CLIMATE CHANGE

Mitigation, Vulnerability, and Adaptation in Developing and Transition Countries

U.S. Country Studies Program Support for Climate Change Studies, Plans, and Technology Assessments

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Support for Climate Change

Studies, Plans, and Technology Assessments

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This report has not been subjected to official technical or policy review. It does not necessarily represent the views of the U.S. Government, other governments, or multilateral bodies.

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Nine climate change specialists in U.S. Country Studies Program (USCSP) countries served as technical editors of the report: Leoncio Amadore (Philippines), Saleemul Huq (Bangladesh), Wilfred D. Kipondya (Tanzania), Alexey Kokorin (Russian Federation), Julia Martinez (Mexico), Francis Mkanda (Malawi), Olga Pilifosova (Kazakhstan), Cecilia Ramos-Mañé (Uruguay), and Wu Zongxin (China). Many of the Country Study Coordinators in Program countries also offered comments on the draft versions of this document. Additional technical review was conducted by Ron Benioff and Brandon Owens at NREL, and Jayant Sathaye and Steve Meyers at Lawrence Berkeley National Laboratory.

This effort, and more broadly the U.S. Country Studies Program, owes its success to the hundreds of researchers in the 56 countries participating in the Program who are responsible for the body of work upon which this document is based. They have made an invaluable contribution to the international field of climate change science and policy.

Executive Summary

This report provides an overview of the work conducted by developing and transition countries participating in the U.S. Country Studies Program (USCSP, or the Program). Under this Program, participating countries evaluated climate change mitigation options, assessed their vulnerability to climate change, identified methods for adapting to climate change, and developed plans for responding to climate change.

Since its inception, the USCSP has facilitated:

- a high level of participation of developing and transition countries
- increased capacity of climate change researchers in developing and transition countries
- a better understanding of current emissions and projected growth in individual countries
- a better understanding of high greenhouse-gas-emitting sectors, mitigation options, costs of mitigation, and barriers to implementing mitigation options
- a better understanding of countries' vulnerability to climate change, and their potential for adaptation.

Additionally, the Program has offered training and technical assistance through workshops and publications.

Mitigation Analysis Results

Many of the countries participating in the USCSP conducted analyses of options for mitigating greenhouse gas (GHG) emissions. These mitigation analyses model the climate change impacts of these options alone and in combination with other options, and in some cases, provide quantitative assessments of the costs of mitigation. Thirty-five of 56 USCSP participants have initiated mitigation studies. Almost all of these countries have completed these studies. The country participants that conducted mitigation assessments considered emission reduction options in the energy, forestry, agriculture, waste, and industrial (non-energy) sectors. The energy sector was the highest priority for participants, followed by the forestry sector.

Despite population pressures and economic growth that suggest that emissions from developing countries will increase in the future, more than two-thirds of the USCSP participants conducting mitigation assessments demonstrate the ability to reduce CO_2 emissions by at least 10 percent below projected baselines by 2010. In addition, most transition countries expect to achieve emission levels close to their 1990 levels in 2010, even without considering mitigation options.

The key findings of the mitigation analyses are summarized below by sector. In addition, the participating countries analyzed barriers to the development and implementation of new technologies, and mechanisms for implementation of mitigation options. These findings also are presented below.

Energy Sector

Energy Supply

- The energy supply sector offers the greatest mitigation potential. Countries participating in the USCSP identified a number of promising options in the power sector, including both short-term and long-term opportunities.
- Improving energy efficiency of power plants is the most important energy sector option in the near term.
- Installing renewable energy and energy-efficiency technologies and switching from carbon-intensive fossil fuels are long-term priorities.
- Considerable improvements in regional air quality may result from mitigation measures in the energy supply sector.

Industrial Sector

- The industrial sector offers the next largest energy-related mitigation potential after the energy supply sector. Increasing the use of cogeneration, improving boiler efficiency, and improving the efficiency of motors and lighting are attractive mitigation options, in terms of emission reduction potential and costs. Negative incremental costs were found for a number of these options by the majority of countries analyzing costs.
- Improving energy efficiency is the highest priority in the industrial sector. In both developing and transition countries, existing equipment is generally energy-inefficient and offers considerable mitigation potential. Significant reductions can be achieved by increasing the efficiency of supply-side and demand-side technologies.

Residential/Commercial and Institutional Sector

- The residential/commercial and institutional sector has significant opportunities for cost-effective emission reductions. In general, installing energy-efficient lighting was found to be the most important money-saving option in a number of countries. Other opportunities for savings include increasing the efficiency of appliances and replacing traditional energy sources with renewable energy or electricity.
- Both transition and developing country participants generally reported that GHG emissions from the residential/commercial and industrial sector are likely to increase substantially in the future. This increase is due largely to a combination of population growth and increased energy consumption per capita, resulting from continued urbanization and improvements in the standard of living.

Transportation Sector

- Further study is needed in the transportation sector. While the need to identify mitigation options in the transport sector was recognized by many countries, few countries provided a quantitative analysis of particular mitigation options.
- Transportation sector emissions are increasing rapidly in both transition and developing countries.
- The range of mitigation potential and costs for the transportation sector varied widely.

Forestry Sector

- The three highest priority mitigation options in the forestry sector examined by USCSP participants were (1) afforestation, reforestation, and forest productivity improvements; (2) protection of existing forests; and (3) substitution of sustainably produced biofuel for fossil fuels and substitution of wood products for more emission-intensive, nonwood products.
- Reforestation and afforestation were determined to be the most promising mitigation options in the forestry sector of the transition countries because for-

est management is already fairly developed, annual rates of change in forest cover are negligible or positive, and fuelwood is not a major source of energy.

- Forest protection mitigation options were considered by participating countries in Asia and Africa. This may be due to pressure on forests from rapid population growth in those countries.

Agricultural Sector

- Mitigating emissions from rice cultivation is critical for most Asian countries and in Côte d'Ivoire because rice cultivation is the largest source of agricultural GHG emissions in these countries. Mitigation options focused mainly on changes in water management practices and switching to alternative rice cultivars.
- Livestock production accounts for more than half of total methane and nitrous oxide emissions in all of the participating countries in Central and Eastern Europe, the Former Soviet Union, and Latin America, and in most participating African countries. Improving livestock productivity through improved nutrition was the most common mitigation option considered. Manure management options, such as methane recovery for use as energy, were also a priority.
- More research is needed to analyze emission reduction potential and costs associated with mitigation options in all areas of this sector.

Waste Sector

- For many USCSP participants mitigating GHG emissions from the waste sector was generally not a high priority because methane emissions associated with this sector are relatively low.
- For those that did analyze this sector, landfill methane recovery and utilization as energy, comprehensive waste management, and alternative waste management (recycling, composting, etc.) were priority mitigation options.

Industrial Processes (Non-Energy)

- Process emissions from the industrial sector represent a small percentage of overall national GHG emissions in transition and developing countries, and were not a priority for mitigation analysis. The USCSP participants that evaluated mitigation options in this sector focused primarily on the cement, lime, pulp and paper, and iron and steel industries.

Barriers to Implementation of GHG Mitigation Options

Program participants identified the following barriers to the development and implementation of new technologies and energy sources across sectors:

- Insufficient domestic infrastructure for supporting new technologies and new energy sources.
- Insufficient capital for investment in development of new technologies, energy sources, and infrastructure.
- A lack of data and methods for conducting comprehensive cost-benefit analyses of mitigation options.
- The high capital costs of purchasing more efficient technologies, and a lack of a mechanism for reducing the initial costs borne by consumers.
- A lack of domestic supply of renewable energy and energy-efficiency technologies and certain alternative fuel sources.
- Existing policies and regulations that favor current technologies and energy sources and discourage the development and implementation of new technologies and energy sources.
- A lack of people trained in the manufacture, installation, use, and maintenance of new technologies as well as in the implementation of new resource management practices.
- A lack of general education to improve public awareness and acceptance of new technologies and resource conservation opportunities.
- A lack of access to efficient technologies because of insufficient networks for equipment distribution and maintenance.
- General economic or political instability, leading to competing demands for scarce economic resources and political attention.

Economic and Other Policy Mechanisms for Implementation of Mitigation Options

- While countries generally recommended the use of tax incentives and subsidies to support emissions-reduction activities, countries did not reach firm conclusions about the ultimate effectiveness and feasibility of taxes on carbon or energy consumption.

Vulnerability and Adaptation

Forty-nine of the 56 participating countries conducted assessments of the vulnerability of their climate-sensitive resources (i.e., the potential physical and economic impacts of climate change). Several countries also addressed adaptation (i.e., steps that countries could take to respond to the physical impacts of climate change). The vulnerability and adaptation assessments cover eight sectors that are sensitive to climate change: coastal resources, agriculture, grasslands/livestock, water resources, forests, fisheries, wildlife, and human health.

Vulnerability

In general, it appears that more heavily managed systems are less at risk than relatively unmanaged systems. For the managed systems, the USCSP participants found the following:

- Sea level rise could cause substantial inundation and erosion of valuable lands, but protecting developed areas would be economically sound. Limited assessments of the ecological consequences of sea level rise were conducted.
- Across the 49 participating countries, there were mixed results for changes in crop yields. African and Asian countries, particularly southern Asian countries, tended to estimate decreases in yields. Many participating countries found mixed results, and some even estimated increases in yield of some crops, particularly in Europe and Latin America. Adaptation could significantly affect yields, but it is not clear whether these adaptations are affordable or feasible (e.g., whether farmers could afford fertilizers or pesticides).
- Impacts on water resources are unclear mainly because of uncertainty about regional changes in precipitation patterns. The studies show that runoff is highly sensitive to climate change, which could result in increases in droughts or floods. The ability of water resource systems to adapt was not thoroughly assessed.
- The impacts on grasslands and livestock are mixed, but for the few countries studied, there appears to be a large capacity for adaptation.

For the more unmanaged systems, the vulnerability assessments found the following:

- Climate change could result in increased human health problems, particularly for populations in low-latitude countries with inadequate access to health care.
- The composition of forests is likely to change. Many of the assessments found that biomass could be reduced.
- There are potentially negative impacts on wildlife, threatening the populations of some species.
- The effects on fisheries are indeterminate.

Adaptation

- In coastal sector analyses, protection options for sea level rise scenarios up to 1 meter by 2100 were evaluated. The benefits (e.g., avoided land and infrastructure losses) generally exceeded the costs for most of the locations studied. However, researchers found that costs could outweigh benefits along less-developed shoreline segments.
- In the agriculture sector, seed banks were among the more cost-effective options in Kazakhstan and Uruguay. Egypt found that switching crops or cultivars was the best option. Other options in this sector focused on educational or outreach activities to alter farm-level management practices. This suggests that the first reaction in adaptation may be to examine technological- or operator-level changes that may enable activities such as farming or living in coastal areas to continue as before. Policy changes as a means of addressing these issues were not preferred. The results, however, are too preliminary to draw any conclusions about whether these trends indicate

that technological or educational/outreach options are the best adaptation approaches in these sectors.

- The adaptation options across sectors primarily affected domestic activities. However, there were some options pertaining to uses of international rivers that would benefit from international coordination. This suggests that it will be important to coordinate some adaptation assessments and activities at the international level. It will also be important to ensure that adaptation options are consistent with other policy objectives such as greenhouse gas emissions reduction.

1. Introduction

This report presents an overview of the work conducted to date by developing countries and countries with economies in transition participating in the U.S. Country Studies Program (USCSP, or the Program) in evaluating climate change mitigation options, assessing their vulnerability to climate change, identifying methods for adapting to climate change, and developing plans for responding to climate change. Table 1 presents the work that participating countries have conducted under the Program.

1.1 U.S. Country Studies Program

The USCSP, first announced in 1992 at the United Nations Conference on Environment and Development in Brazil, provides developing countries and countries with economies in transition with financial and technical assistance in order to address the problem of global climate change. The main goal of the Program has been to enhance the capacity of developing and transition countries to conduct their own studies and develop country-specific strategies and priorities for understanding and addressing the problem of climate change.

Developing and transition countries have received assistance in:

- preparing inventories of their emissions and sinks of greenhouse gases (GHGs)
- identifying and evaluating options for controlling GHG emissions and for increasing GHG emissions sinks
- assessing their potential vulnerability to climate change and approaches for adapting to such change
- developing national action plans for addressing climate change
- assessing related technological needs that increase public understanding of climate change.

The USCSP has been a highly collaborative effort. Ten U. S. government agencies participate in the USCSP (see Box 1). Fifteen senior officials from participating countries helped to shape the Program by working for a number of months with the Country Studies Management Team in Washington, DC. The Program has also coordinated its activities with, and benefited greatly from, those of the Secretariat of the United Nations Frame-

Box 1 U.S. Government Agencies Participating in the USCSP

- *Department of Agriculture*
- *Department of Energy*
- *Department of Health and Human Services*
- *Department of the Interior*
- *Department of State*
- *Agency for International Development*
- *Environmental Protection Agency*
- *National Aeronautics and Space Administration*
- *National Oceanic and Atmospheric Administration*
- *National Science Foundation*

Table 1 Reporting Status

Country	Inventory	V&A	Mitigation	Action Plan
Bangladesh	T	T	T	In process
Bolivia	T	T	T	T
Botswana	In process	In process	In process	NA
Brazil	T	NA	NA	NA
Bulgaria	T	T	T	In process
Central America*	NA	T	NA	NA
Chile	T	NA	NA	NA
China	T	T	T	In process
Cote d'Ivoire	T	T	T	NA
Czech Republic	T	T	T	T
Ecuador	T	T	T	NA
Egypt	NA	T	T	In process
Estonia	T	T	T	NA
Ethiopia	T	T	T	NA
Fiji	T	T	NA	NA
Gambia, The	T	T	NA	NA
Hungary	T	NA	T	T
Indonesia	T	T	T	In process
Kazakhstan	T	T	T	T
Kenya	T	T	NA	NA
Kiribati	T	T	NA	NA
Malawi	T	In process	In process	NA
Marshall Islands	T	T	NA	NA
Mauritius**	T	T	NA	T
Mexico	T	T	T	T
Micronesia	T	T	NA	T
Mongolia	T	T	T	NA
Mozambique	In process	T	In process	NA
Nepal	T	T	T	NA
Nigeria	T	NA	T	NA
Oman	T	NA	NA	NA
Peru	T	T	T	NA
Philippines	T	T	T	In process
Poland	NA	T	T	NA
Romania	T	T	T	NA
Russian Federation	T	T	T	T
Samoa	T	In process	NA	NA
Slovak Republic	T	T	T	NA
South Africa	T	In process	In process	NA
Sri Lanka	T	T	T	NA
Tanzania	NA	T	T	In process
Thailand	T	T	In process	In process
Uganda	T	T	T	NA
Ukraine	T	T	T	T
Uruguay	NA	T	NA	T
Venezuela	T	T	T	T
Zambia	T	T	NA	NA
Zimbabwe	T	T	T	NA

T = completed report received
In process includes draft, draft final.
NA = not applicable or this work may have been funded by other donor organizations.
Countries in italics are in SNAP.
*Central America includes Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama.
**Mauritius assessed mitigation options in its Action Plan.
Note: Argentina and Malaysia are USCSP participants, but only engaged in technical cooperation.

work Convention on Climate Change (UNFCCC), the United Nations Environment Programme, the United Nations Development Programme, the Global Environment Facility, and numerous other multilateral and bilateral institutions and programs.

1.2 Major Results

The major results of the USCSP include the following:

- A high level of participation of developing and transition countries: 56 countries have participated in the Program.
- Increased capacity of climate change researchers in developing and transition countries: hundreds of researchers in countries participating in the USCSP are capable of continuing research on climate change impacts, mitigation, and adaptation, and advising policy makers on the vulnerability of their countries to climate change and options for mitigation and adaptation.
- A better understanding of current emissions and projected growth in individual countries: 43 countries have prepared national greenhouse gas inventories.
- A better understanding of high GHG-emitting sectors, mitigation options, cost of mitigation, and barriers to implementing mitigation options in those sectors in participating countries: 35 countries have undertaken studies of mitigation options; 19 countries also conducted mitigation assessments and vulnerability and adaptation assessments under the Support for National Action Plans (SNAP) Program.
- A better understanding of countries' vulnerability to climate change, and their potential for adaptation: 49 have conducted vulnerability and adaptation assessments.

Earlier reports summarizing the results of the Program include:

- *Greenhouse Gas Emission Inventories: Interim Results from the USCSP* (Braatz et al., 1996).
- *Vulnerability and Adaptation to Climate Change: Interim Results from the U.S. Country Studies Program* (Smith et al., 1996a).
- *Global Climate Change Mitigation Assessment: Results for 14 Transitioning and Developing Countries* (Meyers et al., 1997b).
- *Climate Change Assessments by Developing and Transition Countries: U.S. Country Studies Program Support for Climate Change Studies, Plans, and Technology Assessments* (USCSP, 1998).

1.3 Technical Guidance, Training, and Assistance

The USCSP has given great emphasis to the development and provision of technical guidance, training, and ongoing technical assistance during the conduct of countries' studies. An array of guidelines, state-of-the-art models, and other analytical tools for conducting climate change studies has been developed or disseminated. This analytical support is summarized in four primary guidance documents:

1. *1995 IPCC Guidelines for National Greenhouse Gas Inventories* and *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1995; 1997)

2. *Steps in Preparing Climate Change Action Plans: A Handbook* (Benioff and Warren, 1996)

3. *Vulnerability and Adaptation Assessments: An International Handbook* (Benioff et al., 1996)

4. *Greenhouse Gas Mitigation Assessment: A Guidebook* (Sathaye and Meyers, 1995).

To ensure that countries could use these tools most effectively, the Program has also provided extensive training in the adaptation of these tools to meet each country's unique circumstances and informational needs. This support included the provision of training at 10 global workshops and over 20 regional workshops, as well as more than 100 visits to the participating countries by technical experts.

Except in the greenhouse gas emission inventories, where all countries used the Intergovernmental Panel on Climate Change (IPCC) Guidelines, participating countries were encouraged to adapt these tools

and develop their own methods to meet their own unique circumstances and informational needs.[1] This approach has enabled countries to direct their effort and resources to the areas of greatest interest and importance to them and increased the breadth of the overall body of work. Therefore, the scope and depth of the assessments necesarily vary widely. Given this variation, it is not practical to aggregate the findings of the countries into a comprehensive statement of their climate change mitigation potential, cumulative vulnerability to climate change, or costs and benefits of adaptation. Emissions and cost information are presented in this report as provided by each country, unless noted otherwise.

1.4 Greenhouse Gas Emission Inventories

The USCSP has provided financial and technical support to 43 developing and transition countries to assist them in preparing greenhouse gas emissions inventories. National inventories identify and quantify national GHG emissions from five key source categories, including energy, land use change and forestry, agriculture, industrial processes, and waste. Most countries developed their inventories using the *1995 IPCC Guidelines for National Greenhouse Gas Inventories*. However, some have begun to update their inventories using the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*.

The technical support provided by the Program has included:

- training in the preparation of GHG inventories
- guidance in inventory design and data collection
- review of preliminary and draft inventories
- organization and delivery of regional workshops to share results and discuss issues of regional significance
- assistance in the preparation and reporting of inventory results.

In most cases, the national greenhouse gas inventories developed by countries participating in the Program, either with assistance from or independently of USCSP, have played a central role in the countries' mitigation assessments. The preparation of inventories enabled these countries to improve their understanding of the relationship between resource management activities and GHG emissions or carbon sequestration. It also enabled them to develop a base-year estimate of emissions and sequestration that could then be used to provide key inputs for scenario development and modeling. This report does not review the national inventory work undertaken by countries under the USCSP; a summary of the results of national inventories can be found in *Greenhouse Gas Emission Inventories: Interim Results from the USCSP* (Braatz et al., 1995). Provided below is a brief outline of the activities related to the development of the national inventories, and a summary of key findings from this effort (see Box 2).

The three basic elements of the inventory development process are as follows:

- **Preparatory work for inventory participants**. Training workshops for inventory teams from the participating countries were offered in each of the USCSP regions (Africa, Asia, Central and Eastern Europe, and Latin America) and in Washington, DC, and addressed various aspects of inventory development. In addition, the country teams held kickoff workshops after the training was completed and the inventory had been structured. The purpose of the kickoff meeting was to introduce the national inventory effort to the public and private sectors.
- **Development of three versions of the inventory.** The preliminary inventory is prepared solely using the IPCC Tier 1 Methods, and is compiled in order to identify significant sources of GHG emissions. Additional data gathering needs are also identified at this stage. After the country team and the USCSP have reviewed the preliminary inventory, and the additional data has been gathered, a draft inventory is prepared. This document is the first attempt at creating a complete inventory and includes more

[1] The IPCC Guidelines already allow countries to adapt portions of the methodologies to meet national circumstances.

Box 2 Main Conclusions from the USCSP National Inventories

GENERAL

- *Of the participating countries, the most highly industrialized and highly populated countries produced the largest emissions.*

ENERGY

- *Per capita emissions of carbon dioxide from fossil fuel combustion and per unit gross domestic product (GDP) carbon dioxide emissions were highest in the more industrialized and energy-intensive countries, and in the transition countries were comparable to, or higher than, emissions in the United States, United Kingdom, and Japan.*
- *The countries in each region reporting the greatest carbon dioxide emissions from fossil energy also had the highest GDP and, except for South Africa, the highest population.*
- *Carbon dioxide is the most important GHG in many industrialized countries of Africa, Asia, Latin America, and Central and Eastern Europe because they typically have energy-intensive economies and rely largely on fossil fuels. In other countries in Africa, Asia, and Latin America, carbon dioxide is the most important GHG because of land use change and forestry.*
- *Smaller countries and those using large quantities of biofuels are the smallest emitters of carbon dioxide. These countries produced a significant portion of the methane and nitrous oxide emissions from the energy sector.*

LAND USE CHANGE AND FORESTRY

- *Land use change and forestry activities appear to be an important source of GHG emissions, especially carbon dioxide, in all Latin American countries, and in several African and Asian countries.*
- *Land use change and forestry are also important carbon sinks in several countries, especially Zimbabwe, where carbon sequestration from forestry far exceeds total gross emissions of carbon dioxide, methane, and nitrous oxide.*

AGRICULTURE

- *Methane is most important in countries in which agriculture is the predominant source category. This is due primarily to heavy use of biomass as fuel, large emissions from livestock, rice cultivation, and savanna burning.*
- *Livestock account for 50% or more of methane and nitrous oxide emissions in all participating countries in Africa (except Uganda) and Latin America, and in the transition countries.*
- *Rice cultivation is the largest source of agricultural GHG emissions in all participating Asian countries except Bangladesh, where livestock and agriculture produce the same amount of emissions, and Mongolia, where rice is not grown.*
- *Per capita GHG emissions from agriculture are much more uniform across countries and regions than per capita fossil fuel carbon dioxide emissions.*

Source: USCSP, 1998.

refined estimation methods and a bottom-up estimate of energy sector emissions. This version is again reviewed by the USCSP and the final inventory is prepared based on the comments provided during reviews.

- **Presentation of results**. Results of the final inventory are presented to the public by the country participants at the national workshop, providing an opportunity to raise public awareness of GHG emissions and focus public attention on the future work of vulnerability and adaptation assessments and mitigation analysis.

1.5 The SNAP Program

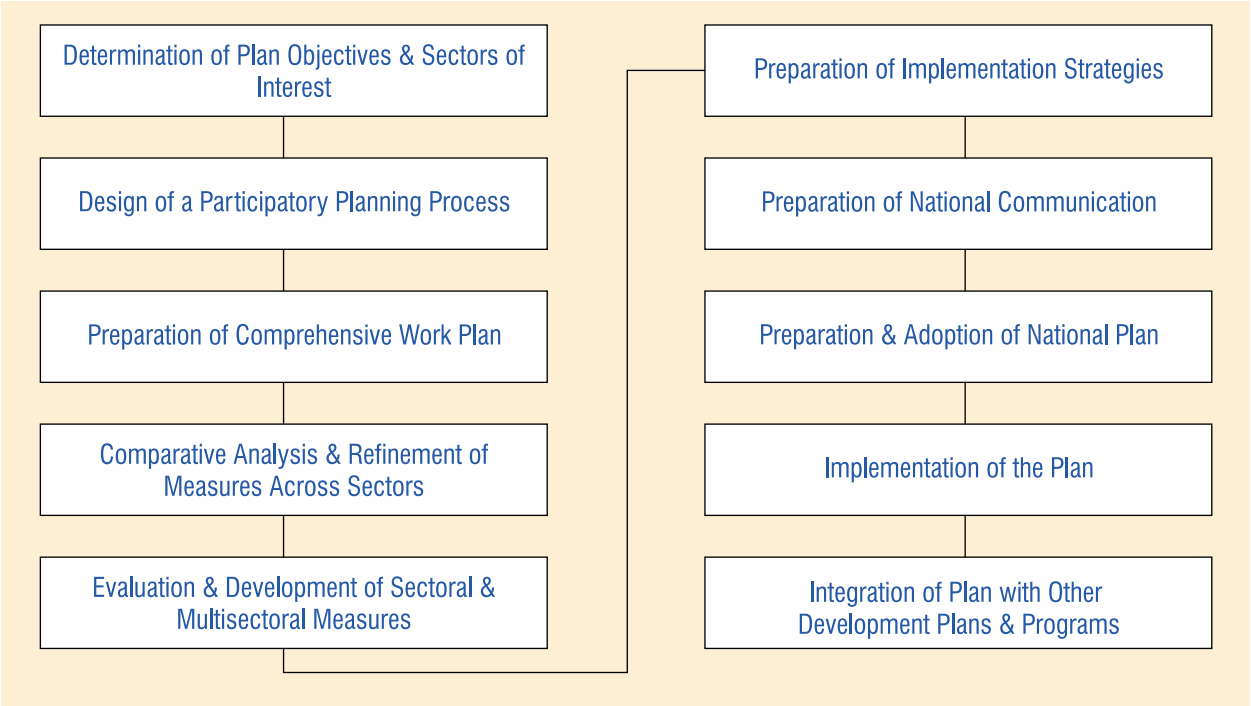
The SNAP Program is assisting countries with developing climate change action plans that integrate the findings of their USCSP Country Study into a comprehensive national policy response to the problem of climate change (see Figure 1). Countries can use these plans as the basis for their National Communications to the UNFCCC. In this report, the work on assessing mitigation options and vulnerability and adaptation options undertaken through the SNAP Program has been integrated into each chapter and is not reported separately.

The objectives of the SNAP Program are:

- to assist countries in preparing climate change action plans that may form the basis of their national communication
- to promote diffusion of mitigation and adaptation technologies
- to enhance support for the objectives and principles of the UNFCCC.

In addition, countries may have their own objectives for preparing climate change action plans, such as:

Figure 1 National Action Plan Preparation Process



Source: USCSP, 1998.

- integrating climate change concerns into other planning processes and programs
- catalyzing consensus and support for climate change mitigation and adaptation measures that will contribute to sustainable development
- developing a plan to achieve specific national mitigation or adaptation goals.

In almost all cases, priority was given to measures that will contribute to sustainable development and measures that will confer economic, social, and environmental benefits.

- Almost all countries focused on mitigation options in the energy sector, recognizing that increased efficiencies in energy production, distribution, and utilization will provide direct economic benefits and improve public health by reducing environmental pollution.
- Vulnerability and adaptation measures designed to preserve food security through improved agricultural productivity and water supply systems are high priorities in national action plans.
- There are certain problems and prospective solutions that countries have in common and may benefit from addressing cooperatively. For instance, neighboring countries whose water resources and agricultural systems are vulnerable to increased incidence of drought and who share a common river could derive benefits from working together. Similarly, countries within a region could organize a regional seed bank to optimize crop variety and increase flexibility within their agricultural systems.

1.6 Report Structure

The main sections of the report focus on the mitigation assessments and the vulnerability and adaptation assessments conducted by the countries participating in the USCSP.

Section 2 contains a summary of the mitigation assessments conducted under the USCSP. The mitigation analyses are presented by sector: energy, forestry, agriculture, waste, and industrial processes. This section also addresses barriers to implementation of GHG mitigation options, as well as economic and other policy mechanisms for the implementation of GHG mitigation options.

Section 3 summarizes the vulnerability and adaptation work that participating countries performed under the USCSP. This section reports on the vulnerability and adaptation potential of coastal resources, agriculture, grasslands and livestock, water resources, forests, fisheries, wildlife, and human health.

Appendices A, B, and C of this report contain more detailed technical information on the methods used by participating countries to prepare their vulnerability and adaptation assessments. Appendices D and E define terms and abbreviations used in the document, respectively. Relevant tables for the conversion of weights and measures are listed in Appendix F. Appendix G contains the bibliography.

2. Mitigation Assessments Under USCSP

2.1 Introduction

This section presents the results of mitigation assessments conducted by countries participating in the USCSP. In the mitigation assessments, the countries identified and evaluated technology and policy options to reduce greenhouse gas emissions and sequester carbon. As shown in Figure 2, 35 of the 56 USCSP participants have initiated studies of mitigation options–31 countries have submitted final studies, and 4 countries are in the process of preparing or completing them. Several of the 56 countries are participating in the SNAP initiative of the Program and have enhanced their studies under this initiative.

2.1.1 Objectives and Scope of USCSP Mitigation Assessments

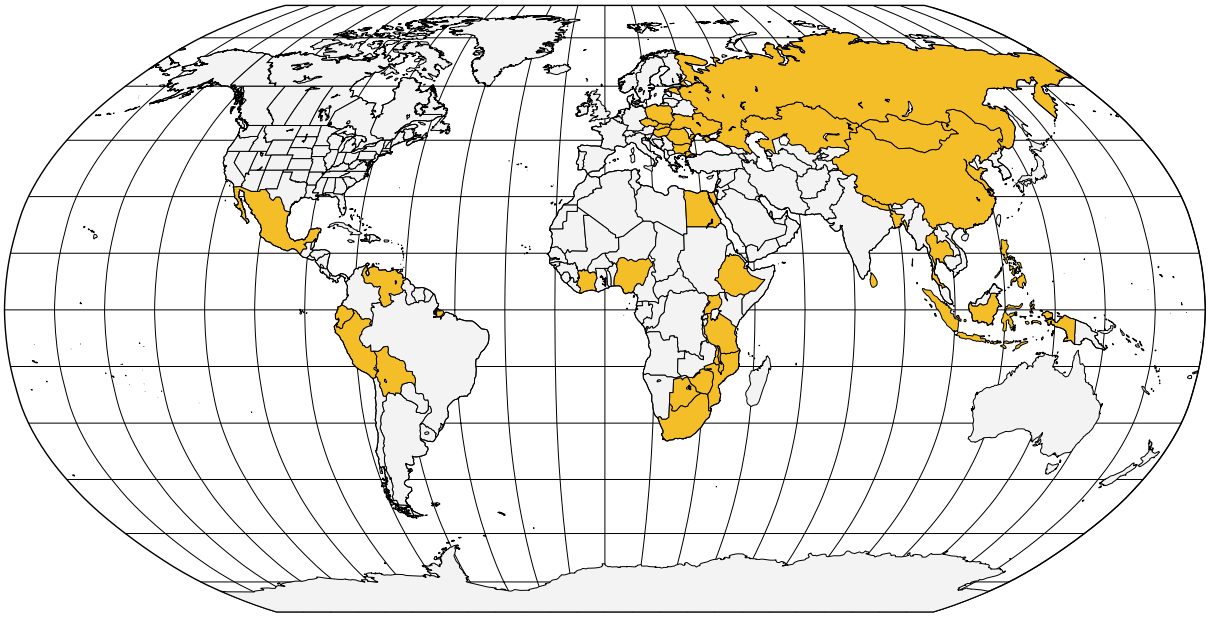
The mitigation assessments were primarily intended to help developing and transition countries[2] identify and evaluate short- and long-term options to reduce GHG emissions. A mitigation assessment allows a country to compare mitigation options or scenarios using a broad set of indicators, including GHG emission reduction potential, cost-effectiveness, and ancillary environmental and social benefits. In this way, the mitigation assessments help countries set priorities for reducing emissions based on the relative implications of their actions. Mitigation assessments evolve as new information becomes available and technology advances. By emphasizing capacity building and training in-country scientists, the Program has helped build the foundation for future mitigation assessments.

Mitigation assessments are one of the key elements of national action plans and provide the framework for integrating GHG mitigation options into national development strategies. Mitigation assessments, in addition to evaluating mitigation options, also address specific technical, market, or economic conditions that could hinder the widespread implementation of emission reduction technologies or practices. Countries typically include in their mitigation assessments options for overcoming these barriers, including legal mechanisms, market-based incentives, educational programs, and international policy mechanisms.

The mitigation assessments conducted by USCSP participants have taken on increased importance since the signing of the Kyoto Protocol. The Protocol, which has not yet entered into force, sets quantified emission limitation and reduction targets for Annex I Parties (i.e., developed countries), which include transition countries. In addition to undertaking domestic GHG mitigation actions, Annex I Parties may meet a portion of their commitments through joint GHG mitigation efforts involving other Annex I Parties and non-Annex I Parties. The

[2] Transition countries are those in Central and Eastern Europe, and the Former Soviet Union.

Figure 2 Countries That Have Conducted Mitigation Assessments Under the U.S. Country Studies Program



Africa & the Middle East	Asia & the Pacific	Transition Countries	Latin America
Botswana*	Bangladesh	Bulgaria	Bolivia
Côte d'Ivoire	China	Czech Republic	Ecuador
Egypt	Indonesia	Estonia	Mexico
Ethiopia	Mongolia	Hungary	Peru
Malawi*	Nepal	Kazakhstan	Venezuela
Mauritius**	Philippines	Poland	
Mozambique*	Sri Lanka	Romania	
Nigeria	Thailand	Russian Federation	
South Africa*		Slovak Republic	
Tanzania		Ukraine	
Uganda			
Zimbabwe			

* Mitigation reports not yet completed.
** Mauritius assessed mitigation options in its action plan.

mitigation assessments conducted by USCSP participants and the understanding gained from developing them have helped, and will continue to help, these countries participate in international climate change mitigation efforts in a meaningful way. Based on the mitigation assessments of the countries participating in the USCSP, key findings are as follows:

- **Although population pressures and economic growth suggest that emissions from developing countries will increase in the future, more than**

two-thirds of the USCSP participants conducting mitigation assessments demonstrate the ability to reduce CO_2 emissions by at least 10 percent below projected baselines by 2010. The mitigation assessments vary considerably in their scope and thus in the range of projected carbon emission reductions. For example, Estonia estimates emission reductions of less than 5 percent in 2010 and China estimates reductions of 24 percent in that same year.

- **Most transition countries expect to achieve emission levels close to their 1990 levels in 2010, even without considering mitigation options.** As Annex I Parties to the FCCC, most of the transition countries have expressed their commitment not to exceed their base year level of GHG emissions in 2000. The baseline scenarios developed in the country studies indicate that they will easily meet this commitment. Within their mitigation scenarios, nearly all of the transition countries demonstrate the ability to maintain 1990 CO_2 emission levels in 2010.

