N., Kanae, S., Oki, T., Masuda, K., Motoya, K., Shirakawa, N., Shen, Y., and Tanaka, K.: An integrated model for the assessment of global water resources - Part 1: Model description and input meteorological forcing, Hydrol. Earth Syst. Sci., 12, 1007–1025, 2008a. Hanasaki, N., Kanae, S., Oki, T., Masuda, K., Motoya, K., Shirakawa, N., Shen, Y., and Tanaka, K.: An integrated model for the assessment of global water resources - Part 2: Applications and assessments, Hydrol. Earth Syst. Sci., 12, 1027–1037, 2008b.
	WaterGAP	Water - Global Analysis and Prognosis	Flörke, M.; Kynast, E.; Bärlund, I.; Eisner, S.; Wimmer, F.; Alcamo, J. (2012): Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study. Global Environ. Change, doi:10.1016/j.gloenvcha.2012.10.018. Döll, P., Kaspar, F., Lehner, B. (2003): A global hydrological model for deriving water availability indicators: model tuning and validation. Journal of Hydrology, 270 (1–2), 105–134. Döll, P., Hoffmann-Dobrev, H., Portmann, F.T., Siebert, S., Eicker, A., Rodell, M., Strassberg, G., Scanlon, B. (2012): Impact of water withdrawals from groundwater and surface water on continental water storage variations. J. Geodyn. 59–60, 143–156, doi:10.1016/j.jog.2011.05.001

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Box A2.1 Overview Table of ISI-MIP Models

Sector	Model abbreviation	Full Model name	References to model
	Mac-PDM.09	Macro-scale Probability-Distributed Moisture model.09	Gosling SN, Arnell, NW (2011) Simulating current global river runoff with a global hydrological model: model revisions, validation and sensitivity analysis. Hydrological Processes 25: 1129–1145. doi: 10.1002/hyp.7727 Arnell NW (1999) A simple water balance model for the simulation of streamflow over a large geographic domain, J. Hydrol., 217: 314–335
	WBM	Water Balance Model	Vörösmarty, C. J., Peterson, B. J., Lammers, R. B., Shiklomanov, I. A., & Shiklomanov, A.I. (1998). A regional, electronic Hydro-meteorlogical data network for the pan-Arctic Region. Retrieved from http://www.r-arcticnet.sr.unh.edu Wisser, D., Fekete, B. M., Vörösmarty, C. J., & Schumann, A. H. (2010). Reconstructing 20th century global hydrography: A contribution to the Global Terrestrial Network-Hydrology (GTN-H). Hydrology and Earth System Sciences, 14(1),1–24. European Geophysical Society, doi:10.5194/hess-14–1-010
	MPI-HM	Max Planck Institute – Hydrology Model	Hagemann, S. and L. Dümenil Gates, 2003: Improving a subgrid runoff parameterization scheme for climate models by the use of high resolution data derived from satellite observations Clim. Dyn. 21, pp. 349–359 Stacke, T., and S. Hagemann, 2012: Development and validation of a global dynamical wetlands extent scheme. *Hydrol. Earth Syst. Sci., 16, 2915–2933*
	PCR-GLOBWB	PCRaster Global Water Balance	Wada, Y., L.P.H. van Beek, C.M. van Kempen, J.W.T.M. Reckman, S. Vasak and M.F.P. Bierkens (2010), Global depletion of groundwater resources, *Geophys. Res. Lett., 37*, L20402, doi:10.1029/2010GL044571. Van Beek, L.P.H., Y. Wada and M.F.P. Bierkens (2011), Global monthly water stress: I. Water balance and water availability, *Water Resour. Res., 47*, W07517, doi:10.1029/2010WR009791. Wada, Y., L.P.H. van Beek, D. Viviroli, H.H. Dürr, R. Weingartner and M.F.P. Bierkens (2011a), Global monthly water stress: II. Water demand and severity of water, *Water Resour. Res.*, *47*, W07518, doi:10.1029/2010WR009792.
	MATSIRO	Minimal Advanced Treatments of Surface Interaction and RunOff	YADU POKHREL et al. (2012) Incorporating Anthropogenic Water Regulation Modules into a Land Surface Model, Journal of Hydrometeorology, Volume 13, Issue 1 (February 2012) Kumiko Takata et al. (2003) Development of the minimal advanced treatments of surface interaction and runoff, Global and Planetary Change, Volume 38, Issues 1–2, July 2003, Pages 209–222
	DBH	Distributed Biosphere-Hydrological Model	Tang, Q., T. Oki, S. Kanae, and H. Hu, 2007. The influence of precipitation variability and partial irrigation within grid cells on a hydrological simulation. Journal of Hydrometeorology, 8, 499–512. Tang, Q., Oki, T., Kanae, S., Hu, H., 2008. Hydrological cycles change in the Yellow River Basin during the last half of the 20th century. Journal of Climate. 21(8), 1790–1806.
Ecosystems	HYBRID4	N.A.	Friend AD, White A. 2000. Evaluation and analysis of a dynamic terrestrial ecosystem model under pre-industrial conditions at the global scale. Global Biogeochemical Cycles 14(4), 1173–1190.
	SDGVM	Sheffield Dynamic Vegetation Model	Le Quere, C., Raupach, M. R., Canadell, et al. Trends in the 5 sources and sinks of carbon dioxide, Nature Geoscience., Vol 2, 831–836, doi: 10.1038/ngeo689, Nov 2009. Woodward F I, Smith T M, Emanuel W R. A global land primary productivity and phytogeography model. Global Biogeochemical cycles, vol. 9, NO. 4, pp 471–490, 1995.