The scope of the mitigation assessments varies greatly among countries. As shown in Table 2, each country conducted a qualitative and/or quantitative assessment of mitigation options for one or more of the following sectors: energy, forestry, agriculture, waste, and industrial processes. For most countries, reducing emissions associated with energy activities is a top priority, and all countries addressed these activities to varying degrees. Another priority area for a number of countries is reducing emissions or sequestering carbon from forestry activities. Emissions from agriculture, waste, and industrial processes were addressed by countries where emissions are significant and where mitigation options are readily available.

While there is clearly a wide range of mitigation measures available in developing and transition countries, it is also clear that not all measures have been fully considered by all countries. Some of the country teams conducted comprehensive assessments that examined a wide range of options for numerous sectors and estimated their potential future impact in the context of integrated national scenarios. Others focused on specific energy sector options only.

2.1.2 Methods for Conducting USCSP Mitigation Assessments

The methods used to assess mitigation options varied widely among sectors and by country. In general, the steps followed for mitigation analysis are as follows:

- assembling base year data
- characterizing and screening technology options
- projecting future activity levels and demand for energy or other products
- developing a baseline scenario
- defining and analyzing mitigation options
- developing one or more mitigation scenarios
- assessing impacts on the economy, social goals, and local environment.

These steps are illustrated in Figure 3.

To assist in the development of these studies, a USCSP technical support team provided training in the preparation of mitigation assessments and prepared *Greenhouse Gas Mitigation Assessment: A Guidebook* (Sathaye and Meyers, 1995). The team also conducted workshops and conferences on developing and evaluating GHG mitigation practices and strategies in Africa, Asia and the Pacific, Europe, and Latin America. These workshops involved over 750 participants and addressed mitigation assessment issues and analytical methods.

To conduct their mitigation assessments, participants selected econometric models, spreadsheets, and methods that best suited their data sources, technical capibilities and socioeconomic needs and priorities. The design and underlying assumptions of the various models vary greatly, and therefore do not facilitate a comparison of mitigation potential and costs across countries. The mitigation assessments, however, provide a comparison of options within a given country and help countries to set national priorities.

2.1.3 Analytical Results

The most recent versions of mitigation analyses submitted by the participating countries have been used to compile the data contained in this section. Country reports are in various stages of preparation, and many continue to evolve. The information presented here comes

Table 2 Country Summary of Mitigation Assessments by Sector

Country	Energy Supply	Industry	Residential & Commercial/ Institutional	Transport	Forest	Agriculture	Waste	Industrial Processes (Non-Energy)
Africa & the Middle East								
Côte d'Ivoire	•	•	•	•	•	•	•	
Egypt	•	•	•		•	•	•	•
Ethiopia	•	•	•	•		•		
Mauritius	•	•	•	•	•		•	
Nigeria	•	•	•	•	•			
Tanzania	•	•	•	•	•	•		•
Uganda		•	•	•	•		•	•
Zimbabwe	•	•	•	•	•			•
Asia & the Pacific								
Bangladesh	•	•	•	•	•			
China	•	•	•	•	•	•	•	
Indonesia	•	•	•		•	•	•	
Mongolia	•	•	•		•	•		
Nepal	•	•	•	•				
Philippines	•	•	•	•	•	•	•	
Sri Lanka	•	•		•		•	•	•
Thailand	•	•	•	•	•	•	•	
Latin America								
Bolivia	•	•	•	•	•	•	•	
Ecuador	•	•	•	•	•	•		
Mexico	•	•	•	•	•	•		
Peru	•	•	•	•		•		
Venezuela	•	•	•	•	•			
Transition Countries								
Bulgaria	•	•	•	•	•	•	•	
Czech Republic	•	•	•	•	•	•	•	
Estonia	•	•	•	•	•	•	•	
Hungry	•	•	•		•	•	•	
Kazakhstan	•				•	•		
Poland	•	•	•	•	•	•	•	•
Romania	•	•	•	•	•	•	•	•
Russian Federation	•	•	•	•	•	•		
Slovak Republic	•	•	•	•	•	•		
Ukraine	•	•	•	•	•	•	•	•

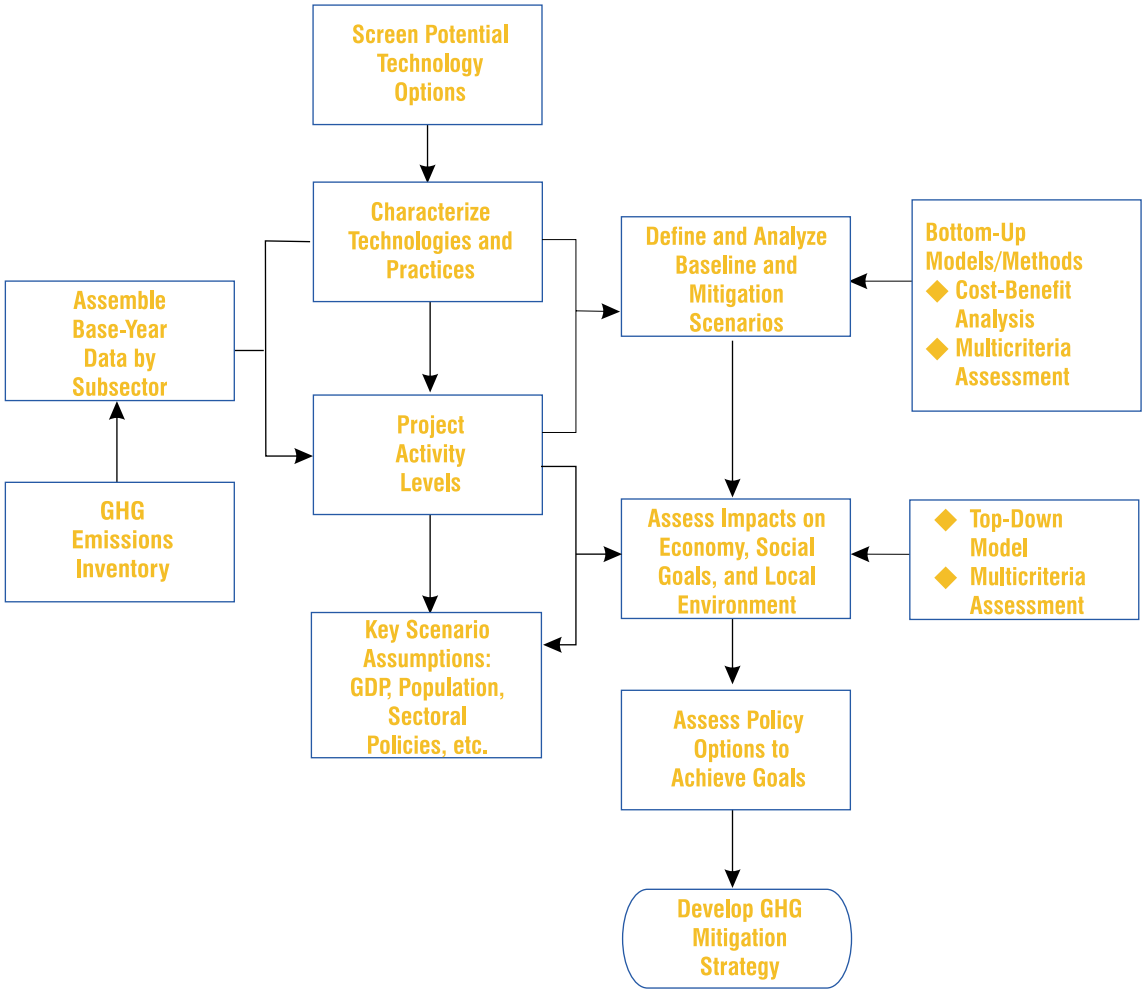
from final and draft final reports. *It should be emphasized that the data on emissions and costs reported in this section were calculated by each country using different methods, and therefore these data should not be compared across countries*. As noted, this is an inevitable outgrowth of encouraging each country to select a methodological approach that best suits its informational needs and available data.

Cost information is presented where available and as developed by the countries. Costs are presented in 1997 dollars to facilitate understanding by the reader. Where countries did not report cost data in 1997 U.S. dollars, the original cost data were converted to 1997 U.S. dollars using the currency exchange rates and producer price indices of the International Monetary Fund (IMF, 1998, 1999).[3]

Most mitigation analyses define costs to include equipment, labor, materials, and fuels. Transaction and administrative costs of actually implementing an option are often not included in these analyses. Partly as a

[3] Note that in the case of Bulgaria, the consumer price index was used in place of the producer price index because the IMF does not report a producer price index for Bulgaria.

Figure 3 Sectoral Mitigation Assessment Process



Source: U.S. Country Studies Management Team and the Energy Analysis Program of Lawrence Berkeley Laboratory, 1995.

result of these costs not being included, there are a number of negative cost options. However, many market barriers prevent adoption of cost-effective mitigation options. If the monetary and other costs of overcoming market barriers are not prohibitive, it is clearly worth pursuing a negative cost option before pursing options with positive costs. The report gives greater attention to those mitigation options that countries have identified as having negative or low costs. Some of the higher cost estimates may result from conservative assumptions about technology cost and availability, energy prices, and other factors.

To make this document easier to read, emissions data have been reported in either metric tons (MT) or million metric tons (MMT) of each gas (e.g., carbon dioxide, CO_2; methane, CH_4; nitrous oxide, N_2O) as reported in the mitigation assessments. Emissions data have also been provided in units of metric tons or million metric tons of carbon dioxide-equivalent ($MTCO_2$ or $MMTCO_2$). One $MMTCO_2$ is equivalent to the average annual emissions of approximately 250,000 cars or carbon sequestered by roughly 66,670 forested hectares(ha) (Figure 4).

2.1.3 Organization of this Section

This section addresses emission reduction opportunities by sector: energy, forestry, agriculture, waste, and industrial processes. The discussion of each sector includes a brief characterization of the nature and magnitude of GHG emissions on a global level. This is followed by a summary of the mitigation options evaluated by USCSP countries, including both a general discussion of findings and more detailed case studies for individual countries. The methods used to identify and assess mitigation options are also discussed briefly for each sector. Following the sectoral discussions, barriers related to implementing mitigation options across all sectors as well as economic and policy mechanisms for overcoming these barriers are addressed.

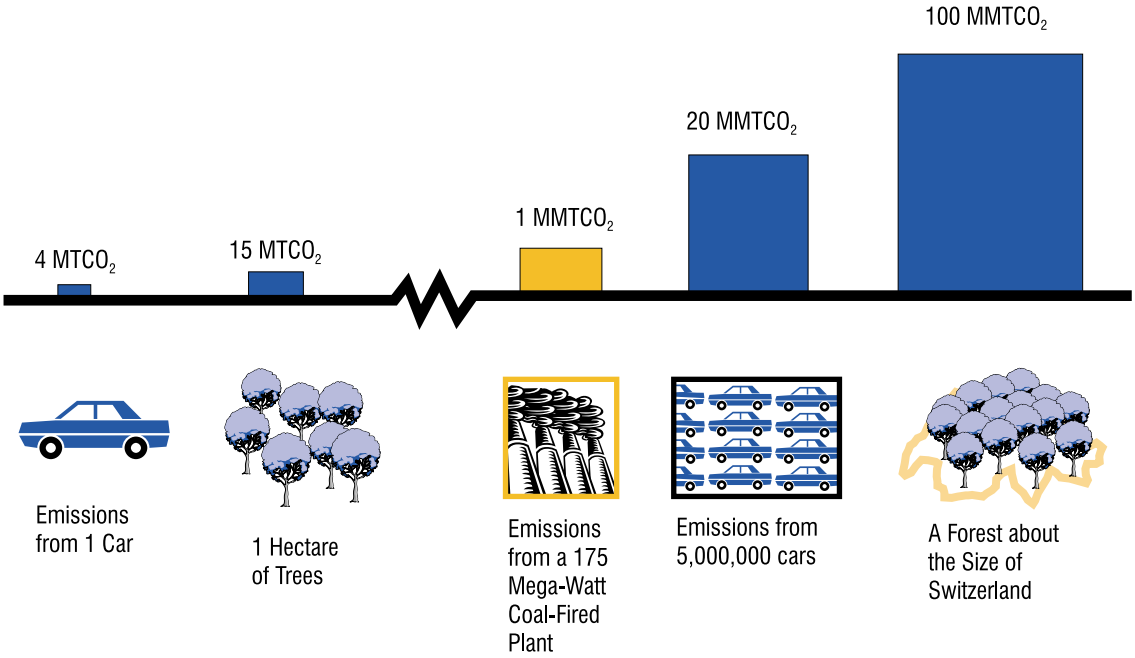
2.2 Energy Sector

2.2.1 USCSP Participants and the Energy Sector

The 56 countries participating in USCSP are significant contributors to global GHG emissions, accounting for over one-third of global CO_2 emissions from fossil fuel combustion in 1995 (Figure 5 and Box 3) (IEA, 1997a). Of these 56 countries, 21 developing countries and 10 transition countries have completed a GHG mitigation assessment for the energy sector.[4] In 1995, energy generation by the USCSP participants produced about 7,900 $MMTCO_2$, with the 31 countries conducting mitigation assessments accounting for about 90 percent of this total (IEA, 1997a; EIA, 1999a). Two of the USCSP countries conducting mitigation assessments,

[4] Thailand's report is still in draft form.

Figure 4 How Much in One Million Metric Tons of CO_2?*



* All values are annual estimates based on assumptions using baseline $MTCO_2$ per unit values.
** Trees sequester carbon as they grow but emit CO_2 when burned.

China and the Russian Federation, ranked second and third to the United States in 1995 in terms of carbon emissions from fossil fuel combustion.

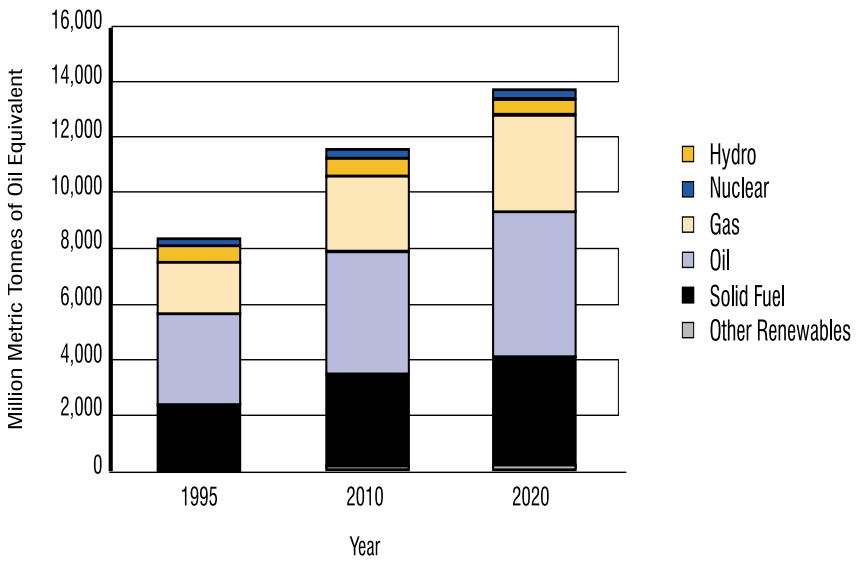
For most countries, the energy sector is currently, or is expected to be, one of the largest sources of GHG emissions. Global GHG emissions from the energy sector account for approximately 21,300 $MMTCO_2$, or about 61 percent of global anthropogenic GHG emissions (Figure 6) (Braatz et al., 1996). In the near future, the ratio of fossil fuel consumption to overall energy consumption is not expected to change dramatically. Therefore, as energy consumption increases over the next two decades, CO_2 emissions will increase proportionally if no mitigation policies are implemented. The greatest increase in energy consumption and CO_2 emissions is expected from developing countries (Figure 7) (IEA, 1998b).

To curb the growth rate of GHG emissions, countries participating in the USCSP can reduce the *energy intensity* and *carbon intensity* of their economies. Energy intensity refers to the energy required per unit of output (e.g., Btu/$GDP), whereas carbon intensity refers to the amount of carbon emitted per unit of energy (e.g., t CO_2/Btu). By reducing energy intensity through conservation or efficiency improvements and reducing carbon intensity by shifting away from the combustion of carbon-intensive fuels, countries can reduce GHG emissions along with local air pollutant emissions.

2.2.2 Energy Sector Mitigation Analyses

The energy sector offers the greatest potential for GHG mitigation in developing and transition countries with significant emission reductions possible. Figures 8 and 9 show the 1990 and 2010 baseline emissions and potential GHG emission reductions in 2010 for selected transition and developing countries, respectively. Over two-thirds of the countries are able to reduce CO_2 emissions in 2010 by at least 10 percent through energy mitigation options. For example, China and the Russian Federation estimate that emissions could be reduced by 24 percent and 33 percent from 2010 baseline emissions, respectively. However, the emission reduction potential varies widely among countries.

Figure 5 CO_2 Emissions from Fossil Fuel Combustion, 1995



Source: IEA, 1998a.

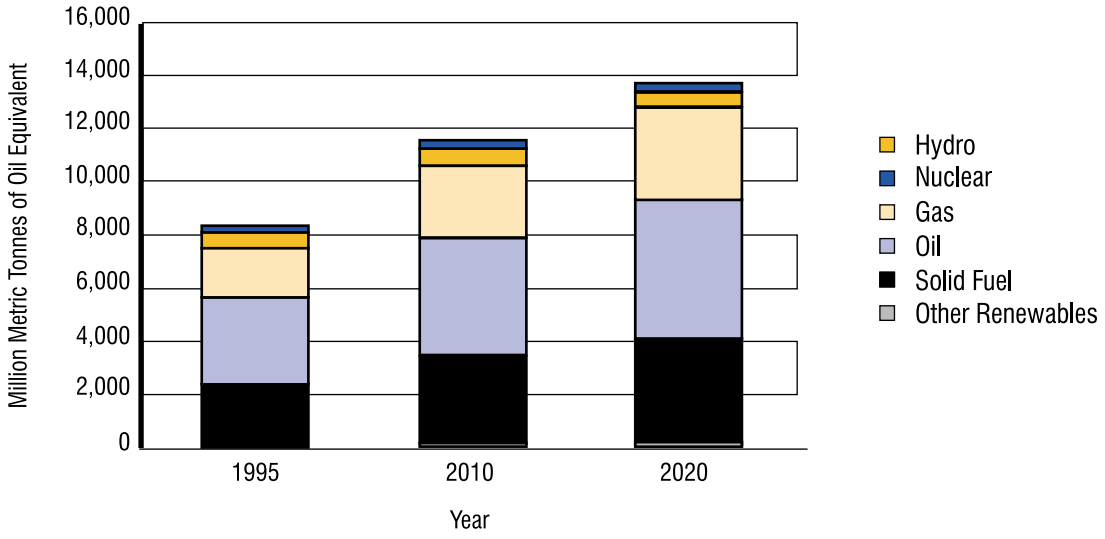
Box 3 The Energy Sector: A Global Perspective

Energy activities constitute one of the largest sources of anthropogenic GHG emissions. GHG emissions are released during all phases of the energy cycle: fuel extraction, processing and refinement, conversion (e.g., fossil fuel combustion), transmission, and end use of energy services. Of these activities, fossil fuel combustion is responsible for the largest share of GHG emissions, primarily as CO_2. Carbon dioxide is emitted as a product of combustion in amounts that depend on the fuel's carbon content and combustion efficiency.

In 1990, global energy consumption reached 343.8 quadrillion Btus, with 53 percent in industrialized countries, 21 percent in transition countries, and 25 percent in developing countries. About 85 percent of the energy consumed was generated using fossil fuel resources. The share of fossil fuel consumption in overall energy consumption is expected to remain roughly constant over the next decades (Watson et al., 1996b). The figure below illustrates the International Energy Agency's business-as-usual projection for the world's total primary energy supply until 2020.

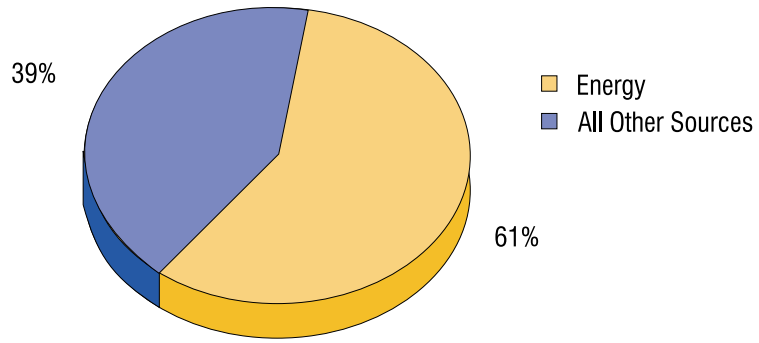
The world's heavy reliance on fossil fuel contributes to increasing GHG emissions from the energy sector. Fossil fuel combustion resulted in approximately 5.8 billion metric tons of carbon emissions into the atmosphere in 1990. Industrialized countries contributed 49 percent of global emissions, transition countries 22 percent, and developing countries 28 percent. Carbon emissions are expected to increase 70 percent during the period from 1990 to 2020 because reductions in carbon intensity are anticipated to occur more slowly than increases in energy consumption. By 2020, the developing countries are projected to contribute about half of global CO_2 emissions from fossil fuel combustion (Watson et al., 1996b).

World Primary Energy Supply by Fuel Type



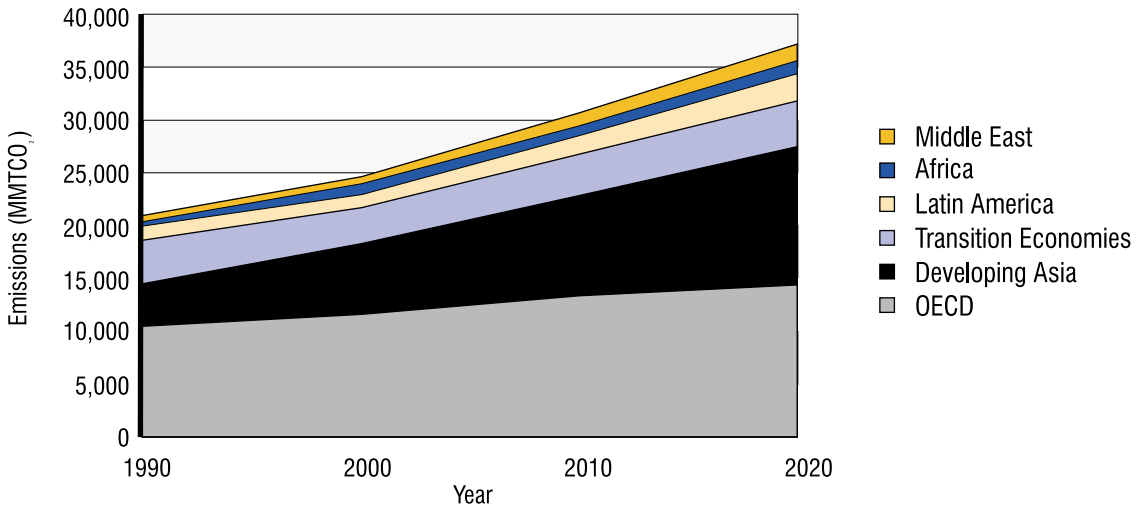
Source: EIA, 1999b.

Figure 6 Contribution of Fossil Fuel Combustion to Global GHG Emissions in 1990



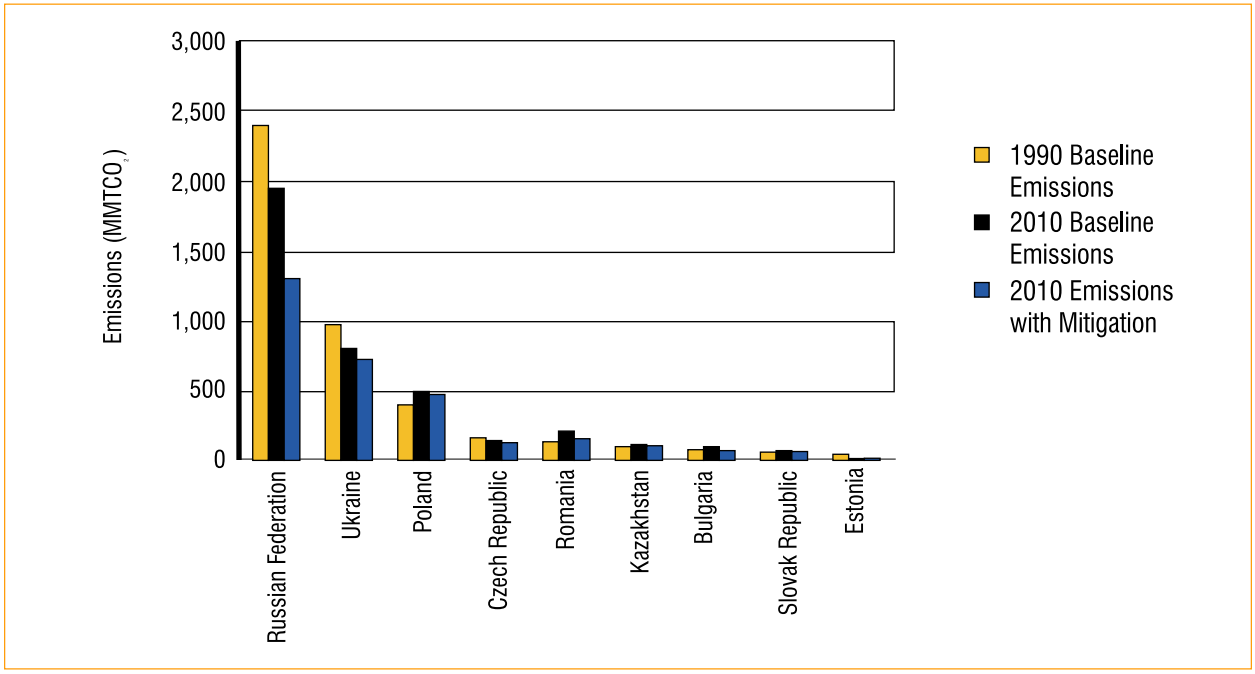
Source: Braatz and Barvenik, 1996.

Figure 7 Forecast of Worldwide CO_2 Emissions from Fossil Fuel Combustion



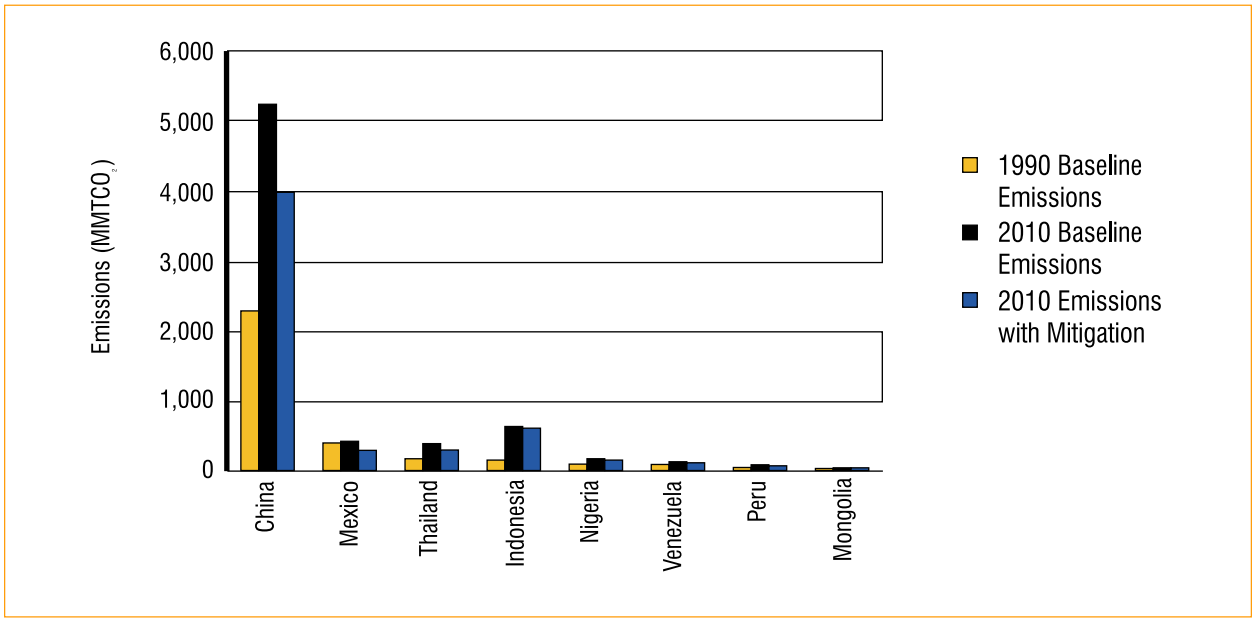
Source: IEA 1998b.

Figure 8 Energy Sector: Baseline CO_2 Emissions and Mitigation Potential, Selected Transition Countries



Source: Compiled from various country studies reports.

Figure 9 Energy Sector: Baseline CO_2 Emissions and Mitigation Potential, Selected Developing Countries



Source: Compiled from various country studies reports.

All countries participating in USCSP identified viable mitigation options. Mitigation options are summarized in four sectors: the energy supply sector and three demand sectors – industrial; residential, commercial, and institutional; and transportation. Some of the country teams conducted comprehensive assessments that examined a wide range of options for both energy supply and demand and estimated their potential future impact in the context of integrated national scenarios. Others focused on specific energy supply options and/or demand-side options.

For all of the energy sectors, the majority of countries assessing costs identified economically beneficial (negative cost) options. Tables 3 and 4 summarize several options that countries believed would actually save money if implemented. Among the options identified were improving energy efficiency, fuel switching to natural gas, and installing hydroelectricity. In addition to these negative-cost options, the countries identified a number of low-cost options. Moreover, because only a portion of the countries included a cost analysis and not all possible options were evaluated, greater cost-effective mitigation potential may exist in countries participating in USCSP. For example, China and the Russian Federation did not evaluate any costs of mitigation. Other key findings include the following:

- **The energy supply sector offers the greatest mitigation potential.** Countries participating in the USCSP identified a number of promising options in the power sector, including both short-term and long-term opportunities. In the short term, improving the efficiency of thermal power plants and reducing transmission and distribution losses in the electricity grid offer the greatest mitigation potential. In the medium to long term, fuel switching to natural gas, upgrading cogeneration, and installing hydroelectric plants can result in the most significant cumulative emission savings.
- **The industrial sector offers the next largest energy-related mitigation potential after the energy supply sector.** Increasing the use of cogeneration, improving boiler efficiency, and improving the efficiency of motors and lighting are attractive mitigation options, in terms of emission reduction potential and costs. Negative incremental costs were found for a number of these options by the majority of countries analyzing costs.
- **The residential, commercial, and institutional sector has significant opportunities for cost-effective emission reductions.** In general, installing energy-efficient lighting was found to be the most important option saving money in a number of countries. Increasing the efficiency of appliances and replacing traditional energy sources with renewable energy or electricity offered opportunities for savings.
- **Further study is needed in the transportation sector.** While the need to identify mitigation options in the transport sector was recognized by many countries, few provided a quantitative analysis of particular mitigation options. In those countries that did, the mitigation potential and associated costs varied widely. Some countries identified negative cost options, whereas others estimated costs over $300 per tonne of CO_2.

In general, the priority area for reducing CO_2 emissions from the energy sector was to install energy-efficient technologies. In most cases, these options provide the means to considerably reduce CO_2 emission levels at relatively low to negative costs in the short term. Options other than energy-efficiency measures tend to require a longer implementation period and more investment. Installing new technologies and shifting to less carbon intensive fuels has significant mitigation potential in countries where coal is a significant resource. These shifts in the generation technology and fuel bring with them significant mitigation potential over the long term and, on average, relatively higher incremental costs.

Energy Supply

Countries participating in the USCSP identified a number of promising options to reduce GHG emissions from energy supply (Box 4), i.e., options addressing production, transmission, and distribution. Tables 5 and 6 show priority areas in energy supply for selected transition and developing countries respectively. These mitigation options include improving the efficiency of existing technologies, installing new energy-efficient technologies, and switching to less carbon-intensive fuels

Table 3 Negative Cost Options in the Energy Sector for Selected Transition Countries

	Energy Supply Sector	Energy Demand Sectors		
		Industrial	Residential and Commercial/Institutional	Transportation
Bulgaria	**Hydroelectricity** Accelerate development of hydroelectric power plants **Fuel Switching** Upgrade cogeneration plants and district heating boilers with natural-gas combined cycle plants **Improved Efficiency of T&D** Reduce electricity and heat losses in transmission and distribution networks		**Efficient Lighting** Install efficient lighting	
Kazakhstan	**Hydroelectricity** Install several small hydroelectric power plants			
Poland	**Improved Boiler Efficiency** Improve efficiency and heat recovery in boilers	**Efficient Motors** Install high-efficiency motors **Improved Efficiency** Use high efficiency turbines in industry	**Efficient Lighting** Install efficient lighting	
Romania			**Improved Efficiency** Restructure and modernize economic sectors	**Improved Efficiency** Modernize public transportation
Slovak Republic			**Improved Boiler Efficiency** Retrofit district heating boilers to increase efficiency	

Table 4 Negative Cost Options in the Energy Sector for Selected Developing Countries

	Energy Supply Sector	Energy Demand Sectors		
		Industrial	Residential and Commercial/Institutional	Transportation
Egypt		**Fuel Switching** Substitute fuel oil with natural gas in 20% of industrial boilers **Efficient Lighting** Install efficient lighting in residential, commercial, and industrial sectors **Improved Efficiency** Recover steam and waste heat	**Improved Efficiency** Install combustion control systems	
Mexico	**Hydroelectricity** Develop small-scale hydroelectric power plants (<10MW)	**Cogeneration** Install cogeneration at sugar, chemical, petrochemical, fertilizer, cellulose, and paper plants **Fuel Switching** Substitute diesel and fuel oil with natural gas for 20% of industrial boilers	**Efficient Lighting** Install efficient lighting in the commercial sector **Efficient Lighting** Install efficient lighting in the residential sector	**Fuel Switching** Substitute 60,000 gasoline microbuses with 30,000 diesel buses in the Mexico City Metropolitan Area
Nigeria	**Hydroelectricity** Retrofit hydroelectric power plants **Hydroelectricity** Develop large-scale hydroelectric power plants	**Efficient Motors** Install efficient motors in industry	**Efficient Appliances** Improve kerosene and wood stoves in the residential sector **Efficient Appliances** Improve efficiency of electrical appliances in the residential sector	
Philippines	**Fuel Switching** Construct a 3,000 MW natural gas combined-cycle power plant **Improved Efficiency of T&D** Implement a system loss reduction program in electric cooperatives and private utilities, improving transmission efficiencies from 83 to 90%	**Efficient Motors** Install efficient motors in industry	**Efficient Lighting** Install efficient lighting in the residential, commercial, and industrial sectors **Efficient Appliances** Promote use of energy efficient room air conditioners	
Venezuela	**Fuel Switching** Change from oil to natural gas			**Improved Efficiency** Switch to buses with larger capacity **Improved Efficiency** Reduce percentage of private vehicles by improving public transportation
Zimbabwe		**Improved Boiler Efficiency** Improve boiler efficiency by 5%		**Fuel Switching** Switch public vehicles to natural gas

such as natural gas, hydro, other renewables, and nuclear. This sector offers the greatest opportunity for CO_2 emission mitigation; e.g., China estimated a mitigation potential of more than 800 $MMTCO_2$ for energy supply options alone. Other major findings include the following:

- **Improving energy efficiency of power plants is the most important energy sector option in the near term.** Reductions of CO_2 emissions in the short term will depend mainly on energy efficiency improvements. The existing technology is generally quite energy inefficient and subject to much improvement. Rehabilitating existing thermal power plants is a promising option in a number of countries, as is reducing losses in transmission and distribution in electricity grids. Upgrading and expanding cogeneration plants is also an attractive option.
- **Installing new technologies and switching from carbon-intensive fossil fuels is a long-term priority.** While improving energy efficiency is a priority, targeting new technology for mitigation options generally yields a larger cumulative impact over time. The long-term priorities for a number of countries is expanding the use of natural gas with combined-cycle technology, installing new coal-combustion technologies, and increasing the use of cogeneration. Using low or zero-emissions energy sources such as hydroelectric and nuclear also provides opportunity for CO_2 emission savings. In transition countries, nuclear power makes up a significant portion of the energy mix. While nuclear power is an option that would considerably reduce GHG emissions in many countries, there are questions regarding the acceptability of nuclear power in some countries. Building other renewable technologies for energy generation was generally found to be costly given expectations based on current technology costs.
- **Considerable improvements in regional air quality may result from mitigation measures.** In addition to reducing CO_2 emissions, the mitigation measures identified in the energy supply sector have the potential to reduce regional air pollutants, thereby supporting national environmental goals.
- **The economic attractiveness of energy supply options varies among countries.** The cost-effectiveness and applicability of different energy supply mitigation options will depend on a number of factors, including the cost of fuel, the capital cost of equipment, the conditions and lifetime of existing power plants, the energy generation mix, the load profile of energy demand, and the state of the transmission and distribution network. For example, switching from coal to natural gas, which would reduce GHG emissions, is not considered a viable energy policy option for Mongolia because this country has no proven reserves of natural gas. On the other hand, countries such as Bangladesh, Peru, and the Philippines found switching to natural gas a feasible mitigation option.

Discussion of the energy supply mitigation options and examples in specific countries follow. The options analyzed were grouped into seven general categories:

- efficiency improvements in fossil fuel use
- reduction of electricity transmission and distribution losses
- fuel switching to natural gas

Box 4 GHG Emissions from Energy Supply

Energy supply consists of activities to extract, transport, and convert energy resources into electricity and heat to meet consumer demand. About 72 percent of energy consumed in 1990 was delivered to end users and the remaining 28 percent was used in energy conversion and distribution (Watson et al., 1996b). The majority of GHG emissions from this sector occur during the production of electricity. Global electricity consumption surpassed 10 trillion kilowatt hours (kWh) in 1990. From 1990 to 2020, electricity consumption is expected to double, reaching more than 20 trillion kWh. The majority of this growth is expected to occur in developing countries.

Table 5 Priority Energy Supply Sector Mitigation Options in Selected Transition Countries

Country	Energy Supply Sector	Mitigation Potential, 2010 ($MMTCO_2$)
Bulgaria[a]	**Fuel Switching** Switch fuel and upgrade technology at existing thermal power plants that are near the end of their lifetime	5.8
	Cogeneration Upgrade and modernize cogeneration plants and switch from thermal plants to cogeneration plants	5.3
	Improved Efficiency of T&D Reduce electricity and heat losses in transmission and distribution networks	4.4
	Hydroelectricity Install hydroelectric power plants	3.2
Kazakhstan	**Cogeneration** Rehabilitate and modernize cogeneration cycle thermal power plants	23
	Nuclear Install nuclear power plant	21
	Hydroelectricity Install several small hydroelectric power plants	10
Romania[a]	**Nuclear** Construct nuclear reactors possessing a total capacity of up to 700 MW	101
	Fuel Switching Construct a 660 MW combined-cycle power plant	42
	Cogeneration Development Develop cogeneration	11.1
Russian Federation[b]	**Improved Efficiency** Increase fuel efficiency of existing compressor units	86
	Cogeneration Upgrade cogeneration and increase natural gas plants	12.5
	Improved Efficiency Improve efficiency of existing thermal power plants	7.6

[a] Mitigation potential estimated in 2020.

[b] Mitigation potential estimated in 2005.

Table 6 Priority Energy Supply Sector Mitigation Options in Selected Developing Countries

Country	Energy Supply Sector	Mitigation Potential, 2010 ($MMTCO_2$)
China	**Improved Efficiency/Cogeneration** Improve efficiency of thermal power plants and increase cogeneration	407
	Hydroelectricity Construct approved hydroelectric plants and develop more plants	293
	Fuel Switching Increase use of natural gas over coal	124
Egypt	**Renewable Energy** Construct a 60 MW Wind Farm	3
	Cogeneration Install gas turbine units	2
Mexico	**Renewable Energy** Increase installed capacity of wind power	6
	Fuel Switching Substitute diesel and fuel oil with natural gas for 20% of industrial boilers	4
Nigeria	**Renewable Energy** Increase use of renewable energy, including solar, and large and small hydroelectric power plants	313
Philippines	**Improved Efficiency** Construct a 3,000 MW natural gas combined-cycle power plant	9
	Improved Efficiency of T&D Implement a system loss reduction program in electric cooperatives and private utilities, improving transmission efficiencies from 83 to 90%	2
	Improved Efficiency Improve the efficiency of 125 coal-fired power plants by at least 5%	1
Thailand	**Fuel Switching** Increase natural gas use	17
	Improved Efficiency Use gas-fired combined cycle technology	2
Venezuela	**Fuel Switching** Convert boilers from liquid fuel to natural gas	11
	Improved Boiler Efficiency Improve efficiency of natural gas boilers	4

- renewable energy technologies
- nuclear power
- rural electrification
- capture of fugitive gas emissions.

Efficiency Improvements in Fossil Fuel Use

In the process of converting fossil fuels into electricity and heat, some useful energy is lost. Reducing these losses, i.e., increasing the efficiency of the conversion process, offers considerable GHG reduction potential. Analyses by the IPCC indicate that the efficiency of electricity generation can be increased from the present world average of about 30 percent to more than 60 percent sometime between 2020 and 2050 (Watson et al., 1996b).

Improving the efficiency of fossil fuel use has potential to reduce CO_2 emissions significantly. Generally, installing new technologies offers the greatest potential, but retrofitting old equipment also provides an opportunity for GHG emission reductions. More than half of the 21 developing countries and 8 of the 10 transition countries conducting mitigation assessments evaluated alternative energy supply options. The countries participating in the USCSP identified the following promising mitigation options:

- *Install new high-efficient technology*. The two most popular and effective new technology mitigation options identified for the power sector were combined-cycle gas turbines and high-efficiency coal combustion. High-efficiency pulverized coal combustion and fluidized bed combustion provide opportunities for countries with extensive coal resources or coal-based generation capacity to reduce GHG emissions compared to baseline projections. In addition to reducing GHG emissions from existing coal power plants, countries cited an important co-benefit of high efficiency coal combustion — reducing local and regional air pollutants such as sulfur oxides (SO_x), nitrogen oxides (NO_x), and particulate matter.
- *Retrofit existing technology*. Installing new power plant technologies requires considerable investment, and if thermal power plants are not at the end of their useful life, early retirement may not be a financially feasible option. Therefore, another option considered by a number of countries is the retrofit or repowering of existing power plant technology. These improvements would increase the efficiency of the existing energy system, extend power plant lifetimes, and provide emission reductions in the short term.
- *Encourage cogeneration*. Cogeneration of heat and power improves the overall efficiency of electricity generation by taking advantage of jointly available demand for electricity and steam. Nearly all countries considered this a viable option.

Examples of these three options include:

In **China**, installing large fluidized bed combustion generating units and integrated gas combined-cycle generating technology is the main priority. While the mitigation capability of these technologies is limited because they are coal based, coal-fired thermal power is expected to dominate China's power generation. Short-term CO_2 reductions at power plants will depend mainly on retrofits of existing plants, cogeneration, and implementation of best practices. These mitigation options are expected to avoid emissions of 365 $MMTCO_2$ compared to baseline projections in 2010, or about 4 percent of 1990 CO_2 emissions from fossil fuel combustion.

The highest priority in **Bulgaria's** GHG mitigation efforts is the selection of alternative combustion technologies to replace existing thermal power plants nearing the end of their lifetime. Bulgaria found fluidized-bed combustion of indigenous coal and natural-gas combined cycle plants to be important mitigation options. Based on a comprehensive study of seven thermal power plants, the average cost of rehabilitation is $US261/kilowatt (kW) with potential reduction of 3.75-4.75 percent CO_2 for plants using local lignite and 1.8 percent reduction for plants using imported coal.

In **Kazakhstan**, rehabilitation of cogeneration is the short- and medium-term priority in the electricity generation sector. This measure has a relatively large potential for reducing annual CO_2 emissions compared to nuclear power plants, wind generation, small hydro electric plants, and solar plants. Cumulative CO_2 emission savings would amount to over 17 $MMTCO_2$ by 2010,

reducing 2010 baseline emissions by 2 percent in that year. In addition to its relatively high mitigation potential, the rehabilitation of thermal power plants has a relatively low cost of emission abatement, compared to other energy supply options, at $US 18/tonne CO_2.

Reduction of Electricity Transmission and Distribution Losses

In both developing and transition countries, reducing T&D losses in the electricity grid would reduce GHG emissions. Energy losses from T&D are approximately 8 to 10 percent in developed countries, but in developing and transition countries they can be much higher. The GHG mitigation potential of reducing losses from the transmission of steam and hot water was also evaluated by some countries.

With the implementation of a system loss reduction program in private utilities and the electric cooperatives in the **Philippines**, transmission efficiency could be improved from 83 percent to 90 percent. This option could avoid about 70 $MMTCO_2$ over the 30-year period from 1990 to 2020 and has a negative incremental cost of –$US16/tonne CO_2. In addition to significantly reducing CO_2 emissions, this measure will also extend the technical life of electric motors.

In **Bulgaria**, the poor technical condition of the electricity distribution system, low loading at the substations due to the economic recession, and insufficient control of electricity metering and bills resulted in an increase of electricity losses from 9.7 percent in 1990 to 14.3 percent in 1994. Implementing measures to reduce electricity losses could save about 4.4 $MMTCO_2$ in 2020 compared to the baseline. These measures were found to be economically feasible, with a negative incremental cost of –$US76/tonne CO_2.

Fuel Switching to Natural Gas

Over half of the countries participating in USCSP recommended substituting natural gas for coal and oil use in the power sector. These options were found to have significant co-benefits such as local air pollution benefits, and they may be cost-effective depending on the availability of gas resources at low cost.

The carbon content of natural gas is considerably lower than that of coal or oil. Since carbon content is directly related to the CO_2 emitted during combustion, switching from coal or oil to natural gas offers potential for CO_2 emission reductions. Whether switching to natural gas is a viable mitigation option depends on the overall energy resources and economics of a country.

In the **Philippines**, investing in natural gas combined cycle power plants is a long-term priority that could reduce CO_2 emissions considerably. This option has the largest potential to reduce CO_2 emissions compared to the other options evaluated; reductions are estimated at 271 $MMTCO_2$ over the 30-year period from 1990 to 2020. Natural gas combined cycle power plants have a lower investment cost compared to oil-fired plants; therefore, this option is expected to save costs and has a negative incremental cost of –$US7/tonne CO_2.

Increasing natural gas-based generation is the most attractive energy-sector mitigation option in **Poland,** with new gas-fired power plants likely to make sense from both an economic and an environmental point of view. For this measure to be implemented successfully, the Polish team recommends increasing the importation of natural gas without compromising energy security, partly by purchasing natural gas from a diverse set of suppliers.

In **Thailand**, natural gas currently dominates the fuel mix, supplying 44 percent of all electricity generation. However, because electricity demand is projected to increase by a factor of nine by 2030, an increasing percentage of the demand will be met by coal-fired plants, assuming no GHG mitigation policies. In this case, CO_2 emissions from fossil fuel combustion are expected to grow from 58 $MMTCO_2$ to 171 $MMTCO_2$ from 1995 to 2020. Constructing combined-cycle natural gas plants could reduce baseline emissions in 2010 by 20 percent.

Renewable Energy Technologies

Installing small hydroelectric plants was a popular option and found to be cost-effective in a number of countries. Generating electricity from other renewable resources was, in general, found to be considerably costly given current assumptions about technology costs and performance. Specific options examined by countries participating in USCSP include the following:

In **Kazakhstan**, introducing small hydro power plants is the most profitable mitigation option in the energy supply sector. It is the only energy supply option that leads to a decrease in the total energy system cost – saving approximately US$46 million annually compared to the baseline scenario and contributing to a 2.6 percent reduction in CO_2 emissions compared to the baseline scenario in 2020. On average, the cost of emission reductions for small hydro power plants is negative at –$US25/tonne CO_2.

Mauritius is examining many renewable energy sources. Foremost is the use of photovoltaics; the island nation is currently researching the option of installing solar panels on government-owned hospitals and constructing solar streetlighting systems. Stand-alone photovoltaic systems are being considered for the outer islands and atolls.

In **Nigeria**, renewables play a prominent role in the energy sector, especially in electricity generation. Building small-scale and large-scale hydroelectric plants, retrofitting existing hydroelectric plants, and establishing central solar power supply were all options that are expected to save money. The overall mitigation potential of these options totaled 307 tonnes CO_2 per year, with negative incremental costs ranging from –$US10.34/tonne to –$US1.28/tonne.

In **Ukraine,** an increase in heat and electricity production from nonconventional renewable resources (geothermal, wind, mini- and micro-hydro plants) could save about 43.6 $MMTCO_2$ in 2015, requiring a total investment of $US 1.8-2 billion.

Nuclear Power

Nuclear power could significantly reduce GHG emissions in many countries; however, in some countries there are questions regarding the acceptability of nuclear power. About one-third of the countries completing a mitigation report evaluated the construction of new nuclear power plants or the rehabilitation of existing plants as an option to decrease GHG emissions. With the exception of China and Mexico, all countries strongly considering nuclear power are transition countries. In the transition countries, nuclear power currently makes up a significant portion of the energy mix and is not easily replaced by other technologies without significantly increasing emissions because nuclear plants do not emit GHGs. Most countries, for example, Ukraine, have noted that the social and political opposition to nuclear power plants makes implementation of new nuclear plants more difficult than the construction of thermal power plants.

Kazakhstan found that using nuclear energy would involve an incremental cost of $US60/tonne CO_2, compared to $US61/tonne CO_2 for wind energy, $US27/tonne CO_2 for solar energy, $US18/tonne CO_2 for rehabilitation of cogeneration and thermal plants, and -$US25/tonne CO_2 for small hydroelectric generation. Although nuclear energy development is more expensive than most of the other options evaluated, Kazakhstan believes it has high potential because their country has 25 percent of the world's uranium resources. However, the environmental and economic viability of this option is being seriously debated.

In **Poland**, introducing nuclear energy sources would displace coal-based thermal generation. Without nuclear power, GHG emissions could increase 19-53 percent or 30-83.9 $MMTCO_2$ by 2030.

Rural Electrification

Increased electrification offers an opportunity for GHG mitigation when electricity replaces the relatively inefficient use of fossil fuels like kerosene for rural lighting or diesel in small-scale agro-industries. In addition to an extension of a country's national power grid, the development of small-scale hydropower projects and small photovoltaic systems can increase the electrification rate. For example:

Almost all of **Uganda's** electricity is generated from hydropower and thus electricity production does not contribute significantly to GHG emissions. Rural areas in Uganda, however, are not electrified, relying heavily on kerosene for lighting. Therefore, the development and implementation of an enhanced rural electrification program could improve the electrification rate from the current 5 percent to 90 percent by 2020. The electrification strategy would be a combination of grid extension, development of small-scale hydropower in areas remote

from the national grid, and use of solar photovoltaic systems. This program could reduce CO_2 emissions by 4.5 percent in 2020 compared to the baseline, or by 2.9 $MMTCO_2$. This option holds the potential for economic benefits over the life of the technology because the total cost to implement the plan is expected to be lower than the cost of the avoided fossil fuel.

Capture of Fugitive Gas Emissions

One option to reduce GHG emissions from the energy supply is to limit or capture fugitive methane (CH_4) emissions. The largest sources of these emissions are coal mines, gas and oil fields, and natural gas transmission and distribution equipment such as compressor stations and transmission pipelines. Methane from coal mines can be collected and used to generate electricity or added to gas systems, or emissions can be flared, converting methane into CO_2.

While most of the USCSP participants focused on ways to reduce CO_2 emissions, about one-fourth of them also addressed the reduction of fugitive methane emissions. Mitigation options for natural gas and oil systems focus on more efficient production, transportation, and distribution of energy. Options include improving the condition of gas pipes, improving operations and maintenance practices, installing advanced compressor technologies, and using advanced dehydration techniques, among others. In general, these options were found to have relatively high mitigation potential.

In **Ukraine**, reducing the losses at all stages of natural gas production, transportation, and distribution has a relatively low incremental cost. Methane emissions can be reduced from 3.4 $MMTCH_4$ to an estimated 1.4 $MMTCH_4$ (31 $MMTCO_2$) with an investment of $US5.2-7.8 million. At approximately $US0.02/tonne CO_2, this option was the most cost-effective mitigation option analyzed in the energy sector.

In **Venezuela**, fugitive emissions from oil and gas systems, both from production and distribution, constitute the largest source of methane: in 1990 these emissions were 1.82 $MMTCH_4$ (38 $MMTCO_2$) and represented 57 percent of national methane emissions. In 1994, a pilot project was initiated to collect fugitive methane emissions from natural gas and oil fields. The procedure resulted in methane emission reductions of about 420,000 $MTCH_4$ (9 $MMTCO_2$). Preliminary results suggest that the collected gas can be used as a fuel substitute in the refinery, displacing liquid fuel that can be exported to generate additional income. The economic feasibility of this option depends on the international prices of the distillates and fuel oil replaced by gas.

China has abundant coalbed methane resources, estimated at 30 to 35 trillion cubic meters (m^3). By the end of 1993, there were more than 50 coalbed methane utilization projects in China, using approximately 400 million m^3 of methane annually. Coalbed methane utilization is predicted to increase to 800 million m^3 or 0.48 $MMTCH_4$ (10 $MMTCO_2$) or more by 2000.

By repairing gas pipelines and undertaking proper maintenance, the **Russian Federation** hopes to reduce methane losses from 3 percent to 2 percent of total natural gas extracted. With these improvements, the direct gas losses are expected to decrease by 2 billion m^3 or 1.2 $MMTCH_4$ (25 $MMTCO_2$).

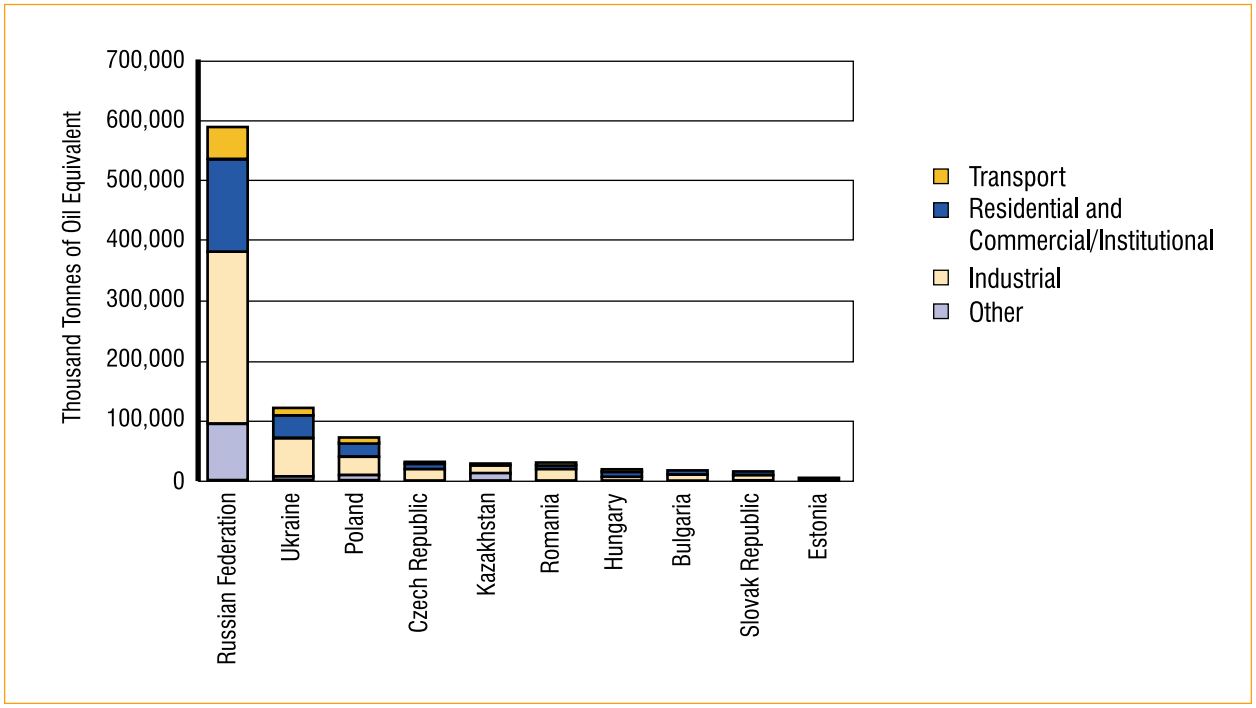
Energy Demand Sectors

Viable options have been identified to reduce energy consumption in the three energy demand sectors – industrial; residential and commercial/institutional; and transport. Figures 10 and 11 show the relative energy demand for the end-use sectors. The industrial sector dominates energy use in the transition countries. For developing countries, the residential and commercial/institutional sector plays a considerable role. Tables 7 and 8 show priority areas for reducing emissions in the energy demand sectors for selected transition and developing countries, respectively. These options focus on improving energy efficiency in all end-use sectors.

Industrial Sector

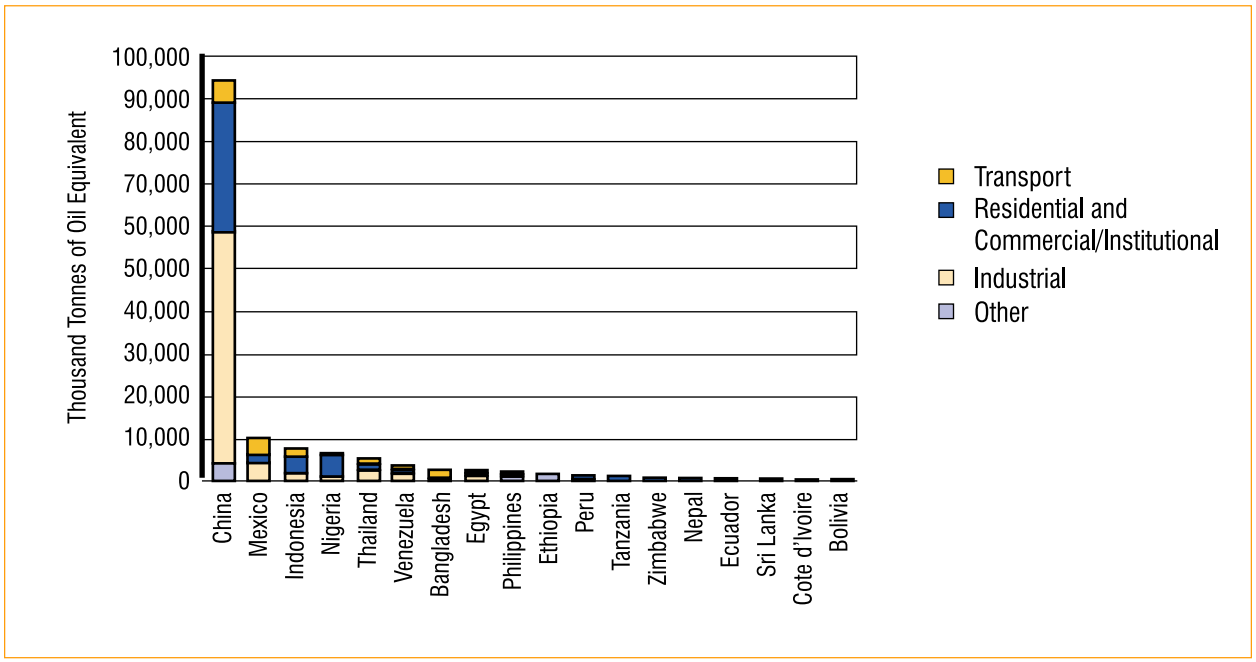
In most of the countries that completed USCSP mitigation reports, industrial activities consume a significant amount of total energy (Box 5), although the pattern of energy consumption varies considerably among these countries. Figures 12 and 13 present the breakdown of energy consumption by fuel type in each transition and developing country that completed a USCSP mitigation assessment (IEA, 1997b, IEA 1998a). Over

Figure 10 End-Use Demand by Sector for Transition Countries, 1995



Source: IEA, 1997b.

Figure 11 End-Use Demand by Sector for Developing Countries, 1995



Source: IEA, 1998a, IEA, 1997b.

Table 7 Priority Energy Demand Sector Mitigation Options in Selected Transition Countries

Country	Energy Demand Sector	Mitigation Potential, 2010 ($MMTCO_2$)
Bulgaria[a]	**Fuel Switching** Replace electricity and coal consumption in households with natural gas	3
	Efficient Lighting Install energy efficient lighting in residential and industrial sector	1.5
	Efficient Motors Retrofit industrial motors	0.8
Estonia	**Improved Boiler Efficiency** Install control equipment in district heating boiler houses and repair as necessary	N/A
	Improved Efficiency in T&D Reduce heat losses in heat transmission, distribution and consumption	N/A
Poland	**Improved Efficiency** Improve efficiency in industrial and residential motors	58
	Transportation Reduce personal mobility and increase fuel efficiency	4
Romania[a]	**Transportation** Modernize infrastructure and public transportation	6.0
	Improved Efficiency Improve thermal insulation of building	0.9
Russian Federation[b]	**Improved Efficiency of T&D** Reduce heat losses via improvements in pipeline quality and insulation	118
	Improved Efficiency in Industry Improve steelmaking technologies	13.3
	Efficient Lighting Install energy efficient lighting	10.8
Slovak Republic	**Cogeneration** Increase cogeneration in industrial and district heating	N/A

[a] Mitigation potential is in 2020.
[b] Mitigation potential is in 2005.
N/A Not available.

Table 8 Priority Energy Demand Sector Mitigation Options in Selected Developing Countries

Country	Energy Demand Sector	Mitigation Potential, 2010 ($MMTCO_2$)
China	**Efficient Motors** Increase motor efficiency, adjustable frequency/speed	389
	Efficient Lighting Improve efficiency of residential and commercial lighting	249
	Improved Boiler Efficiency Improve efficiency of combustion and operation	62
Egypt	**Efficient Lighting** Install energy-efficient lighting in the residential and commercial sectors	6.7
	Fuel Switching Substitute fuel oil with natural gas in 20% of industrial boilers	3.5
Mexico	**Efficient Lighting** Install efficient lighting in the residential and commercial sectors	41
	Cogeneration Install cogeneration at sugar, chemical, petrochemical, fertilizer, cellulose, and paper plants	19.5
	Fuel Switching Substitute 60,000 gasoline microbuses with 30,000 diesel buses in the Mexico City Metropolitan Area	5.3
Nigeria	**Efficient Motors** Increase use of efficient motors in the industrial sector	10.7
	Fuel Switching Replace fuel oil with natural gas in the industrial sector	7.5
	Efficient Appliances Increase use of improved kerosene stoves	6.1
	Efficient Lighting Use compact fluorescent lighting in the residential sector	5.2
Peru[a]	**Transportation and Fuel Switching** Replace 20% of automobiles and 10% of buses that use gasoline or diesel with natural gas vehicles	2.1
	Efficient Appliances Implement new technologies and modernize equipment in the industrial sector	1.9
	Fuel Switching Gradually replace all unsustainably harvested firewood used for fuel with LP	1.2
Venezuela	**Transportation** Switch to buses with larger capacity	5.3
	Transportation Reduce percentage of private vehicles by improving public transportation	1.2
	Transportation and Fuel Switching Switch public vehicles to natural gas	0.08

[a] Mitigation potential is for 2015.

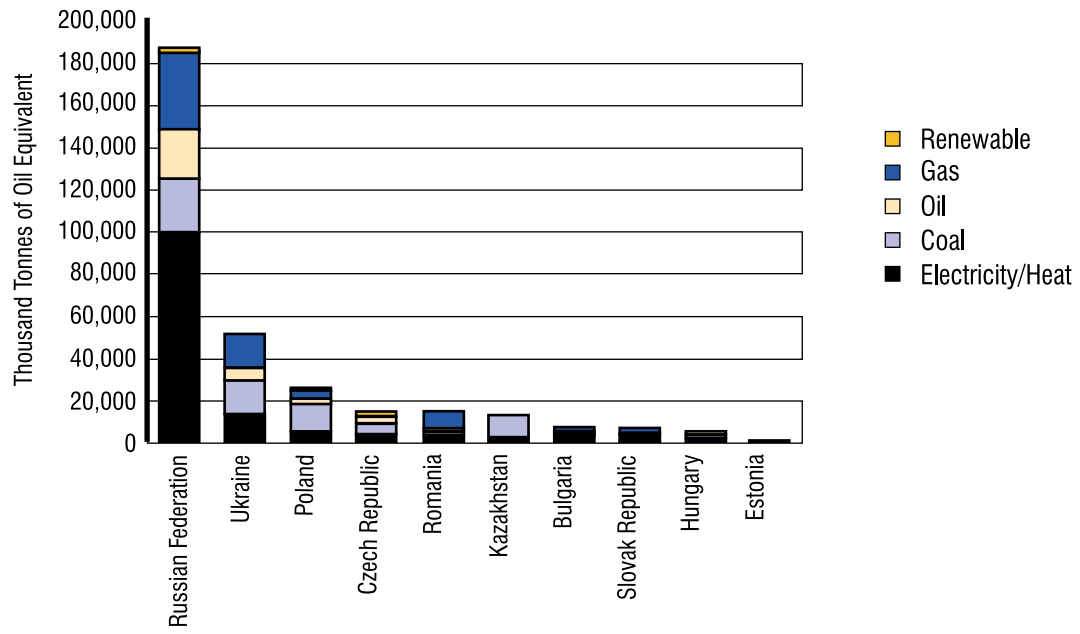
Box 5 Emissions from the Industrial Sector

The industrial sector is a major direct and indirect consumer of fuels that produce greenhouse gas emissions. In 1990, industrial energy consumption, including energy consumed for electricity production in the energy supply sector, accounted for 47 percent of global CO_2 emissions. Of the total energy consumed by the industrial sector in 1990, 57 percent consisted of direct fuel use (including biomass), and 43 percent consisted of electricity produced for the industrial sector. In non-Annex I countries in 1990, the industrial sector accounted for an average of 35 to 45 percent of total energy consumption, whereas in OECD Annex I countries, the industrial sector accounted for 25 to 30 percent of total energy consumption.

Anticipated trends in global industrial production include renewed industrial production in transition countries where industrial production declined in the early 1990s, the increasing industrialization of developing countries, the shifting of heavy industries from developed to developing countries, the shifting of industrial fuel sources from coal and oil to natural gas, and technological improvements that reduce the energy intensity of production processes. IPCC projections indicate that without mitigation policies, energy consumption by the industrial sector could increase by a factor ranging from 1.75 to 3.62 from 1990 to 2050 (Watson et al., 1996b). The share of industrial energy emissions generated by non-Annex I countries, which totaled 25 percent in 1990, is projected to increase to 55-60 percent by 2050.

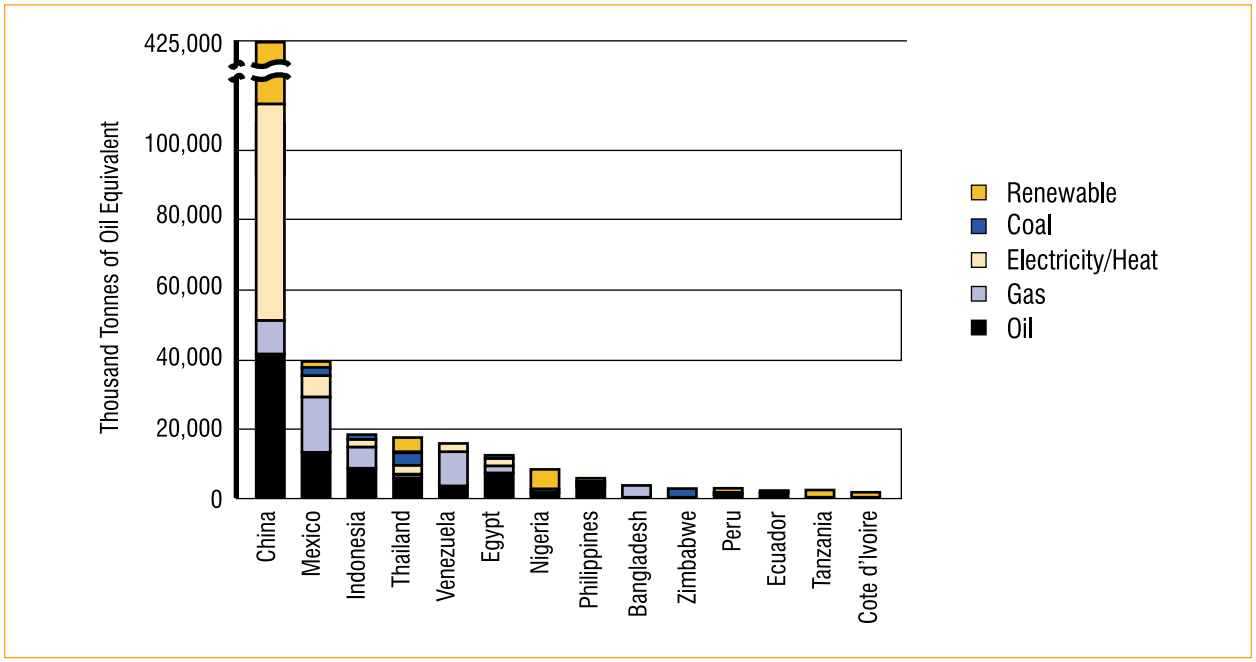
The industrial sector comprises a broad range of production processes. At the global level of industrial production, the largest energy user is iron and steel production. In 1993, iron and steel production accounted for almost 20 percent of global industrial energy consumption (IEA, 1996). Other industries that rank highly in terms of total energy consumption include the production of chemicals, machinery, non-metallic mineral products (e.g., cement, glass, and ceramics), food and tobacco, and aluminum and other non-ferrous metals.