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Box A2.1 Overview Table of ISI-MIP Models

Sector	Model abbreviation	Full Model name	References to model
	JeDi	Jena Diversity Model	Pavlick, R., Drewry, D., Bohn, K., Reu, B., and Kleidon, A.: The Jena Diversity-Dynamic Global Vegetation Model (JeDi-DGVM): a diverse approach to representing terrestrial biogeography and biogeochemistry based on plant functional trade-offs, Biogeosciences Discuss, 9, 4627–4726, 2012.
	ANTHRO-BGC	ANTHRO-BioGeochemical Cycles	Ma, S., Churkina, G., Wieland, R. & Gessler, A., 2011. Optimization and evaluation of the anthro-bgc model for winter crops in Europe. Ecological Modelling, 222 (20–22), 3662–3679 Available from: http://www.sciencedirect.com/science/article/pii/S0304380011004571 Churkina, G., Brovkin, V., Von Bloh, W., Trusilova, K., Jung, M. & Dentener, F.J., 2009. Synergy of rising nitrogen depositions and atmospheric co2 on land carbon uptake offsets global warming. Global Biogeochemical Cycles, 23, GB4027.
	VISIT	Vegetation Integrative Simulation for Trace gases	Inatomi M, Ito A, Ishijima K, Murayama S (2010) Greenhouse gas budget of a cool temperate deciduous broadleaved forest in Japan estimated with a process-based model. Ecosystems, 13, 472–483. Ito A, Inatomi M (2012) Use and uncertainty evaluation of a process-based model for assessing the methane budget of global terrestrial ecosystems. Biogeosciences, 9, 759–773.
Agriculture	GEPIC	GIS-based agroecosystem model integrating a bio-physical EPIC model (Environmental Policy Integrated Climate) with a Geographic Information System (GIS)	Liu, J. G. Zehnder, A.J.B., Yang, H. 2009. 'Global crop water use and virtual water trade: the importance of green water'. Water Resources Research. 45: doi.10.1029/2007WR006051. Williams, J. R., C. A. Jones, J. R. Kiniry, and D. A. Spanel (1989), The EPIC crop growth model, Trans ASAE, 32, 497–511
	EPIC	Environmental Policy Integrated Climate	Williams, J.R. (1995). The EPIC Model. In: V.P. Singh (eds). Computer Models of Watershed Hydrology. Water Resources Publications, Highlands Ranch, Colorado, 909–1000. Izaurralde, R. C., Williams, J. R., McGill, W. B., Rosenberg, N. J., and Jakas, M. C. Q. (2006). Simulating soil C dynamics with EPIC: Model description and testing against long-term data. Ecological Modelling, vol. 192, no. 3–4, pp. 362–384, 2006.
	pDSSAT	Productivity – Decision Support System for Agrotechnology Transfer	N.A.
	DAYCENT	Daily derivative of the Century	S. J. Del Grosso, W. J. Parton, A. R. Mosier, M. K. Walsh, D. S. Ojima and P. E. Thornton. 2006. DAYCENT national-scale simulations of nitrous oxide emissions from cropped soils in the United States. JOURNAL OF ENVIRONMENTAL QUALITY 35 (4): 1451–1460 JUL-AUG 2006 Del Grosso, S.J., D.S. Ojima, W.J. Parton, E. Stehfest, M. Heistemann, B. Deangelo, S. Rose. Global Scale DAYCENT Model Analysis of Greenhouse Gas Mitigation Strategies for Cropped Soils. Global and Planetary Change, 67 (2009) 44–50
	PEGASUS	Predicting Ecosystem Goods And Services Using Scenarios	Deryng et al., GLOBAL BIOGEOCHEMICAL CYCLES, VOL. 25, GB2006, doi:10.1029/2009GB003765, 2011