Figure 12 Industrial Energy Consumption for Transition Countries, 1995



Source: IEA, 1997b.

Figure 13 Industrial Energy Consumption for Developing Countries, 1995



Source: IEA, 1998a, IEA, 1997b.

85 percent of the countries assessed industrial mitigation options. Key findings in this sector include the following:

- **The industrial sector is second only to the energy supply sector for opportunities to mitigate energy-related CO_2 emissions.** In transition countries, obsolete industry has created huge emission reduction opportunities. In addition to increasing efficiency, taking advantage of cogeneration and waste heat recovery offers considerable mitigation potential at relatively low costs.
- **Improving energy efficiency is the number one priority**. In both developing and transition countries, existing equipment is generally energy inefficient and offers considerable mitigation potential. Significant reductions can be achieved by increasing the efficiency of supply side and demand side technologies.
- **Cost-effective mitigation options were identified**. In addition to cogeneration, energy efficient lighting, improved boiler efficiency, and efficient motors were found to be cost-effective by some countries (Tables 3 and 4).

The mitigation options analyzed in the industrial sector fall into three general categories:

- fuel switching
- supply-side energy efficiency improvements
- demand-side energy efficiency improvements.

Fuel Switching

Industries that generate their own heat, steam, and electricity can realize substantial GHG benefits by switching to less carbon-intensive fuels. The assessments focused on switching to natural gas, although switching to hydroelectric power was investigated by Nepal and Uganda. Detailed examples of fuel switching analyses are provided below.

In **Peru**, industry is powered primarily by residual oil, diesel, and wood that is not harvested sustainably. Emissions from industry could be reduced by replacing 30 percent of fuelwood consumption with natural gas and switching from residual fuel oil and diesel to

natural gas in two percent of new machinery. The combination of these mitigation options could reduce annual CO_2 emissions from the industrial sector by about 4 $MMTCO_2$ in 2010, a 25 percent reduction relative to 2010 baseline emissions.

Poland assessed several options involving fuel switching in industrial applications for the period from 2000 to 2030. Replacing coal-fired with natural gas-fired boilers could reduce annual emissions by 1.95 $MMTCO_2$ by 2010 with an investment cost of $US8.5/tonne CO_2.

In **Venezuela,** industrial electricity consumption is projected to grow 4.2 percent per year from 1994 to 2023, increasing from 48 percent of national electricity consumption to 59 percent during this time period. Converting boilers from liquid fuels to natural gas in three industrial subsectors could increase the operating efficiency by 27 percent and reduce cumulative CO_2 emission by 4.7 $MMTCO_2$ by 2020. The incremental mitigation cost of this option is estimated at –$US22/tonne CO_2.

Supply-Side Energy Efficiency Improvements

Supply-side options to improve energy efficiency centered mostly on using cogeneration and waste heat recovery systems, and modifying existing combustion processes. These options were considered in about half of the mitigation analyses, and were often found to be cost-effective. Specific examples are listed below.

In **Mexico,** cogeneration offers significant GHG mitigation potential in three industries in particular: the chemical industry, the sugar industry, and the pulp and paper industry. In 2010, the maximum cogeneration potential for new plants in these industries could reach nearly 20 percent of total installed capacity in 2010, reducing emissions by 19.4 $MMTCO_2$ in 2010. The negative incremental cost of these options varies, depending on the industry: it ranges from -US$121/tonne for the sugar industry to –US$63/tonne for the pulp and paper industry. The economic feasibility of the project depends in part on whether excess power from cogeneration can be sold to utilities at a competitive price.

The **Russian Federation** determined that improved powerplant design in the industrial sector could reduce fuel use by 4 to 6 percent per year, resulting in over 18 $MMTCO_2$ of annual savings. Improvements include using cogeneration, supplying heat to municipal and residential sectors from centralized sources, and replacing obsolete energy equipment.

In **Venezuela,** proper maintenance of natural gas boilers offers a relatively low cost opportunity for reducing GHG emissions. A maintenance program would consist of optimizing the fuel mix of combustion, eliminating steam leaks, cleaning and making repairs properly, and inspecting control and safety devices. Implementing this program in two industries (food, beverages, and tobacco; and chemicals and coal) could reduce cumulative CO_2 emissions by 2.5 $MMTCO_2$ by 2020. The incremental cost would be about $US0.3/$MTCO_2$.

Demand-Side Energy Efficiency Improvements

Demand-side energy efficiency improvements focused on industrial equipment, including motors, lighting systems, and heating, ventilation, air conditioning (HVAC), and refrigeration equipment. Energy efficiency improvements can also be targeted for specific industrial processes, and vary considerably by process. Additional demand-side energy efficiency measures in the industrial sector include recycling to reduce the demand for virgin materials, improved housekeeping practices, process controls, leak prevention, and waste heat recovery. Demand-side improvements in energy efficiency were analyzed by more than two-thirds of the participants.

The **Philippines** reported that motors account for 70 to 80 percent of the country's industrial electricity use, and that the average efficiency of standard electric motors could be improved by at least 5 percent (from 85 to 90 percent). Improvements in motor efficiency could generate GHG benefits totaling 14.7 $MMTCO_2$ over a

30-year period at a negative incremental cost of -$US 3/MT$CO_2$. These efficiency improvements could be achieved by training the technicians that rewind burned-out motors and starting an energy labeling and minimum efficiency standards program.

In **Poland**, annual GHG emissions reductions for the period from 2000 to 2030 for a broad range of industrial demand-side management options were estimated. This team also assessed the GHG mitigation implications of the technological modernization needed for Poland to maintain its international competitiveness. A number of mitigation options have a negative incremental cost, with annual emissions reductions totaling 24 MMTCO_2, including more efficient lighting and motors and process improvements for heating furnaces, for cement production, and for lime production.

Tanzania examined energy efficiency options for cement production. Under business as usual conditions, cement production is projected to increase from 645,000 to 1,080,000 metric tonnes over the period from 1990 to 2020. Using automatic control systems, which optimize feed rates to the kiln, rotational speed, and fuel supply to the main auxiliary burners, could reduce annual CO_2 emissions by 60,000 MTCO_2 in 2010, a 15 percent reduction. Cost savings in power and fuel will be approximately US$350,000 and the capital investment will be US$375,000, requiring a payback period of just over one year.

In the **Russian Federation,** reducing production of energy-intensive products was found to have considerable GHG mitigation benefits. Reductions in the production of rolled metal stock could be achieved through material substitution and quality improvements, and could reduce emissions considerably, by more than 37 MMTCO_2. Additional use of scrap to replace cast iron could save about 15 percent of fuel use and about 18 MMTCO_2. These types of recycling and conservation measures that reduce production not only generate GHG benefits from reduced energy consumption but also reduce process-related GHG emissions.

Residential and Commercial/Institutional Sector

Nearly all of the Program participants completing mitigation reports identified promising mitigation options to reduce energy consumption in the residential and commercial/institutional sector. The relative significance of emissions from this sector varies by country according to the level of industrial development and urbanization (Box 6). Figures 14 and 15 present energy consumption in 1995 in this sector by fuel type for each participant completing a mitigation report.

Key findings in this sector are as follows:

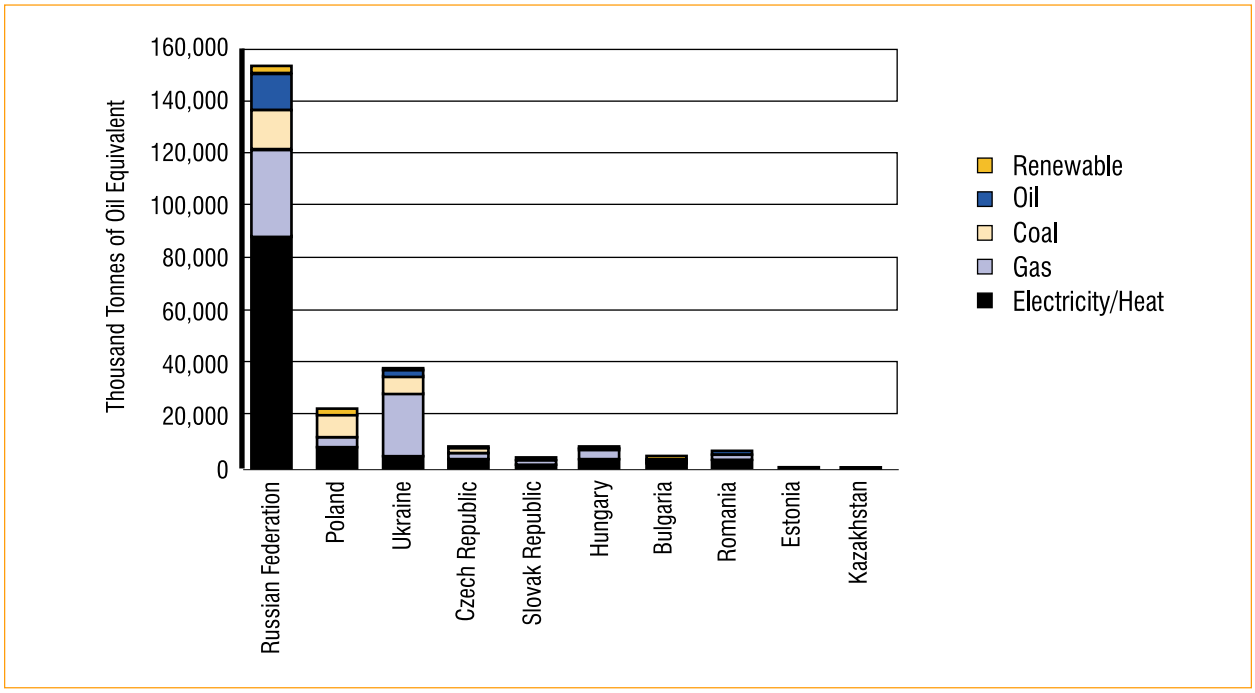
- **Emissions are expected to increase substantially.** Both transition and developing country participants generally reported that GHG emissions from this sector are likely to increase substantially in the future because of a combination of population growth and increasing energy consumption per capita re-

Box 6 Emissions from the Residential and Commercial/Institutional Sector

Energy demand from the residential and commercial/institutional sector accounted for 32 percent of global energy consumption in 1990. Of the total energy consumed by this sector in 1990, 55 percent consisted of direct fuel use, and 45 percent consisted of electricity produced outside of this sector. Annex I countries were responsible for 75 percent of the CO_2 emissions from this sector in 1990. However, while energy consumption by this sector in Annex I countries is projected to grow modestly by a factor of 1.1 to 1.9 from 1990 to 2050, it is projected to grow by a factor of 2.8 to 6.8 in non-Annex I countries. By 2050, non-Annex I countries may account for 48 to 56 percent of energy consumption by this sector (Watson et al., 1996b).

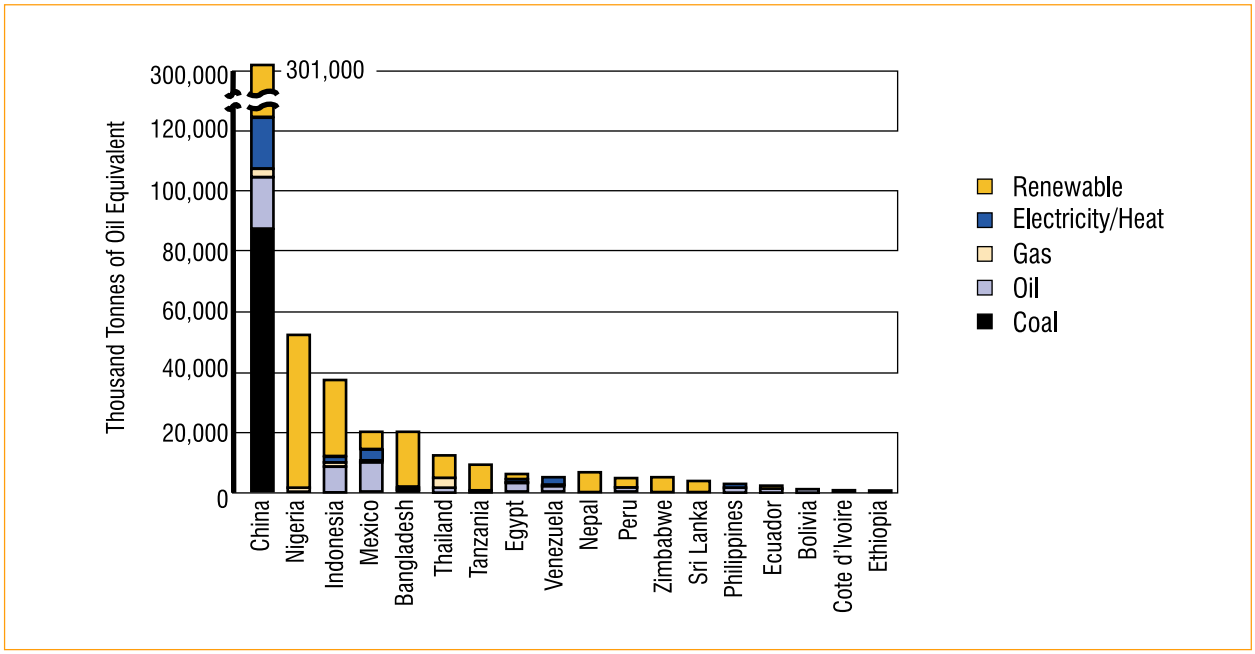
The International Energy Agency reports that the residential and commercial/institutional sector is expected to be the fastest growing sector of energy demand in non-OECD countries. Anticipated trends in energy consumption by this sector include continued increases in the share of electricity used in buildings, increases in the energy efficiency of building appliances, continued fuel switching from traditional fuels (i.e., fuelwood, charcoal, crop residues, and animal waste) to oil and electricity in developing countries, and the increasing market penetration of electrical appliances in developing countries (IEA, 1996).

Figure 14 Residential and Commercial/Institutional Energy Consumption for Transition Countries, 1995



Source: IEA, 1997b.

Figure 15 Residential and Commercial/Institutional Energy Consumption for Developing Countries, 1995



Source: IEA, 1998a, IEA, 1997b.

sulting from continued urbanization and improvements in the standard of living.

- **Cost-effective mitigation options were identified.** In general, energy-efficient lighting was found to be cost-effective, and is the most important single option. In some cases, energy-efficient appliances were found to be cost-effective. High initial costs and other market barriers have made implementation of these options difficult
- **Priorities are country-specific**. As with the other sectors, the priority options are country-specific. In transition countries, the focus is on installing energy-efficient technologies. For a number of developing countries, switching from traditional fuels such as biomass and kerosene offers significant mitigation potential. These fuels can be replaced by renewable technologies, electricity, or natural gas (Tables 7 and 8).

The mitigation options identified by USCSP participants completing a mitigation report are grouped into three categories:

- fuel switching
- efficiency improvements in building-related equipment
- efficiency improvements in buildings.

Fuel Switching

Direct fuel consumption in the residential and commercial/institutional sector is used primarily for activities such as cooking, heating, and lighting. In transition countries, considerable coal is consumed in this sector. In developing countries, there is a heavy reliance on traditional biomass fuels and kerosene. Some participating countries also reported that emission reductions could be achieved by switching from direct consumption at the end use to consumption of electricity generated with fewer GHG emissions. Detailed examples are provided below.

In **Bulgaria,** the most significant mitigation option in the residential and commercial/institutional sector over the next 25 years is fuel switching from electricity to natural gas for heating, hot water, and cooking. In 2020, increasing the natural gas supply from 1.2 million to 2 million households could reduce CO_2 emissions by about 0.34 $MMTCO_2$. The average costs of reduction for these options were $US29/tonne CO_2 for heating, $US32/tonne CO_2 for hot water, and $US29/ tonne CO_2 for cooking.

In **China**, town gas includes mainly natural gas, liquefied petroleum gas (LPG), and artificial gas (including coal gas and oil gas). Increasing the supply of town gas and reducing coal consumption in the residential sector has the potential to reduce CO_2 emissions by 124 $MMTCO_2$ by 2010.

Peru's residential and commercial/institutional sector generated 15.1 $MMTCO_2$, or about 15 percent of total CO_2 emissions. In urban areas, the substitution of natural gas or LPG for kerosene could reduce emissions by 0.37 $MMTCO_2$ in 2015 relative to the baseline, and achieve a cumulative benefit of 2 $MMTCO_2$ from 1990 to 2015. In rural areas, increasing the use of LPG and gas in place of unsustainably harvested fuelwood could reduce annual CO_2 emissions by 3 $MMTCO_2$ in 2015, and produce a cumulative benefit of 31 $MMTCO_2$ from 1990 to 2015.

Energy Efficiency Improvements in Building-Related Equipment

All of the participating countries that assessed mitigation options for the building sector examined options for improving the energy efficiency of building equipment. The types of building equipment assessed varied somewhat by country. The majority of countries specifically evaluated the use of energy-efficient lighting technologies such as compact fluorescent lights and electronic ballasts. Other priority equipment assessed included cooking stoves, space and water heating equipment, air conditioners, and refrigerators. Some countries assessed the potential for energy efficiency improvements in office equipment, televisions, and miscellaneous household appliances.

In **Bulgaria,** lighting improvements in the residential and commercial/institutional sector offer substantial opportunity to reduce electricity consumption over the next 25 years. Installing compact fluorescent lighting in the residential sector is estimated to save about

75,000 $MTCO_2$ at an incremental cost of about $US29/tonne CO_2.

In the **Czech Republic**, introducing labeling for electricity-consuming products and introducing energy standards could promote the use of energy-efficient building appliances. The labeling initiative could reduce electricity consumption in household appliances by 0.5 to 3 percent, reducing average annual emissions by 28,000 $MTCO_2$. The Czech Republic also examined the potential benefits of introducing minimum energy efficiency standards for household refrigerators, freezers, automatic washing machines, electric boilers, dryers, and dishwashers beginning in 2000. Assuming the energy efficiency standard produced a 15 percent improvement in energy consumption, this measure could generate an average annual CO_2 reduction of 48,000 $MTCO_2$. Both initiatives would be enacted through legislation, and would require negligible investments for government administration.

In **Egypt**, the most effective way to increase lighting efficiency is replacement of incandescent lighting with fluorescent lighting. Annual savings depend on the number of lamp replacements, ranging from 0.4 $MMTCO_2$ to 67 $MMTCO_2$ if 1 million lamps or 190 million lamps are replaced, respectively. This option has a negative incremental cost of approximately –US$27/tonne CO_2, but the high initial capital investment is the current barrier to implementation.

Mauritius found that implementing a public education campaign for higher energy efficiency and instituting energy consumption labeling on household appliances would mitigate emissions due to electricity consumption. In conjunction with new labeling, the government may implement minimum standards as well as an "energy-efficient" label similar to "Energy Star" in the United States.

Energy Efficiency Improvements in Buildings

Over one-third of the USCSP countries identified energy conservation measures for reducing emissions associated with buildings. These measures consisted of improving building insulation and reflectivity, using automatic devices for controlling lighting and space conditioning, implementing metering and auditing programs to encourage overall energy conservation, and instituting general housekeeping measures.

In the **Czech Republic**, the residential and commercial/institutional sector is responsible for about 19 percent of combustion-related emissions. Developing methods and requirements for building energy audits could reduce energy used for space heating. In the residential sector, these measures could reduce heat consumption in apartments by 20 percent, resulting in annual emission reductions of 990,090 $MTCO_2$. Depending on the price of energy, the payback period for the investments by households could be approximately 10 years.

Thailand estimated the energy reduction potential of energy conservation measures in three classes of commercial buildings: office, retail, and hotel. The mitigation options evaluated included efficient lighting, reduced window area and increased shading, and the use of light- colored walls and roofs. Energy-efficient lighting has the greatest potential to reduce energy consumption in buildings, with cost-effective reductions possible.

Transport Sector

About three-quarters of the participating countries completing mitigation assessments considered mitigation options in the transportation sector (Box 7). Mitigation options addressed different modes of transport, but tended to focus on ground transportation. Reducing the number of private vehicles, increasing the fuel efficiency of vehicles, and switching to less carbon-intensive fuels were all options considered. Implementation measures such as emissions testing programs and inspection and maintenance programs were also discussed.

Key findings are as follows:

- **Transport sector emissions are increasing rapidly.** In both transition and developing countries, emissions from the transport sector are increasing rapidly.
- **The range of mitigation potential and cost for this sector varied widely.** Some countries identified negative cost options, whereas others estimated costs over $300 per tonne of CO_2.

- **Options in the transport sector need further analyses.** While a number of countries addressed the need to identify mitigation options in this sector, few countries provided a quantitative analysis of the particular options.

Mitigation options are discussed below and examples of these options in specific countries are provided in the following section. The mitigation options analyzed in the transport sector were grouped into three general categories as follows:

- energy-efficiency improvements
- fuel switching
- mass transit, management, and infrastructure

Energy Efficiency Improvements

Improvements in vehicle fuel economy can reduce emissions from vehicle operations. This mitigation option relies on more efficient engine technologies in both new vehicles and vehicles currently in use.

In **Sri Lanka**, the technical potential for energy efficiency improvements in road transport is between 10% and 50%. Encouraging the use of more fuel-efficient vehicles, retrofitting existing vehicles, and requiring proper inspection and maintenance of vehicles are possibilities for improving motor vehicle energy efficiency. These mitigation options can reduce overall emissions in 2010 by 290,000 $MTCO_2$.

In **Thailand**, the efficiency of light-duty vehicles could improve by 1 percent per year over the next 30 years as older cars are replaced by newer, more efficient models. Projected emissions reductions compared to baseline forecasts are 3 $MMTCO_2$ by 2000 and 5.3 $MMTCO_2$ by 2030. Both of these reductions represent a 5 percent decrease from the total energy emissions baseline.

Fuel Switching

Heavy reliance on petroleum as a transportation fuel contributes to high CO_2 emissions from the transportation sector. Fuels from renewable energy sources have the greatest potential to reduce GHG emissions. Given current growth rates in motorization and motor vehicle usage, these low-carbon or no-carbon alternatives will be needed to limit or reduce total GHG emissions from the sector.

Many countries are also considering switching to less carbon-intensive fossil fuels such as diesel, LPG, and compressed natural gas (CNG). Less carbon-intensive fossil fuels are already cost-effective for high-mileage and fleet vehicles, and provide emission reductions of 10-30 percent over conventional gasoline-powered vehicles. Technical and cost challenges have limited the marketability of electric vehicles (Watson et al., 1996b). Barriers to the use of renewable fuels include the cost of transitioning to new vehicles, fuel production and distribution, and vehicle performance problems in some climates.

In **China**, energy use in this sector is expected to increase from 5 to 9 percent of total energy consumption

Box 7 GHG Emissions from the Transport Sector

The transport sector is a significant consumer of fossil fuels. In 1990, the transport sector accounted for one-fifth of global CO_2 emissions from fossil fuel use. IPCC projections indicate that without mitigation policies, energy consumption by the transportation sector could increase almost 3.5 times from 1990 to 2050. This increase is driven by nearly universal patterns of both increasing motorization (especially private vehicle ownership) and of increasing per-vehicle usage (related to land use patterns and the pricing of private vehicles versus mass transit). The share of transportation energy emissions generated by non-Annex I countries, which totaled 25 percent in 1990, is projected to increase to 30 to 40 percent by 2020. Globally, energy consumption in the transport sector grew more quickly than any other sector between 1973 and 1990 (Watson et al., 1996b). Much of this growth came in developing countries, where this sector is projected to grow at an annual rate of 3.9 percent, more than double the rate of industrialized countries (EIA, 1999b).

The transportation sector encompasses a broad range of mobile sources. The largest energy users are road vehicles including cars, other light-duty vehicles, and heavy-duty vehicles. However, the sector also includes emissions from rail, air, and other non-road uses including construction and agricultural vehicles. Current trends indicate a particularly high growth rate in light and heavy-duty vehicle use in southeast Asia, Brazil and Argentina; increased use of two-wheel vehicles with two-stroke engines in Asia and Latin America is also projected. Overall, the transportation sector will account for more than half of the world's oil consumption by 2020 (EIA, 1999b).

from 1990 to 2030. Several mitigation measures are being considered that could reduce emissions by 37 $MMTCO_2$ by 2010. Mitigation options include shifting from petroleum fuel to less carbon-intensive fuels such as CNG, LPG, alcohol fuel, and solar energy. Substitution of fuels can result in considerable emission reductions. For example, using CNG vehicles can significantly reduce CO_2 emissions and can reduce 95 percent of CO emissions, 87 percent of hydrocarbon emissions, and 67 percent of NO_x emissions.

In **Venezuela**, switching from gasoline to natural gas vehicles has potential to reduce CO_2 emissions. Converting buses, trucks, and passenger cars to natural gas could result in a cumulative CO_2 savings of 1.3 $MMTCO_2$ by 2010, a reduction of about 2 percent of baseline emissions. This option has a negative incremental cost of –US$58/tonne CO_2.

Mass Transit Systems, Management, and Infrastructure

Several countries are considering options in transportation systems, management, and infrastructure. These options generally aim to shift from energy intensive modes of transportation to less energy intensive modes, or even to reduce the absolute demand for transportation through more economically efficient pricing. Generally, traffic and fleet management systems are estimated to decrease energy use by 10 percent (IPCC, 1996). Shifting from road to rail may generate large GHG benefits, especially when trains are powered by electricity generated with renewable energy (Watson et al., 1996b).

In **Mexico**, private automobiles contribute to nearly 70 percent of total emissions in the Mexico City Metropolitan Area (MCMA). Since 1989, atmospheric pollution prevention programs in the MCMA have included different measures such as emission standards, the "one day without a car program," fuel substitution for light freight vehicles, and production of cleaner fuels. Mexico analyzed other promising options to decrease emissions in the MCMA, including substituting large diesel buses for smaller gasoline microbuses. The substitution of 60,000 gasoline microbuses with 30,000 diesel buses could result in an emission reduction of over 5.1 $MMTCO_2$ in 2010. Annual mitigation costs for 2010 resulted in a negative marginal cost of –$US5/tonne CO_2.

In **Peru**, the transportation sector is the most important consumer of oil products and, therefore, a significant contributor to GHG emissions. Because road transport, the largest energy consumer, is concentrated in large cities, urban transport mitigation options were analyzed. Mitigation options include limiting operating time for vehicles (e.g., HOV requirements or hourly or daily vehicle use restrictions), increased use of CNG, proper inspection and maintenance, and compliance with environmental regulations. For 2015, a reduction of 23 percent, or 4.7 $MMTCO_2$ from the baseline forecast, is estimated.

In **Romania**, modernizing the infrastructure for public transportation could contribute to energy savings. Mitigation options include increasing the average fuel efficiency of cars and buses on the road by promoting public transportation. At a negative cost of CO_2 of –US$1.28/tonne, the cumulative reduction potential was 5.9 $MMTCO_2$ from 1990 to 2020.

In **Uganda**, almost 80 percent of fossil fuel use is for road transport. Cost-effective use of energy in the road transport sector, therefore, can significantly contribute to reduction of GHG emissions. The Uganda team investigated reducing emissions from operational deficiencies by reducing traffic congestion, ensuring proper road maintenance, improving road infrastruc-

ture, ensuring proper vehicle maintenance, installing proper road signals, and developing and implementing policies and fiscal incentives to encourage mass public transport. This option could reduce emissions by 3.85 percent in 2020, and was considered very attractive because it results in cost savings, although these savings are difficult to quantify.

2.2.3 Mitigation Assessment Methodology

To conduct their energy sector assessments, countries selected those models that best suited their technical capabilities and socioeconomic needs and prioirities or, in some cases, used their own analytical tools and models. The main models used in the energy sector were LEAP (SEI-B, 1993), ETO (Mongia et al, 1991), MARKAL (Manne et al., 1992), and ENPEP (Buehring et al., 1994). Table 9 provides a brief description of these models and lists some countries that used them for their mitigation analysis. The energy sector models used facilitate a "bottom-up" approach that is engineering oriented, characterizing technologies and processes. In addition to the bottom-up models, some USCSP participants, including Mexico, Nigeria, and Poland, used a "top-down" approach. The top-down approach primarily evaluates the impact of policy instruments (e.g., carbon emission limit or energy tax) on a nation's gross domestic product and other variables (Sathaye et al., 1997).

Using an energy sector model, assumptions about macroeconomic indicators, and country-specific data, each country established a baseline scenario of energy use and associated CO_2 emissions for the coming decades. These baseline scenarios assume that policies to reduce GHG emissions are not implemented. While the nature of the assessments varied considerably among countries, in most cases, mitigation options consistent with national development goals were defined and analyzed. Then, one or more mitigation scenarios were developed. The difference between GHG emission levels in the mitigation scenario and in the baseline scenario highlights the potential for emission reductions over time. The mitigation scenarios or options were evaluated based on emission reduction potential, cost, and, in some cases, a broad set of quantitative and qualitative criteria (Box 8).

In conducting their studies, the countries encountered numerous analytical challenges and had to grapple with various issues. In collaboration with other co-sponsors, the USCSP provided participating (and other) countries with an opportunity to discuss methodological issues and report their preliminary assessment results at four regional workshops that were convened in Mexico, Poland, Republic of Korea, and Tanzania in 1995. Selected papers from these workshops were assembled in special issues of scientific journals.

Box 8 Criteria Used to Evaluate Mitigation Options

GHG mitigation potential	*Consistency with development goals*
Mitigation costs	*Cost-effective GHG reduction*
Uncertainty	*Benefits to local environment*
Significance	*Market potential of technologies*
Sustainability/reproducibility	*Reduced dependence on imports*
Public acceptance	*Potential social and environmental impacts*

Table 9 Energy Sector Models

Model	Countries	Type of Model	Description
ETO: Energy Technology Optimization	Mexico	Linear optimization model	Uses the criterion of the total cost of providing economy-wide energy services under different scenarios. The model minimizes the cost of providing energy and satisfying end-use demands, ensuring that the amount of energy supplied is at least equal to demand and does not exceed available resource limits.
MARKAL: Market Allocation	Indonesia Philippines Sri Lanka Czech Republic Estonia Nigeria	Linear optimization model	Calculates the cost of providing economy-wide energy services under different scenarios, and compares different means of satisfying given end-use demands for energy services.
ENPEP: Energy and Power Evaluation Program	Kazakhstan Peru Hungary Slovak Republic Romania Poland Venezuela	Iterative equilibrium model	Incorporates the dynamics of market processes related to energy via an explicit representation of the balancing of energy supply and demand.
LEAP: Long-Range Energy Alternative Planning	Mongolia Tanzania Bolivia Cote d'Ivoire Bangladesh	Energy accounting model	Tracks energy flows along with related information such as carbon emissions. The model quantifies the effects of mitigation policies, which must then be ranked according to the researcher's judgment.
LBL-CGE: Lawrence Berkeley Laboratory-Computable General Equilibrium	Nigeria	Computable general equilibrium model	Analyzes macroeconomic effects of investments in the energy sector and the effects of energy price increases on sectoral energy consumption.

2.3 Forestry Sector

2.3.1 USCSP Participants and the Forestry Sector

Over 85 percent of the 31 USCSP participants that completed mitigation assessments evaluated mitigation options in the forestry sector. Program participants possess 60 percent of the world's total forest cover (see Figure 16). Those with the largest forest cover are the Russian Federation (22 percent of world forest cover), China (4 percent), Indonesia (3 percent), Peru (2 percent), and Mexico (2 percent). From 1990 to1995, total global forest cover decreased by over 56 million hectares (see Box 9). Sixty-eight percent of this occurred in the 56 countries participating in the USCSP (see Figure 17) (FAO, 1997). Because forest area in transition countries has remained relatively stable over the last decade, most of the deforestation is largely attributable to the developing countries (FAO, 1997). Both developing and transition participating countries analyzed mitigation options for protecting existing forest resources.

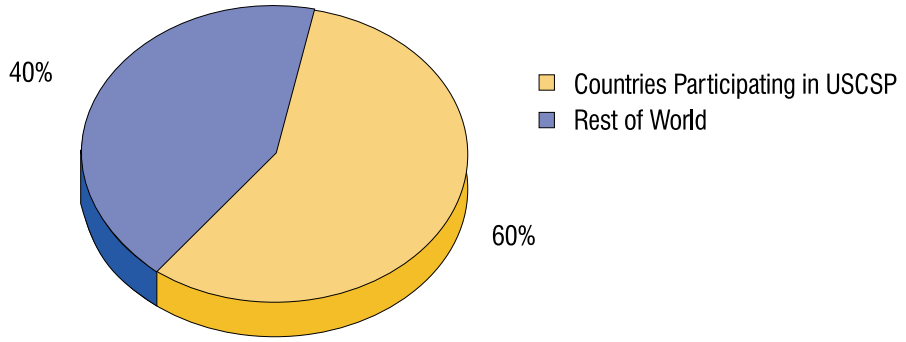
2.3.2 GHG Mitigation Options Evaluated

The forestry sector provides significant opportunities for mitigating climate change. International estimates suggest that carbon sequestration from reduced deforestation, forest regeneration, and increased development of plantations and agroforestry between 1995 and 2050 may be as much as 12 to 15 percent of fossil-fuel carbon emissions over the same time period (Brown et al., 1996a).

The key findings from these mitigation analyses are as follows:

- The three highest priority mitigation options in the forestry sector examined by USCSP participants were:
  - afforestation, reforestation, and forest productivity improvements[5]
  - protection of existing forests
  - substitution of sustainably produced biofuel for fossil fuels and substitution of wood products for more emission-intensive, nonwood products.

Figure 16 Global Forest Cover, 1995



Note: Total global forest cover in 1995 was 3,454.4 million ha.
Source: FAO, 1997.

[5] Afforestation is the planting of forested area where none existed before. Reforestation is the replanting of recently harvested forest land. Forest productivity refers to growth, yield, site productivity, and other dynamics of forests.

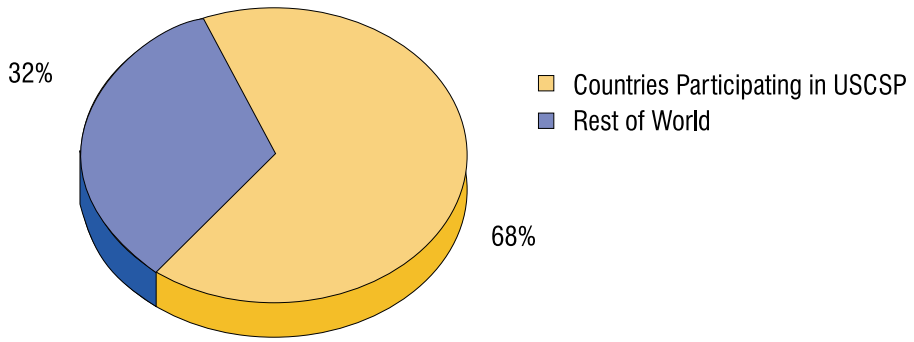
Box 9 The Forestry Sector: A Global Perspective

Rapid population expansion and development over the last several decades have placed mounting pressures on forest resources in developing countries. Net CO_2 emissions from changes in tropical land use (primarily deforestation) contribute about 20 percent of global anthropogenic CO_2 emissions annually. Emissions from tropical land use are 5,900 $MMTCO_2$ annually, as compared with total net global anthropogenic emissions of 22,000–30,000 $MMTCO_2$ per year (Houghton et al., 1996). From 1990 to 1995, total global forest cover decreased by over 56 million hectares, equivalent to an average annual global deforestation rate of 0.3 percent. Almost 80 percent of the world's forest cover lies in developing and transition countries.

Forest productivity, or the net uptake of carbon from new biomass growth, is highest in tropical forests (52 percent of global forests), nearly all of which lie in developing countries.[a] Activities such as clearing for agriculture, excessive logging, increased commercial harvesting, infrastructure construction, and increased fuelwood collection have contributed to high rates of deforestation in developing countries (FAO, 1997). Conversion of forests to other land uses releases the carbon stored in biomass and soils, and reduces the carbon sequestration potential of the land. Thus, deforestation poses a serious concern with respect to global climate change.

[a] Moist tropical forests have a much faster rate of carbon uptake (at least during the first 20 years of forest establishment) than temperate forests. High primary productivity in tropical rain forests is due to the combination of climate and efficient recycling of nutrients through plant biomass.

Figure 17 Global Reduction in Forest Area, 1990-1995



Note: Total global reduction in forest area from 1990 to 1995 was 56.3 million ha.
Source: FAO, 1997.

- The transition countries considered reforestation and afforestation to be the most promising means for enhancing carbon sequestration in this sector because forest management is already fairly developed, annual rates of change in forest cover are negligible or positive, and fuelwood is not a major source of energy.
- Forest protection mitigation options were considered by participants in Asia and Africa. This may be due to pressure on forests from rapid population growth in those countries.

In addition to the three priority options described above, market-based and regulatory tools that influence land use (e.g., fines, taxes, and land tenure policies) were also investigated by both developing and transition countries. Table 10 and Table 11 highlight priority areas for GHG mitigation in the forestry sector for selected USCSP participants. The mitigation potential, eligible land area, and cost data are presented to the extent available. In evaluating mitigation options, these countries considered both carbon mitigation potential and other ancillary benefits (see Box 10).

Box 10 Ancillary Benefits of Forestry Mitigation Options Identified by USCSP Participants

Ancillary benefits identified in the mitigation analyses include:

- *new job opportunities*
- *biodiversity conservation*
- *watershed protection*
- *air pollution control*
- *social infrastructure development (e.g., schools, roads, hospitals)*
- *prevention of land degradation*
- *recreation enhancement.*

The quantification of these benefits is both controversial and uncertain. Therefore, most participants did not quantify these benefits in their analyses. Most participants did, however, address them qualitatively.

Afforestation, Reforestation, and Improved Forest Productivity

Twenty participating countries, evenly divided between developing and transition countries, considered measures involving afforestation, reforestation, and improved forest productivity.

Mitigation options of this variety include:

- reforesting degraded forest areas
- establishing forests on nonforest lands (afforestation)
- increasing forest productivity and biomass density using science-based management
- using agroforestry techniques.

In most transition countries, forest management is already fairly developed, annual rates of change in forest cover are negligible or positive, and fuelwood is not a major source of energy. Therefore, they determined that reforestation and afforestation are the most promising means for enhancing carbon sequestration in this sector.

The **Russian Federation** contains 22 percent of the world's total forest area and has identified a significant opportunity for carbon sequestration. The Russian Federation evaluated various measures to increase its overall forested area, improve forestry practices, and restore degraded areas, including improving productivity, protecting existing forests, and using more efficient harvesting technologies. These measures have the potential to reduce emissions and/or sequester over 100 $MMTCO_2$/yr.

Hungary evaluated three different afforestation/reforestation scenarios against a baseline scenario of no planting until 2050. Hungary estimated the potential for sequestration of up to 143 $MMTCO_2$ between 1996 and 2050 by planting 18,000 hectares per year at a cost of about $US1,020 to $US1,070 per hectare, or about $US7/$MTCO_2$.

Romania evaluated the carbon benefits of extending forests and tree plantations in towns and rural areas, increasing forest productivity, and reducing wood harvests. The study estimated that over the 30-year period from 1995 to 2025, these measures would result in additional sequestration of approximately 17.6 $MMTCO_2$.

In **Kazakhstan**, forests covered 3.7 percent of the country in 1990, and sequestered approximately 4

Table 10 Priority Areas for GHG Mitigation in the Forestry Sector, Selected Transition Countries

Country	Mitigation Option	Mitigation Potential in 2010 ($MMTCO_2$)	Land area Available for Implementation (million ha)	Cost/ha (US$)	Cost/Tonne CO_2 (US$/ t CO_2)
Bulgaria[a]	**Afforestation**				
	Creation of agricultural buffer zone	8.9	0.05	322	1.8
	Afforestation of lands not appropriate for agriculture	0.5	0.25	362	2.0
	Management				
	Greater use of drought-resistant species	0.5	0.008	402	1.8
Hungary[a]	**Afforestation/ Reforestation**				
	Afforestation and Reforestation	N/A	0.015	1,045	7
Romania[b]	**Afforestation/ Reforestation**				
	Extention of forests and tree plantations in towns and rural areas	0.04	0.080	132	26.2
Russian Federation	**Afforestation/ Reforestation**	1.3	5	N/A	N/A
	Management				
	Increased stand age of final harvest	1.8	0.45	N/A	N/A
	Establishment of land-protective forest stands	2.5	71	N/A	N/A
	Fire and Disease Control				
	Increased fire control	100	875	N/A	N/A

Note: Cost data are in 1997 $U.S.
[a] Investment cost.
[b] Initial cost.

Table 11 Priority Areas for GHG Mitigation in the Forestry Sector, Selected Developing Countries

Country	Mitigation Option	Mitigation Potential in 2010 ($MMTCO_2$)	Land area Available for Implementation (million ha)	Cost/ha (US$)	Cost/Tonne CO_2 (US$/ t CO_2)[a]
Mexico[a]	**Management**				
	Selective management in temperate forests and rainforests	322	50.3	30 - 42	-4.6 - 2.1
	Afforestation/ Reforestation				
	Restoration of forests in deforested and degraded areas	20	22	533	6.5
	Agroforestry				
	Increased research and financial incentives for agroforestry projects	10	10	719	-0.1 – 6.8
Nigeria[b,c]	**Forest Protection**	95	9.6	354	0.2
	Afforestation/ Reforestation				
	Establishment of plantations of five types of trees	58.5	7.5	500.6	3.7
	Agroforestry				
	Establishment of agroforestry areas of five different types of trees with maize	28.5	7.5	320.2	4.7
Philippines[b,d]	**Management and Afforestation/ Reforestation**				
	(1) Banning logging in selected areas				
	(2) Protection of old-growth and plantation forests				
	(3) Soil conservation and watershed management				
	(4) Reforestation and urban forestry				
	(5) Scientific management of mangroves	440	30	3,433	17.8
Thailand[e]	**Management**				
	Forest protection	52	16.5	38	0.3
	Reforestation/ Afforestation	23	4.2	207	0.9
Venezuela[f]	**Management**				
	Natural forest protection and management	40	4	N/A	1.6
	Establishment of industrial and small-scale plantations	1.2 - 1.8	0.31 - 0.47	N/A	6.7
	Agroforestry				
	Development of agroforestry system	2.1	1	N/A	8.0

Note: Cost data are in 1997 $U.S.

[a] Net costs with 5% discount rate.
[b] Data are for year 2030.
[c] Costs represent material costs only, with a 12% discount rate.
[d] Cost is net present value at a discount rate of 20%.
[e] Data are for year 2020.
[f] Data are for year 2025.

$MMTCO_2$. Kazakhstan plans to increase forest coverage to 4.6 percent of the country by 2010, and to 5.1 percent by 2020. The new forest area (about 3.8 million hectares) will be planted primarily with mixed softwoods. Kazakhstan projects that the increased annual carbon sequestration from this option will be about 6 $MMTCO_2$ by 2020, at a cost of $US43 million. Foreign investment would be necessary to implement this measure. The Kazakh government has approved two projects for further development as pilot projects for increasing carbon sequestration — "Organization of the Ecological and Resource Monitoring of Forests" and "Afforestation and Reforestation for the Sake of Biodiversity and Biocenosis Restoration and Preservation (200,000 ha)".

Developing countries participating in the Program also studied a variety of options to mitigate emissions from deforestation.

Indonesia, which contains more than 3 percent of the world's forest resources, has forest areas that are relatively productive but have been decreasing at a rate of 1 percent per year. Indonesia determined that afforestation and reforestation offer substantial potential for GHG mitigation (not quantified in its report), and identified the most profitable species for use in these activities. They estimate that reforestation will have a mitigation potential of 785 $MTCO_2$/ha with a net present value of $US 252/ha, and that the creation of timber estates (tree plantations) will have a mitigation potential of 630 $MTCO_2$/ha with a net present value of $US 1,486/ha.

Much of CO_2 emissions in many Latin American countries come from forest clearing. The participating countries in Latin America represent 90 percent of total forest cover in the region. They also account for 41 percent of the total forest cover of USCSP participants, but are responsible for over 71 percent of the deforestation occurring in the countries participating in the Program (FAO, 1997).

Forest clearing accounts for more than 40 percent of national net CO_2 emissions from all sources in **Venezuela**, or over 75,000 $MTCO_2$. Venezuela's mitigation analysis, which used the results of two in-depth case studies to project the carbon storage potential and costs of nationwide forest sector activities, derived cost estimates of $US8/$MTCO_2$ for agroforestry and $US7/$MTCO_2$ for plantations. On a cost-per-ton basis, these two options proved more expensive than the establishment of protected areas (roughly $US1.6/$MTCO_2$) and forest management ($US3.50/$MTCO_2$) in 2025. Venezuela estimates that up to 21 $MMTCO_2$ could be stored by agroforestry systems and 202 $MMTCO_2$ in plantations by 2025.

Protection of Existing Forest Areas

Measures to protect existing forest area focus on reducing the current levels of deforestation or preventing it altogether. Such measures include:

- creation or expansion of protected areas (e.g., national parks and sanctuaries)
- implementation of sustainable logging activities
- control of forest fires
- more efficient production of forest products
- conservation of fuelwood (e.g., use of more fuel-efficient woodburning stoves)
- use of nonwood biofuels such as crop residues.

Because the participating countries contain 60 percent of the world's existing forest resources, protection of existing forest area presents a critical target for immediate action to mitigate climate change. Box 11 displays the extent (1.4 trillion hectares) of forest land that potentially could be protected by those participants that evaluated options of this type.

China possesses nearly 4 percent of the world's forest resources, but relies on this forest cover to satisfy the demands of 22 percent of the world's population. Thus, forest resources face extraordinarily high population pressures. China's mitigation assessment reported that from 1989 to 1993, over 7.5 million hectares of forest were destroyed by excessive cutting and natural disasters. In addition, more than 10 million hectares suffered from diseases and pests. A lack of funds precludes the rehabilitation of much of that forested land. However, China can make a significant contribution to climate change efforts by protecting its remaining forest resources. China estimates that by 2050, through protection of existing forests and aggressive afforestation programs, total carbon storage could reach 18 billion $MTCO_2$. This amount is roughly the same as global emissions of carbon dioxide from fossil fuel consumption in 1995 (IEA, 1998).

Box 11 Forested Area in USCSP Participants Evaluating Mitigation Options

(Thousand Hectares)

Russia	*763.5*
China	*133.3*
Indonesia	*109.8*
Peru	*67.6*
Mexico	*55.4*
Venezuela	*44.0*
Tanzania	*32.5*
Nigeria	*13.8*
Kazakhstan	*10.5*
Ukraine	*9.2*
Philippines	*6.8*
Romania	*6.2*
Estonia	*2.0*
Slovak Republic	*1.1*
Bangladesh	*1.0*
Egypt	*<0.1*

Source: FAO, 1997.

The **Russian Federation** evaluated increased fire control as a measure to protect existing forest resources. It estimates that this option has a mitigation potential of about 458 $MMTCO_2$.

The **Philippines** has identified reducing deforestation as a high priority, having experienced an annual loss of 3.5 percent of existing cover from 1980 to 1990. The Philippines' mitigation assessment evaluates three scenarios for the forest sector: a baseline scenario, a total logging ban scenario, and a "Philippine Master Plan for Forestry Development" scenario. The Master Plan scenario includes a ban of logging in sensitive forest areas and incorporates sustainable forestry practices for the forest areas that remain in production. The analysis demonstrates the emission reduction and carbon sequestration advantages of the comprehensive Master Plan relative to the other scenarios and predicts that, with implementation of the Master Plan, the deforestation rate in the country would be cut in half every five years. The Philippines estimates that in 2030 the Master Plan would result in net uptake of 82 $MMTCO_2$, whereas the baseline scenario would result in net emissions of 471 $MMTCO_2$.

In Africa, agricultural expansion, livestock grazing, increased fuelwood collection, and commercial harvesting contribute to high deforestation rates. It is estimated that about 121,000 hectares of forest are lost annually, equivalent to about 1 percent of Africa's total forest area per year.

Nigeria conducted an extensive evaluation of forest protection and other mitigation options. By enhancing and maintaining existing protected forest areas through tighter control of forest exploitation, increased monitoring of human activities in forest estates, and restoration of degraded parts of existing estates, Nigeria estimates that 3,804 $MMTCO_2$ could be stored from 1990 to 2030 at an initial cost of $US0.20/$MTCO_2$.[6] Of the options that Nigeria evaluated, forest protection was the most cost-effective. However, when factors such as satisfying the demand for wood and nonwood products and other social and economic benefits were considered, agroforestry and afforestation were more attractive options than forest protection.

Substitution Using Sustainably Harvested Biomass

When biomass that can be used as fuel is grown sustainably, such that the harvest of the biomass is offset by regrowth, the use of biofuels in place of fossil fuels reduces net CO_2 emissions. The substitution of sustainably harvested timber for emission-intensive products such as concrete and steel can also reduce GHG emissions. Similarly, substituting wood from renewable sources for wood from depletable natural forests can reduce CO_2 emissions. Several USCSP countries evaluated the mitigation potential of these options.

China suggested increasing its firewood forests. China has identified a variety of species of trees that grow quickly, have high yield, and burn well. Currently, China uses about 160 million tons (330 $MTCO_2$) of sustainably derived firewood. Of this amount, one-quarter comes from firewood forests, and nearly 40 percent comes from timber waste. China estimates that it could

[6] This initial cost does not include future discounted investments required to continue the project; it describes only the resources necessary to establish the project.

double the size of its current firewood forests, planting an additional 8–10 million hectares.

Mexico suggested the use of forest restoration to increase the supply of fuelwood and wood for construction materials (e.g., as a replacement for more GHG-intensive steel and cement materials). Mexico estimated the unit cost of this mitigation option to be approximately $US1.80/MTCO$_2$, roughly three times higher than the cost of forest management options, and comparable to the cost of agroforestry measures.

Bangladesh identified options to increase the efficiency of biofuel use and production, including the use of more efficient wood-burning cook stoves, charcoal kilns, and biogas plants. **Bolivia** proposed improving the efficiency of the wood industry by using more productive tree species that are optimal for use as biofuel. Neither country reported the cost-effectiveness of these mitigation options.

2.3.3 Mitigation Assessment Methodology

Under the Program, the participating developing and transition countries were encouraged to choose the analytical approach they believed was most appropriate for assessing mitigation options. While this approach complicates efforts to aggregate data across countries, its flexibility has allowed countries to select approaches according to country priorities.

Most participating countries employed a bottom-up method that focuses on specific forest management activities to create a large-scale, national picture. These methodologies are based partly on the assumption that market barriers prevent consumers from taking actions that would otherwise be to their own or to their country's economic advantage.

Slightly more than 10 percent of those countries evaluating options in the forestry sector used a top-down model such as the Comprehensive Mitigation Analysis Process (COMAP) or Carbon, Pasture, Agriculture, Total, Harvesting (COPATH) to examine regional land-use shifts and assess cost[7] and benefits of options (see Box 12). Top-down methodologies use macroeconomic data to draw conclusions about specific activities. These methodologies are based largely on the assumption that consumers consistently exhibit profit-maximizing behavior (e.g., less afforestation than technically possible occurs because consumers see no further economic gain from increasing afforestation activities). These methodologies adopt a macroeconomic perspective and define mitigation costs in terms of losses in economic output, income, or gross domestic product (GDP).

Box 12 Features of Forestry Sector Mitigation Option Assessment Tools

The Comprehensive Mitigation Analysis Process model, or COMAP, features:

- *assessment of the current and future land area available for emissions mitigation activities given the demand for land by all sectors*
- *estimation of emission reduction and/or carbon sequestration potential per unit area for each option*
- *total and unit costs and benefits for each option*
- *development of future GHG net emissions and cost scenarios*
- *evaluation of the cost-effectiveness of options*
- *exploration of mechanisms required for implementation.*

The Carbon, Pasture, Agriculture, Total, Harvesting model, or COPATH, uses a system of linked spreadsheets to estimate deforestation from conversion to agriculture or grazing land, forest harvesting policy, and other land uses such as dams, roads, forest fire, and human settlement. These data are aggregated to calculate total carbon emissions and sequestration for all forest types.

Source: U.S. Country Studies Management Team and LBL Energy Analysis Program, 1995.

7 Costs of forestry sector mitigation options include the present value of the total expenses necessary to cover the planning, development, establishment, management, protection, and monitoring of a project, as well as the present value of the project's opportunity cost (i.e., the benefits derived from land use in the absence of the mitigation option).

2.4 Agricultural Sector

2.4.1 USCSP Participants and the Agriculture Sector

Global GHG emissions from agriculture account for approximately 7,300 $MMTCO_2$, or roughly 20 percent, of global anthropogenic GHG emissions (Braatz and Barvenik, 1996) (see Figure 18 and Box 13). Agriculture accounts for 50 percent of total global methane emissions and 70 percent of total global nitrous oxide emissions (Watson et al., 1996b). Mitigation options in this sector were examined in over 75 percent of the USCSP mitigation assessments.

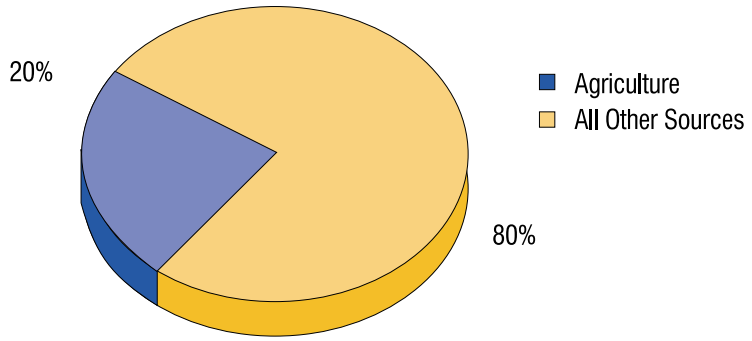
The primary GHG emissions from agriculture are:

- methane from rice cultivation, manure management, livestock digestion, agricultural residue burning, and savanna burning
- nitrous oxide from fertilizer use, manure management and use, production of nitrogen-fixing crops, cultivation of soils with a high organic carbon content, agricultural residue burning, and savanna burning
- carbon dioxide from soil tillage.

The key findings of mitigation analyses in the agricultural sector include the following:

- Mitigating emissions from rice cultivation is critical for most Asian countries and in Côte d'Ivoire because rice cultivation is the largest source of agricultural GHG emissions in those countries. Mitigation options focused mainly on changes in water management practices and switching to alternative rice cultivars.
- Livestock production accounts for more than half of total methane and nitrous oxide emissions in all of the participating countries in Central and Eastern Europe and the Former Soviet Union, Latin America, and Africa, with the exception of Côte d'Ivoire and Uganda. Improving livestock productivity through improved nutrition was the most common mitigation option considered. Manure management options such as methane recovery for use as energy were also evaluated.
- In many African countries, savanna burning constitutes a significant source of methane and nitrous oxide emissions. USCSP inventories indicate that

Figure 18 Contribution of Agriculture to Global Anthropogenic GHG Emissions, 1990



Note: Global GHG emissions in 1990 were estimated at 3,600 $MMTCO_2$.
Source: Braatz and Barvenik, 1996.

Box 13 GHG Emissions from the Agriculture Sector

Rice Cultivation

Methane is produced from the anaerobic decomposition of organic matter in flooded rice fields. Estimates of global methane emissions from wetland rice cultivation range from 20 to 100 $MMTCH_4$, or 420 to 2,100 $MMTCO_2$ per year. This represents 5 to 27 percent of anthropogenic methane emissions (Houghton et al., 1995). Most opportunities for mitigation exist in Asia, which produces over 90 percent of the world's rice (Braatz and Hogan, 1991). With the expected population growth in the next century, the demand for rice will continue to increase, as will associated methane emissions.

Manure Management

Manure management produces both methane and nitrous oxide emissions. Methane is produced when manure is managed in systems that become anaerobic, such as liquid/slurry facilities or lagoons. Methane emissions from livestock manure range from 20.1 to 29.7 $MMTCH_4$ (420 to 620 $MMTCO_2$) annually, or 5 to 8 percent of global anthropogenic methane emissions (Canada Center for Remote Sensing, 1999). The storage and treatment of manure produces nitrous oxide emissions through the combined nitrification-denitrification of ammoniacal nitrogen contained in the wastes. Nitrous oxide emissions from manure management range from 189,000 to 497,000 MTN_2O, or 60 to 150 $MMTCO_2$. This represents 2 to 5 percent of anthropogenic N_2O emissions (Houghton et al., 1995). The emissions associated with manure management in developing countries are expected to increase as growing populations increase demand for food production.

Enteric Fermentation

Enteric fermentation is a part of the natural digestive process of animals. Ruminant animals (e.g., cattle, buffalo, sheep, and goats) contribute the majority of methane emissions from enteric fermentation; nonruminant livestock (e.g., swine and horses) also emit methane, but in smaller quantities. Estimates of methane emissions attributable to enteric fermentation range from approximately 65 to 100 $MMTCH_4$ (1,350 to 2,100 $MMTCO_2$) (Houghton et al., 1995). This large range is a result of the uncertainties associated with methane emissions from individual animals and with estimates of animal populations.

Agricultural Land Management

Changing the management of overgrazed lands can often lead to an increase in plant productivity and carbon storage. The increase in plant productivity and carbon storage helps mitigate the GHG emissions.

Fertilizer Use

Nitrous oxide is emitted from fertilizers used for agricultural practices. While assessing the potential impact of fertilizer use is difficult because of limited data, it has been suggested that about 70% of N_20 emissions originate from soils (Bouwman, 1990; IPCC, 1992). Proper application and substitution with organic fertilizers will reduce the nitrous oxide input of fertilizers.

Use of Agricultural Biofuels

The replacement of fossil fuels with agricultural crops as fuel can diminish the amount of GHGs released into the air. Because of the variety and complexity of agriculture biofuels (ranging from crops to trees to agricultural waste), it is difficult to assess the potential of this option.

nitrous oxide emissions from fertilizer use are particularly important in Central and Eastern Europe, the Former Soviet Union, and many Latin American countries (Braatz et al., 1996).

- More research is needed to analyze emission reduction potential and costs associated with mitigation options in all areas of this sector.

2.4.2 GHG Mitigation Options Evaluated

USCSP participants investigated a number of mitigation options for each source category in the agricultural sector. The most prevalent evaluation criteria considered were the ability to reduce emissions, effects on agricultural productivity, cost-effectiveness, consistency with cultural practices, and social acceptance.

USCSP participants investigated agricultural mitigation options in six different areas:

- rice cultivation
- enteric fermentation
- manure management
- agricultural land management
- fertilizer use
- use of agricultural biofuels.

Rice Cultivation

The mitigation option most commonly considered by USCSP participants in rice cultivation was modification of water management practices, which includes draining rice fields and increasing aeration of water used for irrigation (see Box 14). Periodically draining rice fields during the growing season reduces the duration of anaerobic conditions, thereby reducing methane emissions. Studies have indicated that if fields are drained for fairly short periods, productivity can be maintained. For example, **Tanzania** estimated that a methane emission reduction of 30 percent is possible through the use of drainage techniques. Tanzania also proposed increased aeration of irrigation water. **Indonesia** recommended improving irrigation efficiency, which would reduce methane emissions by an estimated 87 $MTCH_4$/ha (1,830 $MTCO_2$/ha). This would constitute a reduction in per-hectare methane emissions of about 35 percent.

Box 14 Mitigation Options for Reducing Emissions from Rice Cultivation

There are many mitigation options available for reducing methane emissions from rice cultivation. However, the magnitude of reductions achievable through various options and the impact of these options on the yields and costs of rice production are uncertain. It is estimated that the implementation of various practices and technologies could mean that a 10 to 30 percent reduction in emissions from current global levels can be achieved (Braatz and Hogan, 1991). These options focus on reducing methane emissions while maintaining the productivity of the rice fields.

Options considered include:

- *implementing water management techniques*
- *changing rice variety*
- *using nitrogen-based fertilizers*
- *changing tilling and seeding techniques.*

Use of improved cultivars was another common consideration, since lower methane emissions are associated with some rice varieties. **China** found that using hybrid rice varieties could actually increase productivity while reducing methane emissions by 20 to 30 percent. Emissions from rice cultivation in China totaled 11.7 $MMTCH_4$ (246 $MMTCO_2$) in 1990. **Tanzania** analyzed switching to an alternative rice variety with similar productivity but a shorter growing season of only 100 days, compared to the usual 110-150 days.

Other options that participants considered focused on improving cultivation techniques. Reducing the use of organic fertilizers and changing tillage and seeding techniques have been shown to reduce methane emissions from rice fields. **Indonesia** considered practicing zero tillage and modifying nutrient management practices, but determined that improving irrigation and direct seeding (avoiding 58 kg CH_4/ha/season, or 1.2 $MTCO_2$/ha/season) are better options, although expensive at costs of more than \$US700/$MTCO_2$ and \$US1,00/$MTCO_2$, respectively. **China** estimated a possible 20 to 30 percent reduction in emissions by using composted residue from biogas generators in place of organic fertilizers and by adding inhibitors to fertilizer.

Enteric Fermentation

The most common mitigation method considered for reducing emissions from enteric fermentation was to enhance livestock productivity by improving nutrition (see Box 15). Supplying better-quality feed and improving the ability of the livestock to digest the feed would increase livestock productivity and decrease methane emissions per unit of production. For example, **China** estimated that treating straw with ammonia to increase digestibility is the most feasible option for reducing enteric fermentation emissions, and that this method would reduce emissions by about 10 percent per unit of production. Feed supplements such as molasses/urea blocks have been shown to improve microbial growth in the rumen, which reduces emissions. The **Philippines**, with estimated annual methane emissions from animal waste of 68,260 $MTCH_4$ (1.4 $MMTCO_2$), proposed this method as a main option, noting that these blocks are affordable and easy to use. Using local crop residues for feed instead of grasses, which increase livestock protein intake and therefore digestive efficiency, was another option considered by many countries. **Indonesia** estimated that this practice could reduce methane emissions by 30 percent at a cost of $US252 per head, equivalent to a reduction of about $US30/$MTCO_2$. **Hungary** and **Poland** also found this measure to be promising.

Production-enhancing agents, as well as genetic and reproductive improvements, can increase milk or meat production without increasing emissions. **Indonesia** explored the use of a rumen-modifying agent that would reduce methane emissions by 25 percent at a cost of $US274 per head. **Peru** considered the use of bovine somatotropin and anabolic steroids, and investigated genetic improvements to increase productivity.

Box 15 Mitigation Options for Reducing Emissions from Enteric Fermentation

Mitigation options for reducing methane emissions from enteric fermentation largely focus on improving livestock productivity. When ruminants use the energy from their feed more efficiently, they produce less methane per unit of product (e.g., milk and meat). Increased efficiency allows the producer to raise fewer livestock while maintaining the current level of production. (If more livestock are needed, improved productivity lowers emissions per animal.) Increasing productivity also reduces land-use pressures associated with livestock production. The greatest opportunities for emission reductions exist where livestock production is inefficient.

Options considered include:

- *mechanical and chemical feed processing*
- *feed supplements*
- *production enhancing agents*
- *genetic improvements*
- *reproduction enhancements.*

Manure Management

Mitigation options considered by Program participants in the area of manure management dealt with the recovery of methane from manure to be used as an energy source (see Box 16). Digesters, or biodigesters, increase anaerobic decomposition and enhance methane production. This methane can be recovered easily and used for energy. The methane obtained is a more energy-intensive fuel than manure, which is often directly burned for fuel. In addition, the remaining manure still retains some of its value as fertilizer. The **Philippines** analyzed the use of tubular polyethylene digesters for pig manure, and estimated that this measure could reduce methane emissions by 293,910 $MTCH_4$ (6.2 $MMTCO_2$) from 1998 to 2026, an amount equivalent to about five times the annual methane emissions from this

Box 16 Mitigation Options for Reducing Emissions from Manure Management

Recovery and utilization of methane produced from manure is the most common option for reducing emissions in this sector. However, the capacity for mitigating methane emissions from manure management depends greatly on the management system. Livestock confinement facilities that contain and concentrate wastes offer the highest potential for emission reductions through the use of covered lagoons and digesters. Currently, few developing countries have confinement facilities, and most manure is deposited directly on the yard, pasture, or rangeland. However, as population growth increases demands on food and land use, livestock confinement systems may become more common. The use of options such as covered lagoons and digesters maintains the fertilizer value of manure and can provide the benefits of electricity production, reduced pollution, and reduced environmental health risks that are associated with manure production.

source. The recovered methane could be used to fuel cooking stoves, which would offset consumption of fuelwood. The **Slovak Republic** estimated that biogas generation from manure could reduce manure methane emissions by 5 to 15 percent by 2010.

Agricultural Land Management

The most common options considered were:

- reducing livestock on over-grazed lands
- redistributing livestock grazing.

Changes in the management of agricultural land can reduce soil carbon emissions or result in increased carbon sequestration or both. **Mongolia** proposed modifying the distribution of grazing animals by redistributing the water sources. **Ethiopia** determined which mitigation options would increase plant productivity and carbon storage in the highlands. Ethiopia also analyzed the options of spreading manure on overgrazed lands, redistributing watering points, and promoting long-term settlement in lowland areas. The results of the analysis were encouraging: as soil carbon increased, rangeland plant production more than doubled and overgrazed areas recovered rapidly.

Kazakhstan evaluated the soil carbon sequestration potential of converting less productive lands into grasslands and rangelands. Kazakhstan found that a reduction in wheat production on less productive lands with a corresponding intensification of production on the better-suited lands would be economically profitable under appropriate conditions and would enable the replanting of less productive lands with perennial grassy and bushy vegetation. This would enable soil carbon reaccumulation varying from 308,700 to 674,900 $MTCO_2$, or between 1 and 3 percent of Kazakhstan's total emissions from agriculture.

Fertilizer Use

USCSP participants considered various ways to reduce nitrous oxide emissions from fertilizer use, including:

- limiting its application
- reducing spillage
- increasing the utilization efficiency of fertilizer by plants
- employing substitutes.

The **Russian Federation** considered establishing a special price policy to control fertilizer use and improving storage conditions to prevent fertilizer loss. Improving storage conditions was recommended as the best immediate solution. **Egypt** proposed the removal of economic subsidies of fertilizer, as well as the displacement of some fertilizer use with Nile silt. **China** analyzed increasing plant utilization of nitrogen, which could reduce nitrous oxide emissions from agriculture by an estimated 20 percent.

Use of Agricultural Biofuels

Certain agricultural crops can be used as a fuel source and thus displace fossil fuel combustion, thereby producing GHG benefits. **Poland** investigated three crops—rapeseed, triticale, and micanthus—for use as biofuel, and determined that rapeseed would be the most effective. The **Czech Republic** also suggested the use of rapeseed for energy production.

4.4.3 Mitigation Assessment Methodology

The countries participating in the USCSP used a variety of means to assess mitigation options in the agriculture sector. Assessment methods differ by emissions source. Typically, participants first identified the key variables affecting emissions, such as area under planting and type of cultivar to evaluate mitigation options for emissions from rice production, and number, type, and diet of ruminants for options to reduce enteric fermentation emissions. Then, potential emission reductions from changes in these variables were assessed. For instance, Sri Lanka altered rice varieties, application of fertilizer, and water management strategies. Many other factors were used to assess mitigation options, including cost of implementation; availability of the technology; regional conditions or characteristics; impacts to crop, milk, or meat production; and social acceptability of the option. Growth in human and livestock populations was also a major variable affecting projections in the agriculture sector.

The GHG emission reduction benefits of each option were analyzed with a variety of models. The Nitrate Leaching and Economic Analysis Package (NLEAP) was a commonly used model for calculating nitrogen emissions from fertilizer use. The CENTURY model, which can be used to evaluate the influence of various factors on soil organic carbon, was also employed. Participating countries often developed baseline and mitigation scenarios to determine the annual and aggregate benefits of a given mitigation strategy.

2.5 Waste Sector

2.5.1 USCSP Participants and the Waste Sector

Mitigation options in the waste sector were examined in over 55 percent of the 31 USCSP participants that completed mitigation assessments. Methane emissions from waste constituted a high percentage of total methane emissions in the six following countries — Bulgaria (60 percent), Hungary (50), Côte d'Ivoire (39), Poland (38), Zimbabwe (24), and Nigeria (21) — in comparison to a global average of 17 percent (Doorn et al., 1995; Braatz and Barvenik, 1996) (see Box 17 and Figure 19). Common waste management practices in developing and transition countries are summarized in Box 18.

The key findings from this sector are as follows:

- Mitigating GHG emissions from the waste sector is generally not a high priority for many USCSP participants, because methane emissions associated with waste generation are relatively low.
- The most important mitigation options include landfill methane recovery and utilization, improved comprehensive waste management, and alternative waste management such as recycling, composting, and other practices.

2.5.2 GHG Mitigation Options Evaluated

USCSP participants investigated five mitigation options in this sector:

- landfill methane recovery
- integrated waste management
- alternative waste management
- wastewater treatment
- source reduction.