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Box A2.1 Overview Table of ISI-MIP Models

Sector	Model abbreviation	Full Model name	References to model
	IMAGE	Integrated Model to Assess the Global Environment	MNP (2006) (Edited by A.F. Bouwman, T. Kram and K, Klein Goldewijk), Integrated modelling of global environmental change. An overview of IMAGE 2.4. MNP, Bilthoven, The Netherlands Bouwman AF; Kram T; Klein Goldewijk K (eds): Integrated modelling of global environmental change. An overview of IMAGE 2.4, Report 09.11.2006
	LPJ-GUESS	Lund-Potsdam-Jena General Ecosystem Simulator with managed land	Smith, B., Prentice, C. and Sykes, M.T. 2001. Representation of vegetation dynamics in the modelling of terrestrial ecosystems: comparing two contrasting approaches within European climate space. Global Ecology and Biogeography 10:621–637. Sitch, S., B. Smith, I.C. Prentice, A. Arneth, A. Bondeau, W. Cramer, J. Kaplan, S. Levis, W. Lucht, M. Sykes, K. Thonicke, and S. Venevski. 2003. Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ Dynamic Vegetation Model. *Global Change Biology* 9:161–185. Lindeskog, M.; Arneth, A.; Bondeau, A.; Waha, K.; Schurgers, G.; Olin, S.; Smith, B. Effects of crop phenology and management on the terrestrial carbon cycle: case study for Africa. Submitted to Earth System Dynamics.
Agriculture/Agro-Economic models	MAgPIE (connected to LPJmL)	Model of Agricultural Production and its Impact on the Environment	Dietrich, J.P., Schmitz, C., Müller, C., Fader, M., Lotze-Campen, H., Popp, A. (2012): Measuring agricultural land-use intensity - A global analysis using a model-assisted approach. Ecological Modelling, Volume 232, 10 May 2012, Pages 109–118, ISSN 0304–3800, 10.1016/j.ecolmodel.2012.03.002. Lotze-Campen et al. 2008. Global food demand, productivity growth, and the scarcity of land and water resources: a spatially explicit mathematical programming approach, Agricultural economics, VOL 39, 325–338
	GLOBIOM (connected to EPIC)	Global Biosphere Management Model	Havlík, P., Schneider, A.U., Schmid, E., Böttcher, H., Fritz, S., Skalský, R., Aoki, K., de Cara, S., Kindermann, G., Kraxner, F., Leduc, S., McCallum, I., Mosnier, A, Sauer, T. and Obersteiner, M. (2011). Global land-use implications of first and second generation biofuel targets. Energy Policy 39: 5690–5702. doi:10.1016/j.enpol.2010.03.030. Havlík, P., Valin, H., Mosnier, A., Obersteiner, M., Baker, J.S., Herrero, M., Rufino, M.C., Schmid, E. (2013). Crop Productivity and the Global Livestock Sector: Implications for Land Use Change and Greenhouse Gas Emissions. *American Journal of Agricultural Economics* 95(2): 442–448.
	IMPACT (connected to DSSAT)	International Model for Policy Analysis of Agricultural Commodities and Trade	Nelson, Gerald C. et al. 2010. Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options. Washington, D.C.: International Food Policy Research Institute Rosegrant, Mark W, and IMPACT Development Team. 2012. International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) Model Description. International Food Policy Research Institute (IFPRI), Washington D.C.
	AIM	Asia-Pacific Integrated Model	Fujimori S., T. Masui and Y. Matsuoka, (2012), AIM/CGE [basic] manual, Discussion Paper Series, No. 2012–01, Center for Social and Environmental Systems Research, NIES.
	GCAM	Global Change Assessment Model	Wise, M., and Calvin, K. 2011. GCAM 3.0 Agriculture and Land Use: Technical Description of Modeling Approach. PNNL-20971, Pacific Northwest National Laboratory, Richland, WA. Available at https://wiki.umd.edu/gcam/images/8/87/GCAM3AGTechDescript12_5_11.pdf Thomson, A., et al. 2011. RCP4.5: a pathway for stabilization of radiative forcing by 2100. Climatic Change 109, 77–94. DOI 10.1007/s10584-011-0151-4.