The economic and environmental impacts associated with these mitigation measures are often favorable. In many instances, these mitigation measures could generate ancillary benefits, including reduced air and water

Box 17 The Waste Sector: A Global Perspective

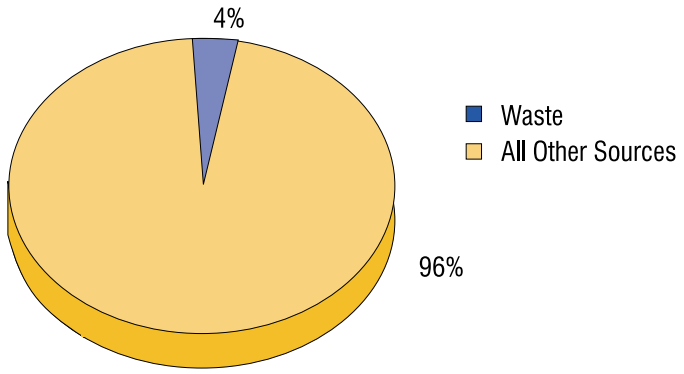
Global greenhouse gas emissions from the waste sector comprised roughly 4 percent of total global GHG emissions, or about 65 MMTCH$_4$ (1,350 MMTCO$_2$) (Braatz and Barvenik, 1996). Most GHG emissions from the waste sector are methane, which is 21 times more effective in trapping heat in the atmosphere than carbon dioxide. The main sources of GHG emissions in the waste sector are landfills/open dumps and wastewater. Emissions from landfills and open dumps constitute roughly 30-60 percent of emissions from the waste sector, and the remaining emissions come from wastewater. Emissions from landfills and open dumps and from wastewater each account for about 10 percent of global anthropogenic methane emissions (Braatz and Barvenik, 1996; Watson et al., 1996b).[a]

The volume of waste that a country generates tends to increase significantly as it develops. Industrialized countries currently generate the majority of global methane emissions from waste, because of higher per capita waste generation rates, more urban areas, and more waste management infrastructure (Watson et al., 1996b). However, as developing and transition countries continue to grow and industrialize, methane emissions from their waste sectors will increase. Developed countries account for approximately two-thirds of GHG emissions from landfills and open dumps, while transition countries are responsible for 15 percent and developing countries for the remaining 20 percent. Conversely, most of the GHG emissions from wastewater occur in developing countries, where there is little or no management or maintenance of domestic sewage and industrial waste streams.

The most significant GHG emissions from waste management in developing and transition countries are methane emissions from anaerobic decomposition of organic wastes. Unless a landfill or pit has a means of collecting methane, the methane is emitted to the atmosphere. Wastewater and sludge also produce methane when they are stored under anaerobic conditions. The amount of methane emitted from wastewater and sludge depends on the organic content of the material and the extent to which it degrades in the absence of oxygen. The waste streams from food processing and pulp and paper production produce the majority of methane emissions from wastewater, followed by domestic and commercial wastewater (Watson et al., 1996b).

[a] Note that estimates of methane emissions from waste remain highly uncertain, because of limited information about waste management practices in different countries, the portion of organic wastes that decompose under anaerobic conditions, and the extent to which wastes eventually decompose.

Figure 19 Contribution of Waste to Global Anthropogenic GHG Emissions, 1990*



*Global GHG emissions in 1990 were estimated at 3,600 MMTCO$_2$.
Source: Braatz and Barvenik, 1996.

Box 18 Common Waste Management Practices of Countries Participating in USCSP

One of the most common waste management practices in developing countries is the disposal of waste in garbage mounds or pits. Many of these disposal areas are not covered daily, and thus host numerous disease carriers such as mosquitoes and rats. It is estimated that almost 80 percent of the waste in Latin America and lower-income Asia, and almost 60 percent of the waste in Africa, is landfilled or dumped in a similar manner (Doorn et al., 1995). Many municipalities in developing countries lack basic waste collection services, so garbage is dumped on streets, down ravines, or in rivers. Although waste disposed in this manner does not typically produce methane, it is not recycled and thus an opportunity is lost to displace emissions from fossil fuel combustion from the manufacture of new products. In addition, these disposal techniques aggravate sanitation and pollution problems. With rapid population growth and escalating migration from rural to urban areas, solid waste management systems in many developing urban areas suffer from increasing pressures and cannot collect a large portion of the waste generated. Uncollected waste is often burned, a practice that may be a significant source of CO_2 emissions.

pollution, improved sanitation, and job creation. Quantification of such benefits remains difficult, and was not included in the USCSP mitigation analyses. Most participants that addressed mitigation in the waste sector primarily evaluated options in a qualitative manner. Each of the options identified by countries participating in the Program is discussed below, and the number of countries evaluating each option is given in Box 19.

Landfill Methane Recovery

Landfills emit methane (landfill gas) during their active lifetimes and for 10 to 30 years after closing. In many instances, more than half of the methane emitted can be collected and either flared or used to generate heat or electricity. Landfill gas can be purified and injected into natural gas pipelines or distribution systems, or compressed for use as a fuel in vehicles (IPCC, 1996). When landfill gas is used for energy, it also displaces the GHG emissions that would have resulted from the use of fossil fuel to generate that energy. Most of the transition countries participating in the USCSP considered options of this sort, as did China, Egypt, and Indonesia.

China estimated that by implementing landfill gas recovery and utilization technology in conjunction with improved waste disposal methods, national methane emissions could be 30 percent lower than the baseline by 2030, a reduction of 3.7 $MMTCH_4$ (78 $MMTCO_2$, or 0.7 percent of total 1990 GHG emissions).

Bulgaria determined that the construction and cost requirements for the collection and flaring of landfill gas are feasible, but that further research is required on the utilization of the gas for energy. Collecting and using landfill gas would provide lasting economic benefits for Bulgaria, but a lack of technical experience and the high capital costs make this measure unrealistic at present. Bulgaria did estimate an annual savings of up to 4.4 $MMTCO_2$.

Integrated Waste Management

Several participating countries considered the development of integrated or comprehensive solid waste management programs. They also entail implementation of more sophisticated waste collection programs. Most of the countries that considered this option discussed these programs on a qualitative basis. For instance, **Bulgaria** considered the adoption of a national policy for solid waste management to implement more effective collection, composting, and recycling of solid waste. **Côte d'Ivoire** described a reorganization of the formal waste sector to increase recycling and reuse of waste. In another approach, **Poland** described the application of a methane emissions tax to landfills. The participants often found that simple changes and improvements in overall waste management would provide municipal, environmental, and climate change benefits.

Box 19 Number of Countries Considering Mitigation Options in the Waste Sector

Landfill methane recovery	*7*
Improved waste management	*7*
Alternative waste management	
- Recycling	*7*
- Composting	*4*
- Incineration	*4*
Wastewater treatment	*5*
Source reduction	*4*

Alternative Waste Management

Waste management practices such as recycling, aerobic composting, and incineration can divert waste from landfills or dumps, consequently reducing the amount of methane generated. These practices can also generate other GHG benefits. Recycling can reduce GHG emissions by offsetting the demand for the manufacture of virgin products. Incineration with energy recovery can offset the consumption of fossil fuels for energy. Compost can offset the manufacture of synthetic fertilizers. However, the appropriateness of these measures varies by country. For example, with regard to composting, less developed countries generate more moist organic waste, which is ideal for composting. Incineration can be a particularly attractive waste management practice when landfill space is restricted, but the incinerator emissions and ash disposal may have negative environmental impacts. Moreover, the moisture content of waste in many developing countries may make incineration impractical, and the costs of incineration systems can be prohibitive.

The **Slovak Republic** forecasted that increased collection of recyclable materials would permit operation of existing recycling equipment at full capacity, thereby producing significant GHG benefits. However, the investment required for container distribution and final paper separation equipment precludes expansion of recycling at present.

Indonesia evaluated recycling, composting, and incineration to reduce the volume of waste in landfills and concluded that waste incineration at dumps could reduce annual methane emissions by 1 percent below the baseline, or 2,876 $MTCH_4$ (0.06 $MMTCO_2$). However, burning in open dumps would have negative environmental effects in the country. Recycling organic waste could reduce methane emissions by 3 percent below the baseline, or 8,628 $MTCH_4$ (0.2 $MMTCO_2$). In Indonesia, composting of organic waste could reduce methane emissions more significantly. Composting is already practiced in rural areas for use as fertilizer, and composting could be promoted in urban areas for use in home gardens. Composting was estimated to reduce methane emissions by 8 percent below the baseline, or 23,007 $MTCH_4$ (0.5 $MMTCO_2$). The costs for these three options are comparable. Indonesia also evaluated waste incineration, and found that it could realistically be implemented only by urban hospitals. Incineration would reduce methane emissions by 15 percent below the baseline, but at a relatively high cost.

Wastewater Treatment

Storage and treatment of wastewater under aerobic conditions can significantly reduce methane emissions from this source. Wastewater can also be treated under anaerobic conditions and the resultant methane captured. This methane can be either flared or used as energy to heat wastewater or sludge digestion tanks. Wastewater also can be applied to land; soil can act as a filter and break down the organic components of the wastewater (LBL, 1995).

The **Philippines** considered adoption of comprehensive wastewater management policies, infrastructure, and treatment systems; assistance with the design and development of smaller-scale community wastewater management systems; and methane recovery from anaerobic treatment. Lack of data on flow rates, system costs, financial inputs, and methane recovery prevented an assessment of potential emissions reductions and cost-effectiveness of these options.

Source Reduction

Source reduction activities seek to eliminate the production of waste. Source reduction can produce three kinds of emission benefits:

- avoided emissions due to reduced consumption and processing of raw materials
- avoided fossil fuel emissions associated with transporting and processing waste
- avoided landfill methane emissions.

Bulgaria, Estonia, Romania, and the Philippines conducted qualitative assessments of the GHG benefits from source reduction.

2.5.3 Mitigation Assessment Methodology

USCSP participants used a variety of methods to assess mitigation options in the waste sector. Typically, countries identified the key variables affecting emissions, and assessed potential emission reductions from changes in these variables. In the waste sector, key variables included waste generation rates, population growth, and waste management strategies. Countries often developed baseline and mitigation scenarios to determine the annual and aggregate benefits of various mitigation strategies. Cost-benefit analyses were used to determine the economic feasibility of each option. Participants also looked at the ease of implementation of each mitigation option, and some involved multiple stakeholder groups in the overall assessment. Ancillary benefits such as improving local environmental conditions were considered qualitatively in the evaluations.

2.6 Industrial Processes

2.6.1 USCSP Participants and the Industrial Processes Sector

Roughly one-fourth of the countries participating in the USCSP evaluated mitigation options in the industrial processes sector. Process-related emissions originate from industrial activities unrelated to energy consumption, such as production processes that chemically or physically transform materials (Box 20). The key findings from this sector include the following:

- Process-related GHG emissions from the industrial sector represent a small percentage of overall national GHG emissions for transition and developing countries, and these were not a priority for mitigation analysis.
- The primary mitigation options evaluated focus on process emissions from the cement, lime, pulp and paper, and iron and steel industries. Additional industrial processes addressed were the production of ammonia, aluminum, adipic acid, nitric acid, and HCFCs.

2.6.2 GHG Mitigation Options Evaluated

Program participants identified several mitigation options for industrial process emissions, including raw material conservation, efficient use of end products, material recycling, technology improvements, and demand reduction. Demand reduction could be achieved through the introduction of substitutes or implementation of policy instruments. Examples of the options analyzed follow.

Tanzania identified options to mitigate CO_2 emissions from pulp and paper production. The production of lime for use in the manufacture of pulp and paper is a main source of process emissions from this industry. Tanzania estimates that it could conserve approximately 10 percent of the lime consumed in the industry by optimizing recovery boiler operations. In addition, Tanzania estimates that by 2020, it could save up to 14 percent of the lime used in this industry by recycling lime mud from the calcination process. This option could reduce CO_2 process emissions by 573 $MTCO_2$ per year.

Sri Lanka examined mitigation options in both the cement and lime industries. Sri Lanka's assessment reported that approximately 5 percent of cement and 8 percent of lime on average are wasted from production to end use of these materials. Fifty percent of this waste could be prevented by installing proper dust collectors at various stages of the process, reducing clinker needs for cement production by developing cement types with high strength properties, and properly managing the end use of cement and lime. By 2015, emissions from clinker production could decrease 5 percent annually, or 154,000 $MTCO_2$, and emissions from lime production could decrease 4 percent annually, or 11,380 $MTCO_2$.

Egypt investigated reducing or limiting the emissions of HFCs and SF_6 by promoting the use of alternatives, reducing anode effects at aluminum smelters, and optimizing the use of these gases in refrigeration, air conditioning, and semiconductors. Policy instruments such as introducing regulation or launching public information campaigns on ways to reduce emissions were discussed.

Romania and **Poland** considered reducing industrial process emissions by conserving raw materials through modernization of industrial technologies. Both countries focused on modernizing energy intensive industries. Romania considered the pulp and paper, ammonia, and iron and steel industries. Poland explored modernization of the iron and steel and aluminum industries, and recommended the use of agglomerated anodes in aluminum production to prevent the anode effects that cause PFC emissions.

2.6.3 Mitigation Assessment Methodology

USCSP participants that addressed mitigation options for industrial processes generally conducted process-specific engineering assessments. Typically, they focused on the industrial processes that contribute a significant portion of national GHG emissions, are expected to increase in the future, or present opportunities for emission reductions. The existing technologies or practices that were commercially available to reduce emissions from this sector were identified. In some cases, practices that reduce GHG emissions also improve the economics of the operation or reduce other environmental emissions or wastes.

Box 20 Industrial Process Emissions

Industrial process emissions are produced directly by an industrial process itself and are not a result of energy consumed during the process. For example, in addition to the substantial energy-related emissions from cement production, the calcining of limestone to form clinker (the key ingredient in cement) generates carbon dioxide. These emissions are the result of the chemical transformation of the limestone, not the burning of fossil fuel.

GHG emissions are produced as a byproduct of various non-energy-related industrial activities. The manufacture of cement, iron and steel, lime, aluminum, magnesium, adipic acid, nitric acid, and semiconductors, among others, represent the main sources of GHG emissions from industrial processes. Overall, cement production and iron/steel production are the most significant sources of noncombustion emissions of CO_2.

In addition to CO_2, industrial processes produce other GHGs such as CH_4, N_2O, perfluorocarbons (PFC), hydrofluorocarbons (HFC), and sulfur hexafluoride (SF_6). While emissions of these gases may be relatively small compared to those from other sectors, they are important because of their global warming potentials and long atmospheric lifetimes. For instance, N_2O has 310 times the global warming potential of CO_2. PFCs such as CF_4 and C_2F_6 have global warming potentials of 6,500 and 9,200 times that of CO_2, respectively. In addition, industrial process emissions represent a significant portion (10 to 50 percent) of global anthropogenic N_2O emissions (Houghton et al., 1992).

Industrial process emissions and their main sources are listed below by industry (IPCC, UNEP, OECD, IEA, 1997; IPCC, OECD, IEA Programme for National Greenhouse Gas Inventories, 1999).

Greenhouse Gas	Production Processes or Uses Generating Emissions
Carbon dioxide	cement, lime, use of lime and limestone (e.g., pulp and paper production), ammonia, carbides, iron, steel and ferroalloys, aluminum, magnesium, soda ash
Methane	carbides, petrochemicals, iron, steel and ferroalloys, aluminum nitrous oxide, nitric acid, adipic acid, urea, caprolactom, petrochemical, dodecanedioic acid
Perfluorocarbons	aluminum, halocarbons, use of halocarbons and sulfur hexafluoride
Sulfur hexafluoride	aluminum, magnesium, halocarbons, use of halocarbons and sulfur hexafluoride
Hydrofluorocarbons	petrochemicals, halocarbons, use of halocarbons and sulfur hexafluoride

2.7 Barriers to Implementation of GHG Mitigation Options

In addition to identifying options for mitigating GHG emissions, many of the USCSP participants assessed key barriers to implementing these options. While some countries assessed barriers by sector and/or by option, others assessed barriers at a broader, multisectoral level. Despite differences in the mitigation options evaluated, socioeconomic conditions, and current level of technological development, the participants generally identified a common set of barriers that apply across sectors. In addition, several barriers that are unique to the forestry sector were identified. These barriers are discussed in greater detail below.

2.7.1 General Implementation Barriers

Program participants identified the following barriers to the development and implementation of new technologies and energy sources across sectors:

- Insufficient domestic infrastructure for supporting new technologies and new energy sources (e.g., lack of reliable infrastructure for distributing electricity and natural gas).
- A lack of capital for investing in the development of new technologies, energy sources, and infrastructure because of (1) competing domestic priorities for scarce capital resources and (2) a lack of foreign investment in these areas for a variety of reasons, including regulatory and political barriers.
- A lack of data and methods for conducting comprehensive cost-benefit analyses of mitigation options.
- The high initial capital costs of purchasing more efficient technologies, and a lack of mechanisms for reducing the initial costs borne by consumers. Such mechanisms could include subsidies, tax incentives, and lowered production costs due to economies of scale.
- A lack of domestic supply of new technologies and alternative fuel sources, resulting in the potential need to increase dependence on foreign imports if these technologies and fuel sources are to be used.
- Existing policies and regulations that favor current technologies and energy sources and discourage the development and implementation of new technologies and energy sources.
- The need to train people in the manufacture, installation, use, and maintenance of new technologies as well as in the implementation of new resource management practices.
- The need for general education to improve the public's awareness and acceptance of new technologies and resource conservation opportunities, and willingness to change their choices and habits.
- A lack of access to efficient technologies because of insufficient networks for equipment distribution and maintenance.
- General economic or political instability, leading to competing demands for scarce economic resources and political attention.

The examples below illustrate the interaction of technological, political, regulatory, and economic barriers to implementing mitigation options in multiple sectors.

In **China**, lighting accounts for 10 percent of national electricity consumption. China's mitigation assessment recommended the use of high-pressure sodium lamps and metal halide lamps for production process lighting, and thin-tube fluorescent lamps, compact fluorescent lamps, and energy-saving halogen lamps for commercial and residential lighting. However, the high price and poor quality of domestic energy-saving lamps were identified as significant barriers to implementing this recommendation. The price of a high-quality energy-saving lamp is about 50 times higher than that of a standard incandescent lamp. Most lighting source factories are small, have little specialized production, and have not been regularly upgraded. For example, China currently lacks mature technology for the mass production of shock-resistant tungsten filaments used in incandescent lamps, produces glass tubes that are not uniform in size and quality, and has access to fluorescent powder that is unstable and low in illuminant efficiency. As a result of these and other factors, domestically produced incandescent and fluorescent lamps have a lighting efficiency that is 10 percent lower, and a lifetime that is 50

to 66 percent shorter, than lamps produced in developed countries. Finally, China does not have a complete and effective quality standard and supervision system, which makes it difficult to prevent inferior energy-saving lamps from entering the market.

Nepal identified the increased use of hydroelectric resources as a key mitigation option in the energy sector. Nepal has substantial hydroelectric potential, only 1 percent of which has been tapped. Further development of that potential would help reduce dependence on foreign imports of petroleum as well as reduce GHG and air pollutant emissions. The key barriers to increasing hydroelectric generation include the high up-front capital costs, compounded by the need to import equipment, and a lack of access to foreign and private capital investments.

In its energy-sector mitigation assessment, the **Philippines** identified barriers to implementing most options that it considered. For example, the replacement of coal-fired plants with combined cycle natural gas plants could be complicated by the need to further explore or develop the country's gas reserves. In addition, facilities for gas processing, transmission, distribution, and storage would need to be constructed. A second option, reducing transmission and distribution losses, is difficult to implement because of the lack of tax and loan incentives or subsidies, particularly for small rural electric cooperatives. Most cooperatives lack sufficient labor and equipment resources to address this problem on their own. Both electric cooperatives and private utilities will need substantial technical assistance to undergo restructuring and build their capability to prepare integrated resource plans. A third option, the use of compact fluorescent lights (CFLs), is impeded by high equipment costs. In 1996, the initial cost of CFLs was 10 times the cost of a standard incandescent light bulb. This constraint could be reduced by rebates to customers and joint manufacturer promotions. In addition, improvements in the stability of local power supplies would help increase the expected lifetime of CFLs.

Tanzania initially conducted a broad barrier analysis and then focused on individual sectors. Across sectors, the key barriers to the implementation of mitigation options include a lack of information on options, capital constraints, market imperfections (e.g., distorted prices and limited competition), rapid payback requirements, institutional barriers, insufficient capacity to produce and maintain new technologies, a lack of social acceptance of new technologies, and concerns regarding the distribution of costs and benefits. Tanzania reported that social acceptance criteria play a greater role when options involve implementing decentralized and small-scale technologies, particularly when these technologies could alter traditional cultural practices or create instability in social structures. For energy supply mitigation options, which involve more centralized decision making, the key barrier is the need for skilled labor to manage and maintain the technologies. The availability of skilled labor as well as adequate service-supplier networks is critical to implementation of mitigation options in the transport sector. In the household and services sector, implementing demand-side management options is constrained by a lack of understanding of the potential economic benefits of these options on the part of utility managers and consumers. In the agriculture sector, a key barrier is a lack of expertise in using more modern agricultural technologies. A lack of sufficient technological capabilities, skilled labor, and managerial capabilities makes implementation of mitigation options more difficult in the industrial sector.

Ukraine identified both legislative and economic barriers to implementing mitigation options in the energy sector. Although the Law of Ukraine on Energy Conservation outlines economic measures for promoting energy conservation, these measures are not reflected in the Laws of Ukraine on the Taxation System and on Taxation of Enterprises' Incomes, as well as other relevant laws. As a result, the existing laws and regulations do not allow the introduction of preferential taxes for the producers and consumers of energy-efficient technologies. Additional barriers to energy-sector emissions mitigation include the current level of economic instability resulting from the transition to a market economy, insufficient economic mechanisms for attracting foreign investment in energy-saving projects, and a lack of experience in the development and implementation of energy-saving projects.

2.7.2 Implementation Barriers Unique to the Forestry Sector

Some USCSP participants evaluated barriers to GHG mitigation that are unique to the forestry sector. The most common barrier to optimal management of forests for GHG mitigation was the demand for alternative forest uses that appear to be more economically valuable to local inhabitants in the short term, but produce higher GHG emissions. Another common barrier is a lack of understanding of the carbon fluxes associated with different land uses. The participants reported that a lack of data, equipment, and training hinders more accurate estimations of carbon fluxes and characterization of land uses. Additional factors such as weather, population, agricultural trends, and economic trends also complicate estimation of carbon fluxes. All participating transition countries that evaluated mitigation options in this sector, and some developing countries, point out that dramatically fluctuating economies make price and cost estimates exceptionally difficult, which complicates the use of cost-benefit analysis to select land-use management strategies. Additional barriers are listed in Box 21.

For example, the **Philippines** considered in more detail the uncertainties related to the data used for land-use and forest classification, rates of land-use change, and long-term economic projections. The Philippines suggested that the development of a database on the actual biomass density of its tropical forests, understory vegetation, and litter and soil carbon, as well as a national inventory of all forest species, would help reduce uncertainties of some inputs into the modeling tools for mitigation activities in this sector. **Venezuela** identified as barriers the lack of reliable estimates on current land conversion from one use to another and the need for long-term government land-use planning.

Several of the Program participants also pointed out that the success of mitigation measures will hinge on the political will of the national government to support climate change programs, or, for this sector in particular, forestry development programs with peripheral GHG benefits. More than 20 percent of the forest sector analyses mention the need to factor into the evaluation of options the ancillary non-GHG benefits of forest management for GHG mitigation, including new job opportunities, biodiversity conservation, watershed protection, and prevention of land degradation and desertification. Because climate change mitigation is not often a top priority of governments in developing and transition countries, emphasis on the economic and other benefits of the mitigation activities would facilitate their implementation.

Box 21 Barriers Unique to Mitigation in the Forestry Sector

- *Unclear land tenure.*
- *Pressures on land available for mitigation activities and existing incentives to clear land for agricultural and livestock production.*
- *Risk of drought, fire, and pests.*
- *Illegal logging activities.*
- *Government financial incentives that encourage use of natural forests by industry.*
- *Inadequate data collection and methods for monitoring and verification of carbon flows.*

2.8 Economic and Other Policy Mechanisms for Implementation of Mitigation Options

Many of the USCSP participants evaluated the potential use of economic and other policy mechanisms for overcoming the barriers to implementation of mitigation options in each sector. The market-based mechanisms evaluated were primarily taxes, tax incentives, subsidies, and price controls. The policy mechanisms included the development, implementation, and enforcement of legislative policies, laws, and regulations; voluntary public and private programs to promote market development; and public and industry education programs.

National-scale mechanisms for promoting emission mitigation were examined more frequently than regional- or local-scale mechanisms. While the Program participants recognized that changes to national economic, regulatory, and social policies would be necessary for implementation of mitigation options in all sectors, they focused their analyses on two key sectors: energy and forestry. The countries that conducted more in-depth assessments of these mechanisms used criteria such as:

- the magnitude of GHG benefits achieved
- the initial investment cost to the government, the producer, and the consumer
- the direct and indirect economic impacts
- the distribution of costs and benefits
- the compatibility with existing policies and regulations
- social acceptability.

Although economic and policy mechanisms tended to be assessed separately and are discussed in separate sections below, most countries recognized that both types of mechanisms are tightly linked and interdependent.

2.8.1 Economic Policy Mechanisms

Many USCSP participants evaluated the use of taxes, tax incentives, and subsidies to overcome the barrier of high investment costs for the implementation of more efficient technologies, less carbon-intensive energy sources, and resource management practices. Several countries, particularly the transition countries, studied the GHG and economic impacts of taxes on the production, importation, and consumption of fuels; the consumption of other natural resources in the forestry and agriculture sectors; and the generation of waste. Conversely, some participants focused on the use of tax incentives for the importation, purchase, and leasing of energy-efficient equipment; the use of equipment fueled using renewable energy sources; and land-use activities promoting afforestation and reforestation. Most indicated that government subsidies would be needed to fund activities such as:

- research and development of new technologies
- infrastructure development to support the production and use of renewable energy and other energy sources
- rebates for the purchase of energy-efficient equipment
- the provision of low-interest loans and revolving loan funds for emission-reduction activities
- the development of public education programs.

While the use of tax incentives and subsidies to support emission-reduction activities was generally recommended, participants did not reach firm conclusions regarding the ultimate effectiveness and feasibility of taxes on carbon or energy consumption. Some were particularly concerned about the direct and indirect economic impacts of carbon or energy taxes. The need for further analytical work to predict the impact of tax mechanisms on overall economic growth, the distribution of costs and benefits across sectors, and GHG mitigation potential was emphasized.

Changes to government price controls were identified by a few participants as an important mechanism for promoting GHG mitigation, particularly in the energy sector. Several reported that controls on fossil fuel prices distorted the market for these fuels, and served as a disincentive for fuel switching. Some recommended that the fuel pricing structure should be modified to reflect the true economic costs of production as well as the environmental costs of production and consumption; how-

ever, methods still need to be developed for effectively quantifying those environmental costs.

Examples of market-based mechanisms analyzed by USCSP participants are provided below.

The **Czech Republic** identified the liberalization of energy prices and changes in taxes as important mechanisms for promoting GHG mitigation. The Czech Republic is considering (1) the removal of cross-subsidies from the price of electricity and gas used by households, (2) the removal of subsidies for coal and uranium mine closures, (3) an increase in the value added tax (VAT) rate for district heating, and (4) the total removal of residual subsidies for heat prices from the central heating system for households. The Czech Republic noted that the VAT rate for district heating should not be raised before removal of cross-subsidies for gas and electricity, since this could place district heating at a disadvantage and limit the development of combined heat and power. They are also examining the potential implementation of carbon and energy consumption taxes, which would be used to shift the tax burden to indirect energy consumption. Finally, possible methods for accounting for environmental externalities in the costs of energy, transportation, and selected industrial products are being explored.

Hungary evaluated the possible effects of a carbon/energy tax system on GHG emissions. Four cases were examined: (1) no carbon/energy tax, (2) a \$US14/MTCO_2 tax in 2000 and \$US28/MTCO_2 tax in 2010, (3) a \$US28/MTCO_2 tax in 2000 and a \$US56/MTCO_2 tax in 2010, and (4) a \$US9/MTCO_2 tax from 2000 combined with a \$US0.67/GJ energy tax. Energy consumption was found to be relatively inelastic, in that the doubling of prices of fossil fuels would reduce CO_2 emissions by only 4 to 8 percent. Installing a new base-load nuclear power plant would reduce far more CO_2 emissions than carbon taxation. However, Hungary also stated that because nuclear energy already constitutes about 50 percent of total energy production and because the national strategy is to diversify energy production to reduce fuel supply risks, construction of a new nuclear power plant is unlikely in the near future.

Nigeria applied a computable general equilibrium model to study the overall economic impact of different economic policy options for mitigating GHG emissions from the energy sector. These options included the following:

(1) taxation of final consumption of petroleum products (20 percent tax)
(2) taxation of intermediate consumption of petroleum products (20 percent tax)
(3) general taxation of consumption of petroleum products
(4) alignment of the domestic price for crude oil with the world export price
(5) reduced crude oil production due to international effort to cut fossil fuel use
(6) a zero-net-cost 20 percent efficiency improvement in the use of petroleum products
(7) a combination of options #3 and 6
(8) a combination of options #4 and 6.

The model outputs showed that the appropriate combination of measures could result in greater combined GHG and economic benefits than could be achieved with individual measures. For example, option #3 resulted in emission reductions of about 2 percent and negative economic growth of 0.7 percent in the fifth time period of the simulation (where each period ranges from one to five years). Option #6, a 20 percent efficiency improvement, resulted in emission reductions of 0.20 percent and positive economic growth of 1.6 percent. However, the combination of both options resulted in emission reductions of 2.3 percent and positive economic growth of 1 percent.

Poland outlined a combination of tax and subsidy mechanisms for promoting emission reduction in the energy, agriculture, and waste sectors. The introduction of an energy-sector carbon tax no earlier than 2000 was recommended. The proposed scale of the carbon tax ranges from \$US16-\$US31/MTCO_2, but under current (1996) conditions the tax should not exceed \$US5.50/MTCO_2 and should be raised gradually. The tax would be levied on the sale of hard coal, lignite, furnace oil, diesel oil, natural gas, and petrol, and the

payment would depend on the carbon intensity per unit of energy production for a given fuel. The tax would be synchronized with the development of a subsidy program. Ten percent of the income from the carbon tax would be used to subsidize federal afforestation projects on approximately 100,000 hectares of farmland annually. The remainder would be used for subsidizing cultivation practices with a high ratio of carbon sequestration, organizing and supporting environmental auditing, subsidizing emission-reducing investments, and conducting ecological education. In addition, Poland recommended a tax on methane emissions from breeding farms, landfills, and coal mines. The entities that recovered and used the methane would be exempted from the tax.

Mexico reported that deforestation was exacerbated by the existence of financial incentives (e.g., crop production incentives) to clear forest for conversion to agriculture and pasture. To address this problem, Mexico proposed creating a 15-year subsidy of $US48/ha/yr that would be used to compensate forest owners for not converting their forests to other land uses or for afforesting degraded forest lands. This subsidy would be equivalent to the subsidy that is provided for corn production.

Estonia proposed to develop a forest-sector taxation policy that would encourage the use of more productive tree species.

2.8.2 Other Policy Mechanisms

All of the countries participating in the USCSP recognized that successful implementation of GHG mitigation options would require coordinated and complementary changes in national policies, laws, and regulations. Participants frequently made the following types of recommendations:

- The development of new national policies to promote GHG mitigation.
- The integration of new GHG mitigation measures into existing national policies.
- Changes in environmental laws to reinforce the measures outlined in national GHG mitigation policies.
- The development of new regulations for energy-efficiency standards and natural resource management practices.
- Improved enforcement of existing regulations.
- The development of voluntary public and private partnerships to promote GHG mitigation.
- The development of education programs targeted to both producers and consumers in all sectors.
- The development of new administrative offices tasked with overseeing the implementation of GHG mitigation options.
- Evaluation of opportunities to participate in joint multinational GHG mitigation projects under the Activities Implemented Jointly pilot phase of Joint Implementation under the UNFCCC or similar initiatives.

While some countries conducted an in-depth examination of which current national policies, laws, and regulations would need to be amended, other countries simply identified the general need to make these types of changes. The examples below illustrate some of the initiatives described by USCSP participants.

To promote the use of renewable energy sources, **Bulgaria** proposed the development of a National Federation of Renewable Energy Sources. The federation would be tasked with protecting the commercial interests of the sector, undertaking research and development activities, providing development strategies, and ensuring the access of its members to financial and technical support. The main membership groups would consist of researchers, investors, and workers in the renewable energy field, designers and producers of equipment for generating energy from renewable resources, and exporters of energy and equipment for renewable resources.

The **Czech Republic** described three mechanisms for encouraging public and private partnerships to reduce GHG emissions:

- The initiation of a voluntary contract agreement between energy producers or producer associations and the government. Under the contract, energy producers would agree to reductions in GHG emissions by 2010 in return for legislative support and subsidies by the government.
- A technology procurement initiative to support the development of small gas boilers (10-30 kW) for providing heat and hot water to households. This

initiative would involve an association of equipment distributors or a wholesale business, and the state guarantor would be the Czech Energy Agency or an independent consulting company.

- The organization of competitions among producers to determine new standards for high-efficiency equipment.

Kazakhstan's Law of the Republic on Energy Savings, adopted in December 1997, covers all aspects of energy savings related to both energy production and consumption, including improvements in energy efficiency and development of renewable energy. The Law defines the framework for governing the implementation of energy-saving policies at the national level. However, the enabling mechanisms for implementation of the Law have not yet been fully developed. Therefore, one of the priority measures for GHG mitigation in the energy sector is the design of enabling mechanisms for implementing the Law.

Poland recommended the integration of statements or amendments favoring GHG mitigation into the draft of the new constitution, the criminal and civil proceedings codes, and the state ecological, energy, transport, and agricultural policies. For example, in the transportation sector, Poland recommended a combination of changes to economic, transportation, and land development policies to promote vehicles with low energy consumption, more stringent fuel emission standards, mass transportation, parking fees to reduce congestion in urban areas, and more effective land-use management.

Romania identified public education as a critical element to implementing GHG mitigation options in the residential and commercial buildings sector. Romania recommended the development of a broad range of educational tools, including equipment efficiency labeling, informational booklets for homeowners and architects, and radio and television advertisements.

2.9 Conclusions

2.9.1 Conclusions from Mitigation Assessments

Thirty-one of the 56 USCSP participants have completed mitigation analyses, and four are in the process of developing their assessments. USCSP mitigation assessments provide the foundation for countries to set priorities among the technologies that reduce GHG emissions and sequester carbon within key GHG-emitting sectors. While there is clearly a wide range of mitigation measures available in the developing and transition countries, it is also clear that not all have been fully considered by all participating countries. In general, the energy sector was the top priority, followed by the forestry sector.

More than two-thirds of the USCSP participants conducting mitigation assessments demonstrate the ability to reduce CO_2 emissions by at least 10 percent below projected baselines by 2010. In addition, most transition countries expect to achieve emission levels close to their 1990 levels in 2010, even without considering mitigation options.

The key findings from the analyses of the major GHG-emitting sectors, and of barriers to and policies for implementation, are presented below.

Energy Sector

Reducing GHG emissions from energy activities was a top priority for most countries, and all addressed this sector in their mitigation assessments. This section examined mitigation options for the energy sector from the perspective of the supply sector and three end-use sectors.