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Box A2.1 Overview Table of ISI-MIP Models

Sector	Model abbreviation	Full Model name	References to model
	Envisage	The ENVironmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model	van der Mensbrugghe, Dominique (2013), "The ENVironmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model: Version 8.0," processed, FAO, Rome. van der Mensbrugghe, Dominique (2013), "Modeling the Global Economy—Forward-Looking Scenarios for Agriculture," Chapter 14 in Dixon, Peter B. and Dale W. Jorgenson, editors, Handbook of Computable General Equilibrium Modeling, North Holland, Elsevier B. V., pp. 933–994.
	FARM	Future Agricultural Resources Model (FARM)	Sands, R.D., H. Förster, K. Schumacher and C.A. Jones (2013) Bio-electricity and Land Use in the Future Agricultural Resources Model (FARM), in review at Climatic Change for special issue on Technology Outcomes and Climate Policy Objectives. Sands, R.D., K. Schumacher, H. Förster and J. Beckman (2013) U.S. CO_2 Mitigation Scenarios in a Global Context: Welfare, Trade and Land Use, in review at The Energy Journal for special issue on US Technology Transitions Under Alternative Climate Policies.
Infrastructure	DIVA	Directions Into Velocities of Articulators	Hinkel, J. and Klein, R.J.T., 2009. The DINAS-COAST project: developing a tool for the dynamic and interactive assessment of coastal vulnerability. Global Environmental Change, 19(3), 384–395. Hinkel, J., Brown, S., Exner, L., Nicholls, R.J., Vafeidis, A.T. and Kebede, A.S., 2011. Sea-level rise impacts on Africa and the effects of mitigation and adaptation: an application of DIVA. Regional Environmental Change, Online first.
Health	MARA (Different model setups for malnutrition; heat; Malaria etc.)	a. Empirical statistical model b. Mathematical malaria models	a) Beguin, A., S. Hales, Rocklöv et al. (2011). "The opposing effects of climate change and socio-economic development on the global distribution of malaria." Global Environmental Change-Human and Policy Dimensions 21(4): 1209–1214. b) Gething, P. W., T. P. Van Boeckel, et al. (2011). Modelling the global constraints of temperature on transmission of Plasmodium falciparum and P. vivax. Parasites & Vectors 4.
	WHO CRA Malaria	N.A.	N.A.
	LMM 205	Liverpool Malaria Model	Hoshen, M.B. and Morse, A.P. (2004) A weather-driven model of malaria transmission, Malaria Journal, 3 (32) pp 14. Jones A.E. and Morse A.P. (2010). Application and Validation of a Seasonal Ensemble Prediction System using a Dynamic Malaria Model, Journal of Climate, 23 (15), 4202–4215. DOI:10.1175/2010JCLI3208.1
	MIASMA	Modeling Framework for the Health Impact Assessment of Man-Induced Atmospheric Changes	Van Lieshout, M., Kovats, R.S., Livermore, M.T.J. & Martens, P. (2004). Climate change and malaria: analysis of the SRES climate and socio-economic scenarios. Global Environmental Change, 14(1), 87–99. Martens, P. (1999). MIASMA: Modelling framework for the health Impact Assessment of Man-induced Atmospheric changes. Electronic Series on Integrated Assessment Modeling (ESIAM), Volume 2, February 1999.
	VECTRI	Vector borne disease model of ICTP	Tompkins A.M. and Ermert V., 2012: VECTRI: A dynamical malaria model that accounts for population density and surface hydrology, Submitted to Malaria Journal.

Appendix 3

Methods for Multisectoral Hotspots Analysis

For the hotspots analysis presented in this report, simulations driven by those ISI-MIP GCMs going up to ΔGMT= 5°C have been chosen. These are the RCP8.5 data from HadGEM2-ES, MIROC-ESM-CHEM, and IPSL-CM5A-LR. The analysis covers 11 global hydrological models, seven global gridded crop models, seven biomes models, and four malaria models.