Energy Supply

- The greatest mitigation potential is offered by the energy supply sector. Countries participating in the USCSP identified a number of promising options in the power sector, including both short-term and long-term opportunities.

- Improving energy efficiency of power plants was identified as the most important near-term mitigation option for the energy sector.
- Installing new technologies and switching from carbon-intensive fossil fuels are long-term priorities.
- Mitigation measures in the energy supply sector could improve regional air quality in addition to reducing CO_2 emissions.

Industrial Sector

- The industrial sector offers the next largest energy-related mitigation potential after the energy supply sector. Increasing the use of cogeneration, improving boiler efficiency, and improving the efficiency of motors and lighting are attractive mitigation options, in terms of emission reduction potential and costs. Negative incremental costs were found for a number of these options by the majority of countries analyzing costs.
- Improving energy efficiency is the highest priority in the industrial sector.

Residential/Commercial and Institutional Sector

- A number of countries identified significant opportunities for cost-effective emission reductions through the installation of energy-efficient lighting. Other opportunities for savings include increasing the efficiency of appliances and replacing traditional energy sources with renewable energy or electricity.
- Both transition and developing country participants reported that GHG emissions from this sector are likely to increase substantially in the future, largely because of population growth and increased energy consumption per capita that will result from continued urbanization and improvements in the standard of living.

Transportation Sector

- Many countries recognized the need to identify mitigation options in the transport sector, but few provided a quantitative analysis of particular mitigation options.
- Transportation sector emissions are increasing rapidly in both transition and developing countries.
- The range of mitigation potential and costs for the transportation sector varied widely.

Forestry Sector

- The three highest priority mitigation options in the forestry sector examined by USCSP participants were (1) afforestation, reforestation, and forest productivity improvements; (2) protection of existing forests; (3) and substitution of biofuel for fossil fuels and sustainable substitution of wood products for more emission-intensive, nonwood products.
- Reforestation and afforestation were determined to be the most promising mitigation options in the forestry sector for transition countries because forest management is already fairly developed, annual rates of change in forest cover are negligible or positive, and fuelwood is not a major source of energy.
- Forest protection mitigation options were considered by many participating countries in Asia and Africa. This may be due to pressure on forests from rapid population growth in those countries.

Agricultural Sector

- Mitigating emissions from the rice cultivation is critical for most Asian countries because rice cultivation is the largest source of agricultural GHG emissions in those countries.
- Livestock production accounts for more than half of total methane and nitrous oxide emissions in all of the USCSP participants in Central and Eastern Europe, the Former Soviet Union, and Latin America, and in most participating African countries. Improving livestock productivity through improved nutrition was the most common mitigation options considered. Manure management options such as methane recovery for use as energy were also a priority.
- More research is needed to analyze emission reduction potential and costs associated with mitigation options in all areas of this sector.

Waste Sector

- Mitigating GHG emissions from the waste sector was generally not a high priority for many USCSP participants because methane emissions associated with waste generation are relatively low.
- Priority mitigation options for this sector include landfill methane recovery and utilization as energy, comprehensive waste management, and alternative waste management (recycling, composting, etc.).

Industrial Processes (Non-Energy)

- Process emissions from the industrial sector represent a small percentage of overall national GHG emissions from both transition and developing countries, and were not a priority for mitigation analysis. Those USCSP participants that did evaluate mitigation options in this sector focused primarily on the cement, lime, pulp and paper, and iron and steel industries.

Barriers to Implementation of GHG Mitigation Options

The main barriers to implementing mitigation options identified by USCSP participants include:

- Insufficient domestic infrastructure for supporting new technologies and new energy sources.
- Insufficient capital for investment in development of new technologies, energy sources, and infrastructure.
- A lack of data and methods for conducting comprehensive cost-benefit analyses of mitigation options.
- The high capital costs of purchasing more efficient technologies, and a lack of a mechanism for reducing the initial costs borne by consumers.
- A lack of domestic supply of renewable energy and energy-efficiency technologies and certain alternative fuel sources.
- Existing policies and regulations that favor current technologies and energy sources and discourage the development and implementation of new technologies and energy sources.
- A lack of people trained in the manufacture, installation, use, and maintenance of new technologies as well as in the implementation of new resource management practices.
- A lack of general education to improve public awareness and acceptance of new technologies and resource conservation opportunities.
- A lack of access to efficient technologies because of insufficient networks for equipment distribution and maintenance.
- General economic or political instability, leading to competing demands for scarce economic resources and political attention.

Economic and Other Policy Mechanisms for Implementation of Mitigation Options

Participating countries generally recommended the use of tax incentives and subsidies to support emission-reduction activities. However, they did not reach firm conclusions about the ultimate effectiveness and feasibility of taxes on carbon or energy consumption.

2.9.2 Suggestions for Future Work

The mitigation assessments conducted by Program participants have strengthened the capacity of developing and transition countries to assess potential options to limit the growth of GHG emissions. The participating countries forecasted GHG emissions from key sectors, identified priority areas for emission reductions, assessed the mitigation potential and cost of various options, and identified policies to promote implementation. In conducting their assessments, they developed a wide variety of methods for estimating emissions, emission reductions, and the costs of implementing options over the long term. These efforts have contributed significantly to the international knowledge base regarding country priorities and the potential contribution and associated costs of GHG mitigation in developing and transition countries.

The preliminary results suggest that future mitigation assessments can be improved by the following:

- Developing integrated assessments that account for the interaction between the various sectors: energy, forestry, agriculture, waste, and industrial processes.
- Integrating the assessment of GHG emission reductions and local air pollutant emission reductions. As is highlighted in a number of country studies, ancillary environmental benefits can contribute significantly to the overall benefits of GHG mitigation and could be the impetus for implementation of GHG mitigation measures.
- Quantifying the costs of mitigation measures and mitigation scenarios where they have not already done so. Many participating countries did not present quantitative cost analysis of mitigation options in some sectors. Some discussed costs only in a qualitative manner.
- Continuing to develop assessment methods that include a broad set of evaluation criteria. In addition to assessing the emission reduction potential and cost of various options, the feasibility, applicability, and replicability of the mitigation options should be incorporated into the assessments.
- Strengthening local capacity to evaluate and implement mitigation options and providing continued technical assistance and training to analysts throughout the assessment process.

3. Vulnerability and Adaptation Assessments Under USCSP

3.1 Introduction

This chapter presents the results of the vulnerability and adaptation assessments conducted under the USCSP. These assessments were conducted under two USCSP initiatives: the Vulnerability and Adaptation Program and the SNAP Program. Most of the 49 countries participating in the Vulnerability and Adaptation Program focused on assessing the vulnerability of their climate-sensitive resources (i.e., the potential physical and economic impacts of climate change). However, a number also addressed adaptation (i.e., what steps countries could take to respond to the physical impacts of climate change). Seven participants in the SNAP Program examined how policy responses relating to adaptation could be incorporated into national climate change action plans. Figure 20 lists the countries that conducted vulnerability and adaptation assessments under USCSP.

3.1.1 Objectives and Scope of Vulnerability and Adaptation Assessments

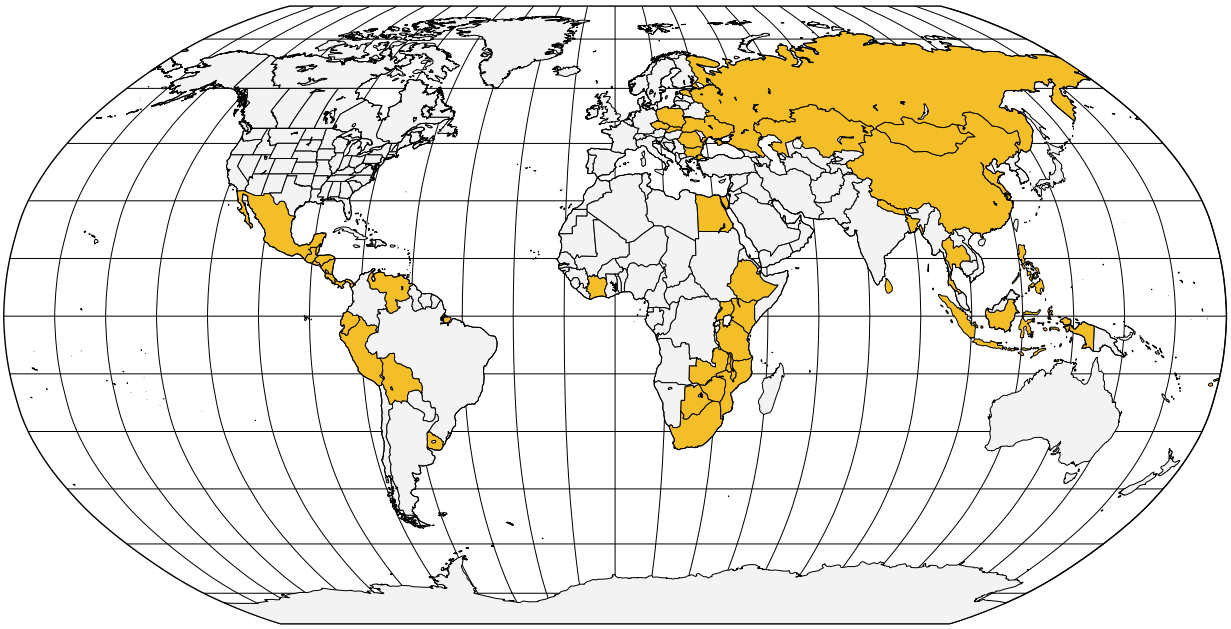
The vulnerability and adaptation assessments were primarily intended to help developing and transition countries understand their potential vulnerabilities to climate change. All of the countries participating in the USCSP are signatories of the UNFCCC, but when they signed, there was little country-specific information on how they could be affected by climate change. The USCSP was one of the first programs to work directly with developing and transition countries to conduct the vulnerability and adaptation assessments. The main purpose of the USCSP was to build capacity, that is, to give countries the training, software, and data they would need to assess potential impacts of climate change. This capacity helps create a foundation upon which future assessments of climate change can be carried out. Thus, the emphasis of the program was on training in-country scientists, who were supported by their governments, and having them conduct their own research.

The vulnerability and adaptation assessments cover eight important sectors that are sensitive to climate change:

- coastal resources
- agriculture
- grasslands/livestock
- water resources
- forests
- fisheries
- wildlife
- human health.

Table 12 displays the sectors assessed by each country that conducted vulnerability and adaptation assessments; about 150 country sector assessments were conducted under the Program.

Figure 20 Countries That Have Conducted Vulnerability and Adaptation Assessments Under the U.S. Country Studies Program



Africa & the Middle East

Botswana*
Côte d'Ivoire
Egypt*
Ethiopia
The Gambia*
Kenya
Malawi
Mauritius
Mozambique
South Africa
Tanzania
Uganda
Zambia
Zimbabwe

Asia & the Pacific

Bangladesh
China*
Fiji
Indonesia
Kiribati
Marshall Islands
Micronesia
Mongolia
Nepal
Philippines*
Samoa
Sri Lanka
Thailand*

Transition Countries

Bulgaria*
Czech Republic
Estonia*
Kazakhstan*
Poland*
Romania*
Russian Federation*
Slovak Republic
Ukraine*

Latin America

Belize**
Bolivia*
Costa Rica**
Ecuador
El Salvador**
Guatemala**
Honduras**
Mexico
Nicaragua**
Panama**
Peru
Uruguay*
Venezuela*

Vulnerability only
* Vulnerability and adaptation
** Countries cooperating in a Central American regional study.

Table 12 Vulnerability and Adaptation Assessments by USCSP Countries by Sector

Country	Coastal Resources	Agriculture	Grasslands/ Livestock	Water Resources	Forest	Fisheries	Wildlife	Human Health
Africa & the Middle East								
Botswana			•	• †	•	•		
Côte d'Ivoire	•	•		•	•			
Egypt	• †	• †		•				•
Ethiopia		•	•	•	•			
The Gambia	• †	•	•	•	•	•		
Kenya		•		•	•	•		
Malawi				•	•		•	
Mauritius	•	•		•		•		
Mozambique	•	•	•	•	•			•
South Africa		fl	fl	fl	fl	fl	fl	fl
Tanzania	•	•	•	•	•			•
Uganda		•	•	•	•			
Zambia		•	•	•	•		•	•
Zimbabwe		•			•			
Asia & the Pacific								
Bangladesh	•	•		•	•	•		
China	• †	•	•	•	•			
Fiji	•							
Indonesia	•	•			•			
Kiribati	•							
Marshall Islands	•							
Micronesia	•	•		•	•		•	
Mongolia		•	•	•	•			
Nepal		•		•				
Philippines	• †	• †		• †				
Sri Lanka	•	•			•			•
Thailand	•	•		•	•			‡
Transition Countries								
Bulgaria		•			• ‡			
Czech Republic		•		•	•			
Estonia	• †	•		•	•			
Kazakhstan		• †	•	• †	•			
Poland	• †	•		•				
Romania		•		• †	•			
Russian Federation		• †		• †	• †			
Slovak Republic		•		•	•			
Ukraine[a]	•	•		• †	•			
Latin America								
Argentina[b]		•						
Bolivia		• †	• †	• †	• †			
Central America	•	•		•				
Ecuador		•			•			
Mexico	•	•		•	•			
Peru	•							
Uruguay	• †	• †	•					
Venezuela	• †				•			

Countries in italics are SNAP participants.

- • Completed vulnerability assessment
- fl Conducting vulnerability assessment [South Africa]
- † Completed adaptation assessment
- ‡ Conducting adaptation assessment
- [a] Ukraine was a SNAP participant, but assessed adaptation as part of its vulnerability and adaptation assessment.
- [b] Argentina did not receive funding from the USCSP on vulnerability and adaptation, but participated in USCSP-sponsored workshops.

3.1.2 Methods for Conducting Vulnerability and Adaptation Assessments

The USCSP provided participating countries with technical assistance and training in assessing their vulnerability and adaptation strategies to climate change (Benioff et al., 1996). Technical advisors were selected to assist with the climate and baseline scenarios, climate model data, and vulnerability and adaptation methods and models. All eight sectors selected for assessment have been subject to past studies on climate change (e.g., Watson et al., 1996). In many cases, the countries adapted the models and methodologies to their unique national circumstances.

The technical advisors provided training, software, and data on specific methods for assessing vulnerability and adaptation through workshops and site visits. Training was provided at two workshops: one in Washington, DC, in January 1994, and the second in Honolulu, Hawaii, in January 1995. The technical advisors also provided written reviews of the accuracy, consistency, and completeness of progress reports, papers, and draft reports submitted by vulnerability and adaptation researchers.

The general approach recommended by the USCSP for conducting a vulnerability and adaptation assessment is presented in Figure 21. The assessment begins with the selection of climate change scenarios and baseline socioeconomic (population, economic conditions) scenarios extending through 2075. The climate change scenarios provide inputs for the biophysical and socioeconomic models or methods that are used to assess potential impacts of climate change. Most of these methods allow the assessment of vulnerability under alternative policy scenarios for adapting to climate change. The vulnerability of each sector is initially analyzed in isolation, and results may then be integrated across sectors to account for interactions among related sectors. For example, an agriculture assessment could incorporate changes in water supply from the water resources assessment. The adaptation assessment is then used to evaluate which, if any, policy options may be implemented in anticipation of climate change to mitigate potential adverse climate change impacts.

Appendices A, B, and C of this report contain more detailed technical information on the methods used by countries participating in the USCSP to prepare their vulnerability and adaptation assessments. Appendix A provides a summary of the key methods used to conduct vulnerability and adaptation assessments. Appendix B contains summaries of the results of vulnerability assessments by 37 countries. Appendix C provides detailed case studies that highlight both representative and unique examples of methods used by a select number of countries to assess adaptation options.

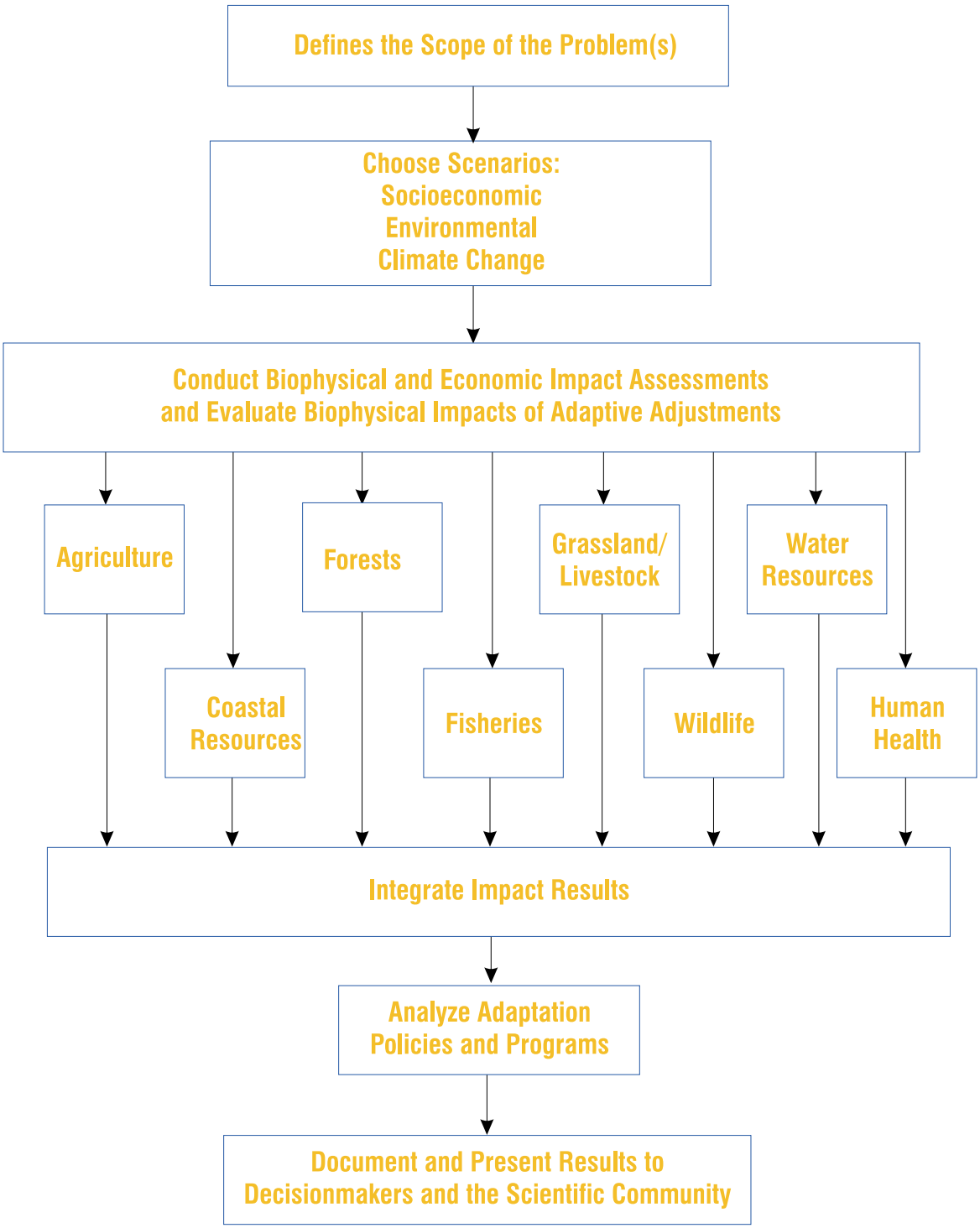
3.1.3 Organization of this Section

This section presents an overview and analysis of the results of the vulnerability and adaptation assessments conducted by countries participating in the USCSP. First the results are summarized by sector: coastal resources, agriculture, grasslands/livestock, water resources, forests, fisheries, wildlife, and human health. Then conclusions are presented on the vulnerability and adaptation assessment process and findings, including a discussion of the challenges inherent in conducting these types of assessments. Finally, the section concludes with suggestions for future work to further refine the methods used for conducting vulnerability and adaptation assessments.

3.2 Results of USCSP Vulnerability and Adaptation Assessments

In this summary of vulnerability and adaptation results by sector, vulnerability results are presented first, followed by results of adaptation assessments. In several sectors, only vulnerability assessments are summarized because no results were available for adaptation assessments. The countries participating in the USCSP tended to focus their evaluations of adaptation options on the relatively heavily managed agriculture, coastal resources, and water resources sectors, and less on the unmanaged systems, particularly forests, grasslands, fisheries, and wildlife.

Figure 21 Vulnerability and Adaptation Assessment Process



Source: Benioff et al., 1996.

3.2.1 Coastal Resources

Vulnerability

Twenty-four countries assessed the vulnerability of their coastal resources to climate change. In general, coastal vulnerability is analyzed by examining the potential impacts from specified levels of sea level rise, most often 0.5 or 1.0 meters (Box 22). Since coastal assessments consider only one variable—sea level—and because the change in sea level is assumed to occur in only one direction (i.e., increase), we can be more certain about potential impacts in this sector than in other sectors such as agriculture and water resources, where the directional impacts of climate change are more uncertain.

Box 22 The Vulnerability of Coastal Resources to Climate Change

The IPCC projects that climate change could result in sea level rise of 15 to 95 cm over the next century, with a best estimate of about 50 cm (Houghton et al., 1996). This threatens to inundate unprotected low-lying lands and wetlands. At particular risk are small islands such as the Marshall Islands and the Maldives and countries with large river deltas, such as Bangladesh, China, Egypt, and Nigeria. Without additional protection, the number of people at risk of flooding by 2100 assuming a 1 m sea level rise could double or triple over the number currently at risk, and most of the people at risk are in developing countries (Watson et al., 1996a; this estimate is based on current population and coastal development). In addition, the intensity of tropical storms could increase as a result of climate change, thereby compounding the risks faced by coastal populations (Henderson-Sellers et al., 1998).

Table 13 presents estimated land loss from inundation and erosion due to sea level rise in 15 countries. This is presented primarily for sea level rise of 0.5 and 1.0 meters, but other estimates are presented as noted. As shown below, in addition to inundation and erosion, some countries considered potential impacts from saltwater intrusion and different conditions for storm surges under increased sea level. Amplified storm surges may create greater vulnerability than sea level rise alone.

An analysis of the results from these countries suggests that with 0.5 m sea level rise, about one half of the land loss is due to erosion and one half is due to inundation. At 1.0 m sea level rise, the portion of land loss attributable to inundation increases faster than the portion attributable to erosion. The total impact (erosion plus inundation) increases almost threefold when predicted sea level rise doubles from 0.5 to 1.0 meters.

The total impact of sea level rise is underestimated by the results presented here, because countries tended to look at only sections of coast and not their entire coast (except for smaller countries and islands such as Kiribati). In doing so, countries generally selected case studies of particularly important or vulnerable coastlines.

A common concern for countries with significant coastal resources is the impact on human populations and on other sectors. For instance, in its study of Chittagong, Bangladesh calculated that 96 percent of the 11.2 km^2 of land lost to erosion under 1.0 m sea level rise would be agricultural land (Huq, 1997). Egypt and Côte d'Ivoire also identified sea level rise impacts on coastal cites as having particular economic importance.

Adaptation

To determine appropriate adaptation responses to sea level rise, a number of countries compared the cost of protecting coastlines from sea level rise with the benefits in terms of the value of land and structures that would be inundated or lost to erosion. For instance, using the replacement cost method, Tanzania estimated the value of structures lost because of 0.5 and 1.0 m sea level rise as US$70 million and US$121 million, respectively. It is estimated that with 1.0 m sea level rise, protection of the vulnerable portion of the coastline of Dar es Salaam would cost US$380 million and protection of the populated coastline of Tanzania would cost US$14.6 billion.[8] Table 14 illustrates other results from comparing benefits and costs of coastal resources adaptation. The benefits exceed the costs in most cases, but the existence of some low ratios points out the importance of carefully evaluating benefits and costs of adaptation. As reported in Appendix B, China, Egypt, Estonia, and Uruguay also estimated costs for protection against sea level rise as part of the USCSP.

Table 15 summarizes the types of coastal resource adaptation options that seven countries selected for in-

[8] Estimates were converted from Tanzanian shillings to U.S. dollars: 1 Tanzanian shilling (Tsh.) = 0.001624 U.S. dollars {9/13/99; *http://www.oanda.com/converter/classic}*

Table 13 Examples of Land Loss from Inundation and Erosion Due to 0.5 and 1.0 m Sea Level Rise

	0.5 meter		1.0 meter	
Country	**Inundation (km^2)**	**Erosion (km^2)**	**Inundation (km^2)**	**Erosion (km^2)**
Bangladesh [a]	NA	5.80 [b,c]	NA	11.20 [b,d]
China [e, f]	1153 [b]	NA	6520	NA
Côte d'Ivoire	8.9	27.6	17.8	55.1
Egypt [e, f, g]	15,473	NA	NA	NA
Estonia	NA	NA	593.0	NA
The Gambia	5.0	NA	92.3	NA
Indonesia	NA	NA	230.04 [h]	NA
Peru	NA	NA	78.32 [i]	NA
Philippines [j]	20.99 [b]	NA	55.6	NA
Poland	845.1 [b]	NA	1727.7	NA
Sri Lanka	41.0 [b]	6.0 [a]	91.2	11.5
Tanzania	NA	2,090	NA	2,117
Ukraine	12.8 [k]	52.25 [k]	190.0 [l]	102.4 [l]
Uruguay	19.8 [e, m]	0.068 [n]	39.6 [e, m]	0.291 [n]
Venezuela	52.6	26.4	77.7	40.5

Note: Many results are only from case studies and are not for the entire country.
NA means not available.

[a] Sandy shores of eastern Bangladesh, i.e. Chittagong, which is a hilly area. A 1.0 m sea level rise is estimated to inundate 17%, or more than 22,000 km^2, of the entire country, and most of this area is in western Bangladesh.

[b] 0.3 m sea level rise.

[c] Agricultural land only.

[d] 0.75 m sea level rise.

[e] Lower bound estimates shown.

[f] Does not distinguish between inundation and erosion.

[g] Alexandria and Rosetta areas only.

[h] Lowland part of Semarang City.

[i] Sum of 10 study areas.

[j] Manila Bay Coastal Area – a 2.0 m sea level rise will result in 89.05 km^2 loss of land by inundation. The greatest potential impact from sea level rise is not the loss of land, but the increased water salinity due to salt water intrusion and more intense storm surges during tropical cyclone occurrences.

[k] 0.46 m sea level rise.

[l] 1.15 m sea level rise.

[m] Coast between Colonia and A Chuy.

[n] Coast of Montevideo.

Table 14 Benefit-Cost Ratios[a] from Coastal Resources Adaptation Assessments in Selected Countries

Location	Level of Protection	Sea Level Rise Scenario 0.3 m	0.5 m	1.0 m
China (Zhujiang Delta)	Full protection	7.7	14.3[b]	12.8
Estonia (Tallinn/Pärnu)	Full protection	—	—	0.9/2.3[c]
Poland (entire coastline)	Full protection	2.6	—	4.6
	Partial protection	3.3	—	—
Venezuela (all study sites)	Full protection	—	0.02	—
Uruguay (entire coastline)	Full protection (sea walls)	7.6 - 21.6	7.0 - 30.8	10.3 - 42.9
	Full protection (beach nourishment)	3.2 - 9.0	3.2 - 13.9	4.9 - 20.4

[a] Benefit-cost ratios calculated from the benefit-cost analyses in the national reports.
[b] Ratio based on a benefit-cost analysis for a 0.65 m scenario.
[c] These ratios are for a 1.0 m sea level rise and a 1.5 m storm surge.

Table 15 Summary of Coastal Resource Adaptation Options

Adaptation Option	Uruguay	Egypt	China	Estonia	The Gambia	Poland	Philippines	Venezuela
Protection	✓	✓	✓	✓	✓	✓		✓
Development planning/ building requirements	✓	✓	✓		✓			✓
Research/ monitoring	✓		✓				✓	
Integrated coastal zone management	✓	✓					✓	

depth evaluation. The countries listed evaluated one or more protection strategies, particularly for economically important areas in the coastal zone, such as large cities or resorts. Technology-based protection options such as building sea walls were the most widely selected responses to sea level rise. However, many countries also considered policy changes such as development planning (e.g., setbacks), although relatively few included an integrated coastal zone management (ICZM) framework among the evaluated options. To be sure, virtually all the assessments of vulnerability as well as adaptation are consistent with ICZM (for more information on ICZM, please consult IPCC, 1990, and Huang, 1997). Two of the countries conducted surveys to obtain stakeholder opinions about what policy adaptation measures should be undertaken.

3.2.2 Agriculture

Vulnerability

In part because of the importance of agriculture in developing and transition country economies, more countries (36) undertook vulnerability assessments of this sector than any other sector (Box 23). These assessments were generally more detailed and extensive than other analyses, and examined the vulnerability of numerous specific crops and cultivars under a variety of climate change scenarios.

Many countries included CO_2 fertilization effects on crop yields in their analysis. In some cases, CO_2 fertilization was found to have a larger impact on crop yields than temperature or precipitation changes, although drier conditions could offset the positive effects of CO_2 fertilization.

Box 23 The Vulnerability of Agriculture to Climate Change

The IPCC concluded that global agricultural production is at little risk from climate change. However, regional crop yields might change considerably. The change in crop yields may alter competitive advantage among nations, resulting in shifts in where crops are grown. A number of studies have found that production of grain crops may increase in high-latitude countries but decrease in low-latitude countries (Rosenzweig and Parry, 1994; Darwin et al., 1995). In addition, changes such as reductions in water supplies and increases in pests, plant disease, and extreme climate events could affect agricultural production. The IPCC identified sub-Saharan Africa, South and Southeast Asia, some Pacific islands, and tropical Latin America as being at greatest risk (Watson et al., 1996a).

Table 16 indicates the general direction of changes in crop yields summarized across different models for most of the countries assessing agriculture, based on scenarios generated from climate change models.[9] This table does not reflect how yields would change after farmers make adaptations such as changing practices or crops. Although the table emphasizes many of the most important crops worldwide, several countries also considered the vulnerability of additional crops of national importance, such as barley, cotton, and groundnuts. There appears to be a mix of estimated increases and decreases in crops, although of the crops studied, more are estimated to decrease than increase. There also appear to be some differences in the regional sensitivity of crop yields to the climate change scenarios. Africa (mainly Egypt and Côte d'Ivoire) and Asia (particularly Bangladesh and the Philippines) show a tendency toward decreases in crop yields, whereas Europe and Latin America (mainly Bolivia) show a tendency toward increases in crop yields. Because results are limited and scattered, these conclusions should be treated as preliminary.

Some individual countries did estimate increases across all crops (e.g., Romania), whereas others found decreases across most or all crops (e.g., Cote d'Ivoire, Egypt, Bangladesh, and Bulgaria). Overall, the results suggest that while agricultural impacts may not be catastrophic, especially when potential adaptation measures are considered, individual countries and regions within countries could experience significant negative or positive impacts. Thus, some countries could be harmed while others could benefit.

Table 16 also suggests the importance of different types of crops and their response to an increase in atmospheric concentrations of CO_2. Crops can be classified into two groups, C_3 and C_4, according to how efficiently they use CO_2 during photosynthesis. The C_3 crops such as rice, wheat, soybeans, potatoes, and vegetables, which make less efficient use of CO_2 during photosynthesis, may be less vulnerable to climate change because increased CO_2 may enhance their growth. The C_4 crops, on the other hand, such as grasses, maize, sugar cane, millet, and sorghum, may be more vulnerable to climate change. For instance, maize yields decrease in 7 of the 13 countries. This is quite consistent with other studies of climate change impacts (see Reilly, 1996).

Some countries noted that current interannual climate variability may be of more immediate concern than long-term climate change. For example, Indonesia found that the vulnerability of its agriculture sector to variable El Niño/Southern Oscillation effects under current climate conditions is greater than the vulnerability to climate change over the next 20 years, but in 60 years the effects of climate change could be as great as the El Niño effects.[10] Other issues that may be important in understanding vulnerability of agriculture to climate change include the following:

- Warmer temperatures may lead to increases in pests and diseases harmful to crops.
- Changes in frost-free dates may affect soil nutrient changes.
- Changes in precipitation may induce flooding or drought, causing direct physical impacts on agricultural lands.

Adaptation

The assessments also examined management adaptations that could lessen climate change impacts in the agriculture sector, including:

- shifts to alternative planting dates
- changes in fertilizer (nitrogen) applications

[9] Countries calculated crop yields under a series of climate change scenarios developed using General Circulation Models. For additional explanation ofthese models and the methods used to estimate changes in crop yields as a result of climate change, please see to Appendix A.
[10] Some recent research has found that climate change could result in more frequent El Niños (e.g., Timmerman et al., 1999).

Table 16 Direction of Crop Yield Changes across General Circulation Model Scenarios

Country	Crop					
	Wheat	Maize	Soybean	Rice	Other	Other
Africa & the Middle East						
Côte d'Ivoire		↓		↓ [b]		
Egypt	↓	↓	↓	↓	↑ Cotton	↓ Barley
Ethiopia	↑↓					
The Gambia		↓			↓ Millet	↑ Groundnuts
Kenya		↑↓				
Zambia	↑↓	↑	↑↓	↑	↑ Oils[a]	↑ Cassava
Zimbabwe		↑↓				
Asia & the Pacific	Wheat	Maize	Soybean	Rice	Other	Other
Bangladesh	↓			↓		
China[a]	↑↓	↑↓		↓		
Indonesia				↑↓		
Mongolia[a]	↑↓					
Philippines		↓		↑↓		
Sri Lanka					↑↓Tea	
Transition Countries	Wheat	Maize	Soybean	Rice	Other	Other
Bulgaria	↑↓	↓				
Czech Republic	↓	↑			↓ Potato	↑ Early Vines
Estonia					↓ Barley	
Kazakhstan[a]	↑↓					
Romania	↑	↑				
Russian Federation	↑↓					
Slovak Republic	↑					
Ukraine	↑					
Latin America	Wheat	Maize	Soybean	Rice	Other	Other
Argentina	↑↓	↓	↑			
Bolivia		↑[c]	↑↓		↑ Potato	
Mexico [a]		↓[d]				

Note: Summary based only on GCM scenarios, and includes CO_2 fertilization unless otherwise noted. Countries that conducted only sensitivity analyses (Nepal, Poland, Uruguay) are not included because the range of sensitivity analyses is so broad that crop yields would generally have mixed results. Results for these countries are summarized in Appendix A.

[a] Does not include CO_2 fertilization.

[b] Results are mixed when adaptation is assumed.

[c] Irrigated maize is estimated to have decreased yields. Irrigated land in Bolivia is a small fraction of total arable land (CIA, 1999).

[d] Indicated as an increase in land area unsuitable for crop.

↓ Yield decreases for all GCM scenarios.

↑ Yield increases for all GCM scenarios.

↑↓ Yield increases and decreases for all GCM scenarios.

- use of alternative crops and cultivars
- increased irrigation and water management
- changes in diets away from vulnerable crops.

For example, because the Gambian diet includes meals prepared from maize and millet, both of which may experience significant declines in yields, adaptation may best involve switching to other, less vulnerable crops.