All indicators have annual temporal resolution, neglecting seasonal patterns. For discharge and the Γ-metric, very low values (for the latter of natural vegetation) can lead to spurious effects when looking at changes by amplifying very small changes and overemphasizing those regions (e.g., the Sahara). Therefore, values are set to zero below a lower limit 0.01 $km^2\,yr^{-1}$ and a 2.5 percent cover fraction of natural vegetation, respectively (Warszawski et al. in review; von Bloh et al. 2010). The four crops are combined through conversion to energy-weighted production per cell using the following conversion factors for energy content [MJ kg^{-1} dry matter]: wheat – 15.88, rice (paddy) – 13.47, maize – 16.93, and soy – 15.4 (Wirsenius 2000; FAO 2001). Since only negative changes are considered, a possible expansion of cropland to higher latitudes, which is not accounted for because of the masking, is not important. Furthermore, this analysis can only give a limited perspective of agricultural hotspots as for instance millet and sorghum, crops widely grown in Africa, are not included in the analysis. Malaria prevalence, representing the health sector, is only one example of human health effects from climate change—although it is a very relevant one given its potential links to human welfare and economic development (Sachs and Malaney 2002). The impact of climate change on malaria occurrence focuses on changes in length of transmission season. This simple metric represents an aggregated risk factor, since it neglects age-dependent immunity acquisition associated with transmission intensity. Increases in impacts associated with transitions from malaria-free to epidemic conditions are also not considered. Initial areas of endemic malaria vary widely between models and depend on their calibration and focus region.

GMT is calculated from the GCM data before bias correction; change is measured with respect to pre-industrial levels assuming an offset from 0.8°C of the ISI-MIP 1980–2010 baseline.

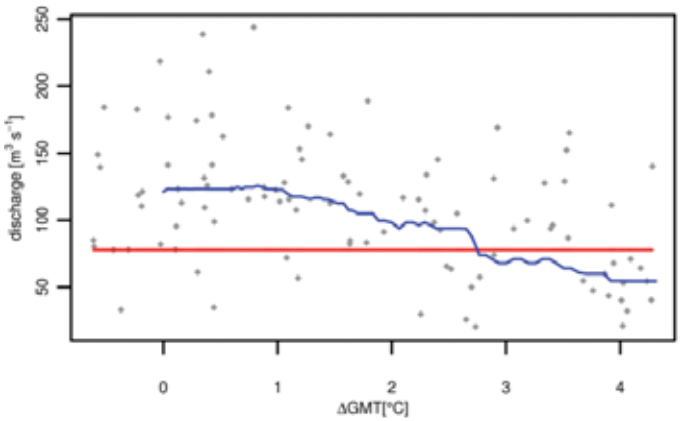
Temperatures are binned at ΔGMT = 1,2,3,4, and 5°C (± 0.5°). If a grid cell is identified as having crossed the threshold, the whole area of the grid cell is assumed to be affected. This neglects, for example, the separation of agricultural and natural vegetation areas in a grid-cell, as such separation is below the resolution of the analysis. The affected population fraction is not very sensitive to applying population distributions for the year 2000 or for 2084, although the total number of affected people would increase, possibly substantially.

Methodology for Sectoral and Multisectoral ISI-MIP Climate Model Projections

Discharge is chosen as a measure for water availability. Food security is represented by crop yields from four major staple crops (wheat, rice, maize, and soy) on current rainfed and irrigated cropland, synthesized by their caloric content. Thresholds are selected to represent severe changes in the average conditions people have experienced in the past. This suggests that impacts would be severe, particularly when occurring simultaneously

For discharge (and cropland), severe changes are assumed when the future projected average discharge (and crop yields) measured over periods of 31 years is lower than today's (1980–2010) 1-in-10-year events. This concept is illustrated in Figure 6.2, and it means

A3.1 Illustration of the method for discharge in one grid cell in Sub-Saharan Africa (longitude = 18.75, latitude = –15.25)



The points are the annual discharge from 1980–2099; the red line is the threshold (the 10th percentile of the reference period distribution, which is the first 31 points); the blue line is the running 31-year median, ranging from 1995 (1980–2010 median) to 2084 (2069–99 median). The crossing temperature would be the temperature where the blue line falls below the red line.

that very low discharge/crop yields would become the norm. The risk of a biome change metric with a severity threshold of 0.3, as introduced in Chapter 6 on "Risk of Terrestrial Ecosystem Shifts", is applied to measure the impacts on ecosystems. Such impacts could severely affect biodiversity and ecosystem services, which would certainly affect livelihoods. Finally, the length of transmission season for malaria is included as an example for impacts of climate change on human health, relevant not only for individuals but also for societies in terms of economic consequences. The selected threshold is a transition from a transmission season shorter than three months to one longer than three months, which is associated with a transition from epidemic to endemic malaria.[133] All the indicators measure potential impacts and do not take into account socioeconomic conditions, livelihood strategies, and a multitude of adaptation options that could mitigate the impacts of the changes. Moreover, no absolute level of impacts is taken into account, merely the crossing of the threshold.

As this analysis is based on multiple impact models per sector, the robustness of results is ensured by requiring at least 50 percent of the models to agree that the threshold has been crossed. A risk estimate is included in the analysis, as the uncertainty stemming from the different impact and climate models turns out to be very large, and a weighting of models is neither possible nor desirable. For that risk estimate, all regions with overlapping impacts are taken into account, without restrictions on the minimum number of models agreeing, and the sectoral crossing temperature is taken as the 10th percentile of all climate-impact-model combinations. The area is estimated in which two, three, and four sectors have crossed their respective thresholds. Note that the maximum area assessed is not equal for all sectors, as crop yields are only considered on present day cropland.

[133] This is based on data from the MARA (Mapping Malaria Risk in Africa) Project: www.mara.org.za.

Appendix 4

Crop Yield Changes under Climate Change

Crop yield projections were extracted from the studies listed in the table below. In an attempt to identify a common pattern of the effects of CO_2 fertilization and adaptation measures on crop yield, all crops were gather together and no distinction was made between crop types, irrigation systems, or regions in Asia. Moreover, whenever a study showed a range of GCM models for a specific crop, the average of the models as representative of yield change was considered.

Table A4.1 List of Studies Analyzed in Chapter 5 on "Agricultural Production"

Crop	Author	Description of Results
All crops	Müller et al. (2010)	In absolute numbers, Müller et al. (2010) project mean changes in crop yield (area-weighted mean crop productivity) for South Asia (here also including Afghanistan and Myanmar) for the 10-year period 2046–55 compared to agricultural productivity in the 10-year period 1996–2005 in the range of –18.9 percent (A1B scenario projections ranging from –7.9 percent to –21.9 percent among the five GCMs), –15.3 percent (A2 scenario projections ranging from –9.9 percent to –16.6 percent), and –14.4 percent (B1 scenario projections ranging from –7.2 percent to –17.8 percent) without CO_2 fertilization (+21.3 percent, +24.6 percent, and +14.6 percent with CO_2 fertilization respectively). Estimations are based on the assumption of static production area and adjustment of sowing dates. For wheat, maize, sunflower, and rapeseed, it is additionally assumed that adaption in selecting suitable varieties is undertaken (Müller et al. 2010).
Rice	Nelson et al. (2009, 2010)	A minor increase of 0.1 percent to 2.6 percent (8.5 to 10.2 percent with CO_2 fertilization) is projected for rainfed rice, while irrigated rice yields are expected to decrease significantly by up to 17.5 percent (+1.4 to 2.5 percent with CO_2 fertilization).
	Jalota et al. (2012)	Rice-wheat cropping systems in central India are projected to see a decline in rice yields of –4.6 percent for 2020, –16.1 percent for 2050, and –29.1 percent for 2080 compared to crop yields under the baseline climate of 1989–2009 (estimates averaged over three GCMs for the A2 SRES scenario leading to a global-mean warming of 2.0°C and 3.2°C above pre-industrial levels by 2050 and 2080). Yield declines are found to be smaller (in the range of –2.4 percent, –13.3 percent, and –26.6 percent, when the transplanting date is shifted by +7 days for rice. Jalota et al. (2012) also find a strong correlation between yield declines and the shortening of crop duration under high temperature, whereas shifting the transplanting date seems to be an effective measure to reduce the shortening of crop duration for both crops (Jalota et al. 2012). When assuming that the full benefits of CO_2 fertilization can be realized, declines in yield are again projected to be lower but still smaller than yield levels under the current baseline climate for both crops. Declines in rice yield are estimated to be in the range of –0.2 percent, –7.0 percent, and –17.5 percent, with no adjustment of sowing dates and for the years 2020, 2050, and 2080, respectively (+2.2 percent, –3.8 percent, and 14.6 percent with shifting the transplanting date by +7 days).
	Ruane et al. (2012)	Bangladesh—Boro Rice without CO_2 fertilization (A2 average of GCMs) Bangladesh—Aman (monsoon) Rice without CO_2 fertilization (A2 average of GCMs) Bangladesh—Aus Rice without CO_2 fertilization (A2 average of GCMs)
Wheat	Jalota et al. (2012)	Declines in wheat yields in the range of –8.8 percent for 2020, –22.5 percent for 2050, and –41 percent for 2080 compared to crop yields under the baseline climate of 1989–2009 (estimates averaged over three GCMs for the A2 SRES scenario leading to a global-mean warming of 2.0°C and 3.2°C above pre-industrial levels by 2050 and 2080). Yield declines are found to be smaller (in the range –4.3 percent, –13.6 percent, and –28 percent) when the transplanting date is shifted by +15 days.
	Nelson et al. (2009, 2010)	The impacts on wheat yields are particularly severe. Irrigated wheat is projected to decrease by up to 53.9 percent (–45.8 percent with CO_2 fertilization) by 2050 compared to 2000 levels of crop yields, while rainfed wheat yields may decline by up to 44.4 percent (–28.9 percent with CO_2 fertilization).
	Ruane et al. (2012)	Bangladesh—Wheat without CO_2 fertilization (A2 average of GCMs)
Maize	Nelson et al. (2009, 2010)	Compared to crop yields in 2000, rainfed maize yields are projected to decline by 2.9 percent to 7.8 percent (+0.2 percent to –4.9 percent with CO_2 fertilization), while irrigated maize is projected to decline by 6.4 percent to 5.5 percent (–4.4 percent to –3.6 percent with CO_2 fertilization).

(*continued on next page*)

Table A4.1 List of Studies Analyzed in Chapter 5 on "Agricultural Production"

Crop	Author	Description of Results
Sorghum	Srivastava, Kumar, and Aggarwal (2010)	For a global-mean warming of 2.0°C and 3.2°C above pre-industrial levels by 2050 and 2080 (A2 SRES scenario) and compared to baseline yields for the period 1970–95, HADCM3 projections show a significant decline in sorghum yields in the major sorghum growing areas (Madhya Pradesh, Andhra Pradesh, and Karnataka) in India. With current management practices, the monsoon crop is projected to decline by 16 percent in Madhya Pradesh and Karnataka, and by 3 percent in Andhra Pradesh by 2020. Declines are more severe for the 2050s and 2080s with reductions in yield of up to 17 percent in Madhya Pradesh and Andhra Pradesh and as much as 76 percent in Karnataka. The winter crop is projected to decline, on average, up to 7 percent by 2020, 11 percent by 2050, and 32 percent in 2080 with strongest declines in Karnataka. These projections account for the potential beneficial effect of higher CO_2 levels, although it has to be noted that sorghum is a C4 crop, for which yield effects of CO_2 fertilization are limited (Srivastava, Kumar et al. 2010). Srivastava et al. (2010)[1] also analyze the effects of low-cost adaptation measures, change in crop variety, and shifting sowing dates, on yield. For the monsoon crop, low-cost adaptation measures can reduce the impact on yield by up to 25 percent in Karnataka in 2050, whereas adaptation gains in Madhya Pradesh and Andhra Pradesh are in the order of 2–4 percent in 2020 and 4–10 percent in the 2050s and 2080s. For the winter crop, projected adaptation gains are, on average, 2–4 percent in 2020, 1–11 percent in 2050, and 12–26 percent in 2080. However, even with adaptation, sorghum yields are expected to decrease 1–2 percent in 2020, 3–8 percent in 2050, and 4–9 percent in 2080 in Madhya Pradesh and Andhra Pradesh, while yield reductions in Karnataka are expected to remain at 3–4 percent post-2020 (Srivastava, Kumar, et al. 2010).
Groundnut	Nelson et al. (2009, 2010)	Groundnut crop yields are expected to decline by 8.9 percent (up to +9.1 percent with CO_2 fertilization) for rainfed crops and by up to 10.6 percent (+9.4 percent with CO_2 fertilization) for irrigated crops (Nelson et al. 2009, 2010).
Soybean	Nelson et al. (2009, 2010)	Rainfed and irrigated soybean yields are both projected to decrease without CO_2 fertilization (up to 13.8 percent and 11.5 percent, respectively) while crop yields may increase when the CO_2 fertilization effect is realized (up to + 7.9 and + 12 percent, respectively).

[1] InfoCrop-SORGHUM simulation model.

Table A4.2 The studies depicted in the graph by Müller (2013), in Chapter 3 of this report

Code	Reference
Pae08	Paeth H, Capo-Chichi A, and W. Endlicher. 2008. Climate Change and Food Security in Tropical West Africa—A Dynamic-statistical Modelling Approach. *Erdkunde* 62: 101–15
Seo08	Seo SN and R Mendelsohn. 2008. Measuring Impacts and Adaptations to Climate Change: A Structural Ricardian Model of African Livestock Management. *Agricultural Economics* 38: 151–65
Lau10	Laux P, Jacket G, Tingem RM, and H. Kunstmann. 2010. Impact of Climate Change on Agricultural Productivity under Rainfed Conditions in Cameroon—A Method to Improve Attainable Crop Yields By Planting Date Adaptations. *Agricultural and Forest Meteorology* 150: 1258–71
Gai11	Gaiser T, Judex M, Igué AM, Paeth H, and C Hiepe. 2011. Future Productivity of Fallow Systems In Sub-Saharan Africa: Is the Effect of Demographic Pressure and Fallow Reduction More Significant Than Climate Change? *Agricultural and Forest Meteorology* 151: 1120–30
Sri12	Srivastava AK, Gaiser T, Paeth H, and F Ewert. 2012. The Impact of Climate Change on Yam (Dioscorea Alata) Yield in the Savanna Zone of West Africa. *Agriculture, Ecosystems & Environment* 153: 57–64
Liu08	Liu JG, Fritz S, van Wesenbeeck CFA, Fuchs M, You LZ, et al. 2008. A Spatially Explicit Assessment of Current and Future Hotspots of Hunger in Sub-Saharan Africa in the Context of Global Change. *Global and Planetary Change* 64: 222–35
Lob08	Lobell DB, Burke MB, Tebaldi C, Mastrandrea MD, Falcon WP, and RL Naylor. 2008. Prioritizing Climate Change Adaptation Needs for Food Security in 2030. *Science* 319: 607–10
Ben08	Benhin JKA. 2008. South African Crop Farming and Climate Change: An Economic Assessment of Impacts. *Global Environmental Change-Human and Policy Dimensions* 18: 666–78
Mue09	Müller C, Bondeau A, Popp A, Waha K, and M. Fader. 2009. *Climate Change Impacts On Agricultural Yields*. Washington, DC: The World Bank.
Nel09	Nelson GC, Rosegrant MW, Koo J, Robertson R, Sulser T, et al. 2009. *Climate Change - Impact on Agriculture and Costs of Adaptation. Rep. 21*, Washington D.C.: International Food Policy Research Institute.
Tho09	Thornton PK, Jones PG, Alagarswamy G, and J. Andresen. 2009. Spatial Variation of Crop Yield Response to Climate Change in East Africa. *Global Environmental Change-Human and Policy Dimensions* 19: 54–65
Tho10	Thornton PK, Jones PG, Alagarswamy G, Andresen J, and M Herrero. 2010. Adapting to climate change: Agricultural system and household impacts in East Africa. *Agricultural Systems* 103: 73–82
Moo12	Moore N, Alagarswamy G, Pijanowski B, Thornton P, Lofgren B, et al. 2012. East African Food Security as Influenced by Future Climate Change and Land Use Change at Local to Regional Scales. *Climatic Change* 110: 823–44
Sch10	Schlenker W, Lobell DB. 2010. Robust Negative Impacts Of Climate Change On African Agriculture. *Environmental Research Letters* 5: 014010
Cli07	Cline WR. 2007. *Global Warming and Agriculture. Impact Estimates by Country*. Washington, DC: Center for Global Development and Peterson Institute for International Economics
Wal08	Walker NJ, and RE Schulze. 2008. Climate Change Impacts on Agro-Ecosystem Sustainability Across Three Climate Regions in the Maize Belt of South Africa. *Agriculture Ecosystems & Environment* 124: 114–24
Igl11	Iglesias A, Quiroga S, and A Diz. 2011. Looking into the Future of Agriculture in a Changing Climate. *European Review of Agricultural Economics* 38: 427–47
Ber12	Berg A, de Noblet-Ducoudré N, Sultan B, Lengaigne M, and M Guimberteau. 2012. Projections of Climate Change Impacts on Potential C4 Crop Productivity over Tropical Regions. *Agricultural and Forest Meteorology*
Seo09	Seo SN, Mendelsohn R, Dinar A, Hassan R, and P Kurukulasuriya. 2009. A Ricardian Analysis of the Distribution of Climate Change Impacts on Agriculture across Agro-Ecological Zones in Africa. *Environmental & Resource Economics* 43: 313–32
Tan10	Tan ZX, Tieszen LL, Liu SG, and E Tachie-Obeng. 2010. Modeling to Evaluate the Response of Savanna-derived Cropland to Warming-drying Stress and Nitrogen Fertilizers. *Climatic Change* 100: 703–15
Tho11	Thornton PK, Jones PG, Ericksen PJ, and AJ Challinor. 2011. Agriculture and Food Systems in Sub-Saharan Africa in a 4°C+ World. *Philosophical Transactions of the Royal Society A Mathematical, Physical & Engineering Sciences* 369: 117–36

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