Many of these scenarios did not include the costs of these alternative actions. The studies did not assess whether financial or other resources would be available to adopt these adaptations. As noted by several countries, the ability to cope with vulnerability of agriculture to climate change is dependent on other changes such as changes in population and other impacts such as sea level rise or erosion. For instance, Egypt's ability to adapt will depend on the rate of population growth; a slow growth rate may enable agricultural productivity to keep pace with demand.

Table 17 summarizes the adaptation options that were selected for further evaluation by four countries participating in the SNAP Program. Three of the four countries, Uruguay, Egypt, and Kazakhstan, addressed the potential for reduced crop yields. Their adaptations were designed to offset negative impacts. In contrast, the Russian Federation sees climate change as potentially increasing yields and production. Their adaptation options are designed to take advantage of this opportunity by expanding agriculture to new areas that could become suitable for cultivation and assisting current productive areas in transitioning to cropping systems more appropriate for new climate conditions.

Most of the adaptation options focus on educational and outreach activities that provide farmers with additional information about growing conditions and encourage farmers to change their management practices or crop mix to maintain viability in the market. The table also shows that the options covered a wide range of policy, technology, research, education, and outreach activities. It is interesting that the removal of crop subsidies, which could have benefits under the current climate and make the agricultural system more resilient to climate change, was not evaluated in depth as an adaptation option, although some countries did identify this as an option. This may be due to strong opposition to removing such programs. Finally, all of the options pertain to activities that countries can implement domestically, although regional coordination such as efficient irrigation use of international rivers might be taken into consideration in future studies.

Many of the options considered by all of the countries were no-regrets options—soil conservation, the development of regional centers to provide technical assistance on farming, establishment of seed banks, or planting of more productive crops. Those are the only options identified by more than one country. The first two of these options would most likely require government involvement. Soil conservation needs to be applied on a broad scale to be effective and would probably require government programs. The establishment and operation of regional technical assistance centers would require government funding.

Table 17 Summary of Agricultural Adaptation Options Analyzed by SNAP Countries

Option	Option Type	Kazakhstan	Uruguay	Egypt	Russian Federation
Regional assistance centers/seed banks	Outreach	✓	✓		
Pest/disease forecasts	Research/outreach	✓			
Free market transition	Policy	✓			
Soil conservation	Education/outreach	✓	✓		✓
Development or introduction of new cultivars	Research		✓	✓	✓
Irrigation efficiency	Education/outreach		✓		
Irrigation capacity expansion	Technology		✓		
New crops (switching to different cultivars or developing different crops than currently used)	Education/outreach			✓	
Management practices suitable for new climates	Education/outreach			✓	✓

Although there is some similarity in the options across countries, Kazakhstan's circumstance as a transition economy also led to a unique policy option, supporting the transition to a free market. This transition is already under way because it is expected to have benefits greater than costs under the current climate. However, a free market is also expected to help in adapting to climate change because farmers will see changes in production and demand through changes in prices and will be able to switch crops as long as they have the necessary technical capability and financing. Interestingly, the Russian Federation, which is also in a transition to a market economy, did not identify this option, but focused on outreach, management, and technology options.

3.2.3 Grasslands and Livestock

Vulnerability

Twelve countries conducted, or are conducting, vulnerability analyses for the grasslands and livestock sector (Box 24). These countries generally studied specific regions within the country or types of grasslands, because there is considerable variability within countries. For instance, Mongolia found that while the impact of climate change on pasture production in the Gobi Desert areas may be negative, in colder regions of the country climate change could have favorable effects on plant production. Even with these regional variations, Mongolia still found that at all sites, plant quality and livestock production decline under climate change scenarios.

Although not directly comparable across countries, average biomass generally is estimated to increase for warm-season grasses and decrease for cool-season forbs and legumes as optimal grassland conditions shift toward the poles. There appear to be smaller impacts on livestock yields than on grassland biomass, because livestock can adjust consumption (e.g., they can graze over a larger area should grassland productivity decline). To some extent, this implies that there is currently excess capacity of grasslands in the livestock sector or that analysts are assuming that the area of production can increase.

Although countries found no significant overall change in grasslands and livestock, several countries did note that changes in interannual climate variability would have important impacts. For instance, Uruguay found that because seasonal variability is already a major concern for farmers, increased variability would be detrimental to the production of livestock. Similar results regarding the impact of climate variability on grasslands are discussed in Allen-Diaz (1996). Some countries did find positive net impacts of climate change, such as Tanzania, where scenarios with increased precipitation and temperature led to increased rangeland carrying capacity.

Box 24 Vulnerability of Livestock to Climate Change

Livestock could be directly and indirectly affected by climate change. Change in climate can directly affect milk production, growth, and reproduction. Livestock can be indirectly affected by changes in grassland biomass and quality, changes in distribution of disease, and changes in the marketplace, i.e., changes in feed availability and price (Watson et al., 1996a).

3.2.4 Water Resources

Vulnerability

While most of the vulnerability analyses of water resources focused on runoff, that is, the portion of precipitation on land that ultimately reaches rivers or lakes, some countries also considered factors such as water supply and demand, flooding and drought, river salinity, water quality, irrigation, and hydroelectric generation (Box 25).

Box 25 Vulnerability of Water Resources to Climate Change

Higher temperatures are likely to reduce snowpack, cause earlier runoff in river basins and lakes fed by snowpack, and increase evapotranspiration in all water basins. In addition, sea level rise could increase salinity in estuaries. However, for any given region, whether runoff will increase or decrease as a result of climate change is uncertain. In addition, there are uncertainties about changes in seasonal runoff patterns. Thus, it is not possible to forecast whether specific water basins will be wetter or drier. It is possible that more intense precipitation events could lead to more flooding. The IPCC concluded many regional water systems could become more stressed in the 21st century because of population and economic growth. Arid and semi-arid basins are at greatest risk to climate change. Water demand management and institutional adaptation are the primary means for reducing risks from climate change (Watson et al., 1996a).

Table 18 displays the range of change in runoff for some of the countries assessing water resources. Most countries considered multiple river basins, and the results varied between basins. Generally, scenarios assuming an increase in temperature and no change in precipitation resulted in a drop in runoff. However, changes in precipitation appear to have a greater influence on runoff than changes in temperature. In many countries, if precipitation were to increase, runoff would increase, even with higher temperatures, and if precipitation were to decrease, runoff would decrease. For example, in The Gambia, for each 1 percent change in precipitation, there is a 3 percent change in the same direction of runoff.

Most countries showed mixed results in terms of increases and decreases in runoff. One striking aspect of this table is the range of estimated changes in runoff and the estimated high sensitivity of runoff to changes in climate. For example, estimated changes in runoff in The Gambia ranged from –69 percent to +63 percent. Such large changes in runoff are likely to substantially increase the risk of drought or flood. Two countries, Estonia and Mongolia, estimated no change to increases in runoff under all the scenarios tested. It is interesting that both of these countries are in high latitudes. Since they are likely to receive more precipitation and may not have as large an increase in evapotranspiration as low-latitude countries, high-latitude countries may be more likely to have increased runoff (Rind et al., 1990; Houghton et al., 1996).

Table 18 Change on Annual Runoff for Selected Countries Based on Results from GCM Models

Country	Change in Annual Runoff	
	Minimum	Maximum
Africa & the Middle East		
Botswana	-53%	+17%
Côte d'Ivoire	-22%	-4%
Ethiopia	-33%	+40%
The Gambia	-69%	+63%
Malawi	-40%	+162%
Asia & the Pacific		
Kazakhstan	-29%	+25%
Mongolia	-0.3%	+26%
Philippines	-12%	+32%
China	-15%	+17%
Latin America		
Mexico	-42%	+123%
Transition Countries		
Czech Republic	-10%	+3%
Estonia	+2%	+68%
Kazakhstan	-29%	+25%
Romania[a]	-24%	-3%
Slovak Republic	-100%	+5%
Ukraine	-20%	+128%

[a] Based only on CCCM scenario.

Only two countries, Côte d'Ivoire and Romania, found a reduction in runoff under all scenarios, and a few others, such as the Slovak Republic and Kazakhstan, showed a tendency toward decreased runoff. Kenya conducted only a sensitivity analysis, and its results show a high sensitivity to change in temperature (i.e., a tendency toward reduced runoff). This may not be surprising, given that the country is in a semi-arid climate and already has high temperatures.

Those countries that examined the effects of changes in runoff on the adequacy of the water supply to meet demand found that baseline changes in population would have a much greater effect than climate change. They also found that changes in runoff might be magnified in supply and demand. For example, Ethiopia estimated changes in runoff varying from –33 percent to +40 percent. The estimated change in supply was slightly less negative and more positive than the changes in runoff (e.g., the scenario with a 33 percent reduction in runoff resulted in a 25 percent reduction in supply). Ethiopia found that population and economic growth by 2075 could result in demand exceeding supply.[10] This situation would be made worse if runoff declined and even the 40 percent increase in runoff would not completely meet the higher demand.

In general, the effect of climate change on runoff is difficult to predict. A few areas might see increased runoff (which can alleviate water shortages but increase flood risks), but for most areas the change is uncertain. Change in precipitation, which is uncertain at the regional level, is the most important factor affecting runoff. Until scientists are certain about how precipitation will change, it will remain difficult to reliably forecast future water supplies.

[3] Demand was estimate to increase by twentyfold.

Adaptation

Developing adaptation strategies for water resources affected by climate change is complicated by the fact that climate change could both reduce and increase water supplies. Therefore, countries may need to plan adaptation strategies for both drought and flooding conditions. In spite of the uncertainties about climate change impacts on water resources, there are many adaptation strategies that are likely to reduce the vulnerability of water resources to climate change as well as to current climate variability, regardless of whether runoff increases or decreases (Frederick et al., 1997).

Table 19 summarizes the types of adaptation options evaluated by Bolivia, Botswana, Kazakhstan, Romania, the Russian Federation, and Ukraine. These assessments were made accounting for uncertainties about future water supply and quality. Five countries evaluated options to increase domestic water supply, either nationwide by adding or upgrading storage capacity, or locally through interbasin transfers. Interestingly, four of the countries noted the possibility of increasing water use from international river basins, but Kazakhstan and Ukraine both assumed that this option was not feasible. Implementing such an option would require international cooperation.

Botswana, Kazakhstan, the Russian Federation, and Ukraine also considered technological or outreach options to decrease the demand for water. These options involved programs to either increase efficiency in use or find ways to decrease demand, such as decreasing irrigated farmland or switching to crops that require less water. Botswana also considered a policy option to increase the cost of water, and Bolivia considered use of water metering and direct billing to reduce demand.

The Russian Federation proposed addressing increased risks of flooding by building flood control works in a number of basins that are identified as being at particular risk from flooding (including flooding from sea level rise). The Russian Federation also proposed including Lake Baikal on the World Heritage List to protect the quality of its water. In 1999, the Lake Baikal basin was declared a special water protection zone (A. Kokorin, Institute of Global Climate and Ecology of the Russian Academy of Science and Russian Federal Service for Hydrometeorology, personal communication, 1999). Bolivia proposed generally improving water quality.

Two countries, Romania and Ukraine, proposed changing water management practices, thereby reduc-

Table 19 Examples of Water Resource Adaptation Options

Option	Option Type	Bolivia	Botswana	Kazakhstan	Romania	Russian Federation	Ukraine
Increase water supply (domestic)	Technological	✓	✓	✓	✓		✓
Increase water supply (international)	Technological or policy		✓		✓		
Decrease demand (by efficiency programs or substitution)	Technological or outreach		✓	✓		✓	✓
Increase water price	Policy	✓	✓				
Build flood controls	Technological					✓	
Address ecological risks	Outreach					✓	
Reduce water pollution	Technological and outreach	✓					
Institute drought and flood planning and monitoring	Policy and technological	✓					
Change water basin management practices	Policy	✓			✓	✓	✓

ing hydropower generation, as a way to help offset potential water supply shortfalls. The proposals noted that increasing fossil fuel generation, which would increase greenhouse gas emissions, would make up the power deficit. The studies did not assess the potential for using other renewable power supplies to make up for the reductions in hydropower. It will be important to ensure that adaptation options such as these are consistent with greenhouse gas mitigation strategies.

Bolivia also proposed using river basin planning and drought and flood preparedness and monitoring. Among the options it considered, Bolivia found these options to be the most cost-effective.

3.2.5 Forests

Vulnerability

Most countries evaluated the vulnerability of their forest sector in terms of changes in the land area of different forest types or projected changes in biomass (Box 26). Most countries used the Holdridge Life Zone classification, which allows for a first cut analysis of potential impacts on forest resources under the various climate scenarios. This approach does not consider CO_2 fertilization, which enhances forest growth and reduces water demand (Neilson et al., 1998).

Box 26 Vulnerability of Forests to Climate Change

Climate change is likely to have a substantial impact on the world's forests. Under a doubling of atmospheric CO_2 concentrations, one-third or more of global forests could be in a new climate, outside the range of climate they currently exist in. Suitable climates for many species could shift faster than many species can migrate. Slow-growing species may be replaced with faster-growing species. Tropical forests are more likely to be affected by changes in land use in coming years than climate change. Since warming is likely to be greatest at the poles, boreal forests may be subject to the greatest shift in climate zones (Watson et al., 1996a).

Most countries reported a general shift in forest types to those more amenable to warmer climates (e.g., subtropical shifting toward tropical forests). Countries found that changes from dry to moist forest or vice versa were largely driven by changes in precipitation rather than temperature. Table 20 shows estimated changes in biomass from forest sector studies for regions within countries and for whole countries using a number of different climate change scenarios. While it is difficult to draw specific conclusions from the country studies because of the different models and approaches used, a general impression (as seen in Table 20) is that there could be a decline in biomass. However, it is interesting that some countries such as The Gambia found potential increases in biomass.

For some countries, climate change may exacerbate current deleterious conditions. For instance, in Zambia, more than 80 percent of households use either fuelwood or charcoal for their domestic energy requirements. Zambia is currently losing 250,000-300,000 ha of its forest cover annually to human activities, and a decrease in forest productivity could make the situation worse. Based on this, Zambia concludes that climatic changes that affect the resilience of forest vegetation types could grossly affect income and welfare.

Other interesting results of forest vulnerability assessments under the USCSP include the following:

- Even where the dominant ecosystem type is not expected to change, conditions may change to allow the introduction of invasive species. For example, Estonia found that while the climate change scenarios would not change the primary ecosystem type, they could increase the spread of invasive species, including *Fagus sylvatica*, *Carpimus betulus*, and *Quercus petrea*.
- In some cases, simulations indicate that the estimated climate change would be significant for individual tree species even when the Holdridge model does not estimate shifts in forest type.
- If warming increased potential evapotranspiration, there would be a tendency toward more drought stress.
- Impacts on specific forest reserves or national parks may be important. For example, Sri Lanka found that the most vulnerable forest areas would be the Sinharaja Forest Reserve and the Peak Wilderness Forest Reserve, and Venezuela found that most of

Table 20 Examples of Forest Sector Vulnerability Results

Country	Region	Scenario	Percent Change in Biomass
Bolivia	Nationwide	GISS	-92% to -32%
		UK89	-44% to +34%
		+2°C/ + 10% P	-81% to -13%
		+2°C/ -10%P	-83% to -19%
Estonia	Tudu	Four different scenarios	+5.3% to+13.2%
	Võhma		-33.5% to -28.0%
	Virstu		-47.4% to 9.6%
	Kärevere		-75.9% to -23.5%
	Risti		-42.1% to 1.6%
The Gambia	Nationwide	GFD3	+72.0%
		GISS	+0.2%
		UKMO	-46%
		OSU	-75%[a]
Mongolia	Nationwide	UK89	-27.2% larch
			-35.3% Siberian pine
			-5.1% birch
			-4.2% scotch pine
Romania	Bistrita—2060	GF01	-4.8% red maple
	Predeal—2060		-16.7% red maple
Slovak Republic	Pilsko	CCCM	+17%
	Dobrocsky		+5%
	Sitno		-38%

[a] Estimate is an approximation based on examination of figure in Gambian vulnerability and adaptation report.

the country's natural forest reserve would be affected.

- While the USCSP studies for the most part did not model societal-forest interactions, population pressures were generally recognized. For example, as noted above, Zambia reports that given the country's reliance on forest products, climatic changes could affect the resilience of forest vegetation types and could adversely affect society.

The finding that composition of forests could change with a shift to warmer climate species is consistent with the IPCC. However, the IPCC found that, in general, it is not clear whether forest biomass will increase or decrease (Neilson et al., 1998).

3.2.6 Fisheries

Vulnerability

Few countries examined the vulnerability of fisheries to climate change as part of the USCSP, and we do not attempt to generalize results. For many areas, a lack of location-specific information on species response to potential climate change makes it difficult to assess fishery vulnerability (Box 27). For instance, in Bangladesh, there has been very little or no work on the physiology and ecology of indigenous species of finfish or prawn. As a result, it is difficult to estimate the likely effects of climate change on different fish or prawn populations.

In general, changes in temperature and salinity were estimated to result in changes in species mix and both increases and decreases in different species' productivity. Sea level rise would lead to flooding and loss of productive habitat for many species (e.g., shrimp), generally resulting in decreased productivity. The net result for the fishery sector depends on which effects are stronger. In some developing and transition countries, a significant number of people depend on fish in their diet, especially for protein, so impacts on the fishery sector may also affect the health of the population.

Box 27 Vulnerability of Fisheries to Climate Change

Fisheries will be affected in a number of ways by climate change. Climate change will alter water temperatures, water chemistry (higher temperatures reduce dissolved oxygen levels in water), and circulation. Fish tend to survive only in certain thermal niches and will generally need to migrate or be transplanted poleward. Higher temperatures could result in increased productivity of streams and lakes, especially if terrestrial productivity increases. Fish in small rivers and lakes or where temperature or precipitation changes are greatest may be most at risk. Marine and estuarine fisheries will face higher temperatures and change in the location of thermal niches, but may have increased production if current fisheries management problems are corrected. Estuarine fisheries could also be affected by sea level rise, which could inundate wetlands and move saline water further upstream in estuaries. Loss of coral reefs could adversely affect fish. Coastal protection measures such as bulkheads or dikes can result in additional loss of wetlands by blocking their inland migration (Watson et al., 1996a).

3.2.7 Wildlife

Vulnerability

Two countries, Malawi and Zambia, used the Habitat Suitability Indices to examine the vulnerability of key species to climate change. Although it is difficult to generalize from only two country studies, the vulnerability of wildlife to climate change primarily appears to be a function of changing habitat. Current human activities may be causing habitat fragmentation, which is probably the greatest current stress on wildlife. This could be exacerbated under climate change (Box 28).

Box 28 Vulnerability of Wildlife to Climate Change

The impacts of climate change on wildlife have not been studied as much as impacts on other sectors such as forests. Wildlife is likely to be affected by changes in temperature as well as by shifts in ecosystems. Animals dependent on ice cover may be at particular risk. Migratory species such as birds are likely to alter the timing of their migrations and could be at risk if prey and other food are no longer available. In addition, wildlife is likely to be affected by ecosystem changes such as shifts in vegetation and availability of prey. The IPCC concluded that wildlife populations in Africa are at particular risk from drought (Watson et al., 1998).

For Malawi, vulnerability studies suggest that there would be declines in nyala and zebra in the Lengwe and Nyika National Parks. Nyala is a vulnerable species that may not adapt easily to climate-induced habitat changes. On the other hand, if increased temperature is accompanied by lower precipitation, as is the case in two of the scenarios, tourism might increase because increased ambient temperature could improve accessibility to drier parks. Whether tourists would be less likely to go to the parks because of the loss of nyala was apparently not assessed.

In Zambia, increased or decreased rainfall could significantly affect wildlife through changes from open grasslands and scattered bushlands to denser bushlands (under increased precipitation) or desert-like conditions (under decreased rainfall). In addition, increased or decreased rainfall would significantly affect the behavior and habitat of migratory wetland species. Given the vulnerability of Zambian wildlife to drought and habitat disturbance, it is likely that climate change, whether it leads to increased or decreased rainfall, could dramatically affect both the size and diversity of many populations.

3.2.8 Human Health

Vulnerability

Zambia and Sri Lanka completed assessments of the potential health effects of climate change (Box 29). Although it is difficult to draw generalizations from only

Box 29 Vulnerability of Human Health to Climate Change

Human health is very sensitive to climate, because many maladies are related to temperature. Higher temperatures can increase cases of heat stress and areas where infectious diseases such as malaria and dengue could spread. For example, because of their cooler temperatures, the East African highlands have low risk of malaria. Higher temperatures would make the climate suitable for the survival of malaria-carrying mosquitoes. On the other hand, higher temperatures would also reduce risks of health problems related to cold, such as cardiovascular mortality (Martens, 1998). A key factor affecting the vulnerability of human health is the strength of the public health systems. Countries with weak systems may be at more risk because they would be less able to prevent or contain outbreaks of diseases or other health problems associated with climate change (Watson et al., 1996a; McMichael et al., 1998).

two countries, these countries found that climate change could increase risks to human health. Zambia qualitatively considered characteristics of malaria, bilharzia/schistosomiasis, cholera, dysentery, bubonic plague, and malnutrition. The assessment of health effects was limited largely by the lack of available data. Consequently, no models were run to assess impacts of particular diseases, and potential impacts can only be speculated. In Zambia, the health effects of climate change would appear to affect poorer populations for a variety of reasons, including poorly ventilated structures being conducive to mosquitoes and lack of good water and sanitation services. Existing conditions such as environmental degradation, quarrying, poor drainage systems, and inadequate water taps would exacerbate health impacts from climate change.

Sri Lanka also studied the potential effects of climate change on the incidence of malaria, and found that malaria could become more prevalent in areas where it is not currently a significant risk.

3.3 Assessment Conclusions

3.3.1 Conclusions on Vulnerability Assessments

The IPCC distinguishes between sensitivity, how a system is directly affected by climate change (e.g., change in crop yields), adaptability, how a system could respond to climate change (e.g., switch crops), and vulnerability, the net effect after sensitivity and adaptability are considered (Watson et al., 1996a). Although dozens of countries assessed climate change impacts under the USCSP, one should be cautious about using these studies to draw sweeping conclusions about the vulnerability of developing and transition countries to climate change. The USCSP studies tended to focus on identifying sensitivities of systems, i.e., first-order biophysical effects, and adaptability was assessed only for coastal resources and some of the agriculture, forests, and water resources. Without thorough consideration of underlying socioeconomic changes, integrated impacts, and adaptability in all sensitive sectors, it is difficult to draw firm conclusions about vulnerability.

Nonetheless, some preliminary conclusions about sensitivity and vulnerability can be drawn, although these conclusions do not necessarily apply to all countries. In general, it appears that more heavily managed systems are less at risk than relatively unmanaged systems. For the managed systems, the USCSP studies found the following:

- Sea level rise could cause substantial inundation and erosion of valuable lands, but as is discussed below, protecting developed areas would be economically sound. Countries conducted limited assessment of the ecological consequences of sea level rise.
- The studies tend to show mixed results for changes in crop yields. African and Asian countries, particularly southern Asian countries, tended to estimate decreases in yields. Many countries found mixed results and some even estimated increases in yield of some crops, particularly Europe and Latin America. Adaptation could significantly affect yields, but it is not clear whether these adaptations are affordable or feasible (e.g., whether farmers could afford fertilizers or pesticides). On the whole, some countries may lose while others may win. These conclusions are consistent with those of the IPCC, which found that global agriculture will most likely provide enough food to feed the world, but there are likely to be geographic shifts in production (Watson et al., 1996a).
- Impacts on water resources are uncertain, mainly because of uncertainty about regional change in precipitation patterns. The studies show a high sensitivity of runoff to climate change, which could result in increases in droughts or floods. The ability of water resource systems to adapt was not thoroughly assessed.
- The impacts on grasslands and livestock are mixed, but for the few countries studied, there appears to be a large capacity for adaptation.

For the more unmanaged systems, the USCSP assessments found the following:

- Climate change could result in increased human health problems, particularly for populations in low-latitude countries with inadequate access to health care.

- The composition of forests is likely to change. Many of the assessments found that biomass could be reduced, although this latter finding is not necessarily supported by other assessments (e.g., IPCC).
- There are potential negative impacts on wildlife, with some species possibly having reduced populations.
- The effects on fisheries are indeterminate.

These latter effects were studied in only a few countries, so one should be careful about over-interpreting results. Interestingly, a key factor affecting wildlife and human health is baseline socioeconomic changes. Current baseline issues such as continued destruction of wildlife habitat and lack of healthcare infrastructure may exacerbate the potential vulnerability to climate change. One common theme from many of the assessments is that the impacts of baseline changes may be much greater than the impacts of climate change.

On the whole, it appears that there is high sensitivity to climate change in many developing countries. However, vulnerability is harder to determine. It appears that many unmanaged systems could be quite vulnerable to climate change. Thus, the USCSP has substantially expanded the knowledge about potential impacts of climate change on developing and transition countries, but more work needs to be done to better understand their ultimate vulnerability.

3.3.2 Conclusions on Adaptation Assessments

Table 21 summarizes the results from a number of USCSP adaptation assessments. Since few adaptation assessments have been done to date, these results should be considered preliminary.

- Results for the coastal resources sector (Table 14) show that countries evaluated protection for a variety of sea level rise values and protection options. They also show that most of the benefit-cost ratios are greater than one, indicating that the benefits (e.g., avoided land and infrastructure losses) generally exceeded the costs for most of the locations studied. However, researchers found that costs could outweigh benefits along less-developed shoreline segments.
- In the agricultural sector, seed banks (called regional centers in the Kazakhstan study) were among the more cost-effective options in Kazakhstan and Uruguay, according to Adaptation Decision Matrix (ADM) analyses.[11] In Egypt, switching crops or cultivars was the best option, according to Adaptation Strategy Evaluator (ASE) evaluations.
- In the water resources sector, differences in cost assessment methodology prevent direct comparisons of cost-effectiveness across countries. However, there is some consistency in the way different projects are ranked within a country's assessment. For example, groundwater options tended to be least cost-effective in both Kazakhstan and Botswana.

Countries evaluated a broad mix of policy, technology, research, and education/outreach adaptation options. There do appear to be some sectoral trends. Technological options were more common in the coastal and water resource sectors than were other types of options, and options in the agriculture sector focused on educational or outreach activities to alter farm-level management practices. This suggests that the first reaction in adaptation may be to examine technological or operator changes that could enable activities such as farming or living in coastal areas to continue as before. Addressing policies that change these activities appears not to be the first choice of these countries. The results, however, are too preliminary to draw any conclusions about whether these trends indicate that technological or educational/outreach options are the best adaptation approaches in these sectors.

The adaptation options across sectors primarily affected domestic activities. However, there were some options pertaining to uses of international rivers that would benefit from, if not require, international coordination. This suggests that it will be important to coordinate some adaptation assessments and activities at the international level. It will also be important to ensure that adaptation options are consistent with other policy objectives such as greenhouse gas emissions reduction.

[11] See Appendix A for an explanation of the models used to assess adaptation options in each sector.

Table 21 Summary of Adaptation Evaluation Methods and Results

Sector and Country	Cost-Effectiveness	Multi-Attribute	Benefit-Cost	Key Evaluation Results by Country
Agriculture				Best performing adaption options:
Kazakhstan	✓			Market transition and regional centers
Uruguay	✓			Seed bank and soil conservation
Egypt		✓		Change crops or cultivars
Water Resources				Most cost-effective/least cost-effective options:
Kazakhstan	✓			Diversions/groundwater
Romania	✓			Diversions/diversions and added storage
Botswana	✓			Recycling/groundwater
Ukraine	✓[a]			Dredge navigation routes/switch to rail transport
Bolivia	✓			Planning and drought or flood preparedness/water metering
Coastal Resources				
China			✓	B/C > 0 for full protection and all scenarios
Estonia			✓	B/C > 0 for full protection of Pämu, not Tallinn
Poland			✓	B/C > 0 for full and partial protection for entire coast
				B/C < 0 for some areas
				B/C > 0 most likely for projects in capital city
The Gambia			✓	B/C < 0 for all protection options
Venezuela	✓		✓	B/C > 0 for entire coast, B/C < 0 for some areas
Uruguay	✓	✓	✓[b]	Beach nourishment and ICZM had ASE and ADM best sources
Egypt				Beach nourishment and ICZM had ASE and ADM best scores

[a] The Ukrainian study did not include formal cost-effectiveness estimates like the other water resource studies, but their text indicates some comparison of relative costs across options for navigation.
[b] The Uruguayan coastal zone benefit-cost analysis was performed only for protection measures.

3.3.3 Challenges of Assessing Vulnerability and Adaptation

Although assessments of vulnerability have been conducted for almost two decades in developed countries, assessments of vulnerability in developing and transition countries have only recently begun. The USCSP has broadly expanded the number of developing and transition countries assessing impacts and the sectors being considered. This program has substantially expanded knowledge of potential climate change impacts, but there are a number of important limitations, including the following:

- General circulation models (GCMs) often do not adequately simulate current regional climates, so their estimates of future climate should not be treated as predictions. All methods for creating regional climate change scenarios should be treated as tools in identifying potential changes in climate and sensitivities of sectors to climate change. This uncertainty about regional climate change may be the greatest impediment to predicting the effects of climate change.
- Changes in baseline socioeconomic conditions need to be better integrated into vulnerability assessments. Baseline changes could significantly change vulnerability. Of those countries that developed baseline socioeconomic scenarios, only a few integrated the baseline scenarios into their analyses of vulnerability to climate change.
- Integration of impacts across sectors is important to understanding vulnerability. For example, a reduction in water supplies may limit the availability of water for irrigation. Most of the assessments addressed each sector in isolation, and addressed interactions among sectors only qualitatively, if at all.

Assessing climate change adaptation options is an emerging field. Very little work has been done on this topic in either developed or developing countries. It is probably reasonable to conclude that, to date, the USCSP, including the SNAP Program, is the most extensive assessment of adaptation to climate change.

The assessments done for the USCSP raise a number of analytic issues that should be addressed to aid countries in evaluating, selecting, and implementing adaptation options. Among these issues are the following:

(1) Uncertainties about climate change, particularly at the regional scale, make it difficult to select adaptation policies. Not knowing whether it will be wetter or drier, stormier or calmer, makes it difficult to determine what kinds of adaptations are needed. Should the emphasis be on droughts or floods, wet conditions that may result in spread of many infectious diseases, or dry conditions that increase the risk of fire? As long as this uncertainty continues, proposed policies need to be effective under a wide variety of climate change situations. Policies that address only one type of change may have too low a probability of occurrence to justify their adoption. On the other hand, the assessments of adaptation have identified many policies that have many benefits under the current climate as well as under climate change scenarios.

(2) Estimating the cost of adaptation options is often difficult. Many of the options for adaptation were unfamiliar to a number of USCSP participants, and techniques for cost estimation were not readily available. Future technical assistance should include the development of, and training in, techniques for estimating costs of adaptation options.

(3) Quantification of benefits of adaptation options can be difficult. Most of the assessments of adaptation benefits relied on expert judgment to assess the benefits of adopting measures. This is particularly true for the assessments of water resources and some of the assessments of agriculture. On the other hand, assessments of sea level rise adaptation options often yielded quantitative, even monetary estimates of benefits. This discrepancy is probably a result of a difference in the types of assessment tools made available to program participants. Coastal resource assessments used the Common Methodology, which emphasized analysis and quantification of adaptation costs and benefits. Assessments of other sectors tended to focus on identifying biophysical effects such as changes in crop yields and runoff, and had less capability to evaluate the costs and benefits of adaptation. For example, the DSSAT methodology allows users to assess the effect of farm-level adaptations on crop yields, but it does not estimate costs.

The first limitation, which is also the most important limitation for vulnerability assessment, will take time to resolve. Better science and improved climate models will be needed to make more certain forecasts about regional climate change. The last two limitations can be addressed by applying more sophisticated techniques to adaptation assessments. More sophisticated outputs such as monetary estimates of benefits and costs may well be needed before multilateral funding agencies are in a position to provide financial assistance for adoption of adaptation measures.

Despite these challenges, a number of USCSP countries participating in the SNAP Program have already undertaken extensive analyses of methods for implementing adaptation options as part of national action plans. These analyses serve as useful models for policy makers, nongovernment organizations, and researchers in other countries that are exploring methods for implementing adaptation measures. Examples of two of these analyses are provided in Box 30.

3.4 Suggestions for Future Work

The vulnerability and adaptation assessments conducted by 49 countries under USCSP significantly strengthened the capacity of developing and transition countries to assess their vulnerability to climate change and potential adaptive responses. The countries were able to develop scenarios and apply a variety of biophysical impact assessment methods and models in key sectors. These results significantly expand the literature on climate change impacts. In addition, the countries used a variety of methods to evaluate a wide range of adaptation options, including policy, technology, research, and education/outreach activities.

The preliminary results suggest that future vulnerability assessments can be improved by:

- developing better regional or local climate change scenarios, but still interpreting outputs from GCMs

Box 30 Implementation of Adaptation Measures

Kazakhstan and Egypt are two of the countries participating in the USCSP that assessed adaptation options under the SNAP Program. Kazakhstan has incorporated adaptation measures into its national action plan, and Egypt has begun to implement several adaptation measures.

Kazakhstan

Kazakhstan included the results of its water resource and agriculture adaptation assessments in its national action plan and its national communication as well. Kazakhstan also adopted activities as part of its "Plan on Social and Economy Development of the Republic of Kazakhstan for 1998-2000" that are consistent with recommendations from its adaptation assessment. The findings of the adaptation assessment were considered during the development of the plan, in part because a member of the assessment team was also involved in its development (Pilifosova, 1999). As a result, three pilot projects, which can be considered as the "first step" in implementing a program to reduce soil erosion, were included in the plan:

- *an inventory of land and a program to exclude ecologically damaged and low producing areas from arable lands*
- *development and implementation of measures to raise productivity of arable land*
- *creation of a center to handle land degradation problems in the Akmola administrative region.*

Although these measures are part of national action plans, there is currently no funding or plans for actually implementing them (Pilifosova, 1999).

Egypt

Egypt has begun implementing adaptation measures to address sea level rise and impacts on agriculture.

Over the last two years, Egypt has undertaken the following specific activities on adaptation to sea level rise:

- *An Integrated Coastal Zone Management Committee was formed by the Egyptian Environment Affairs Agency and charged with coordination among stakeholders.*
- *Many developments in the coastal zones of the Mediterranean and the Red Sea have considered the integrated approach and have carried out plans that take into account adaptation to sea level rise. A number of environmental impact assessments of projects also considered future adaptation to impacts of sea level rise.*
- *Periodic nourishment of some specific beaches at Alexandria and Port Said against erosion and sea level rise is in progress.*
- *Because of the SNAP Program, awareness of the effects of sea level rise among stakeholders on those specific beaches has increased. Questionnaires provided these stakeholders with basic information on the problem and its possible implications (El-Raey, 1999).*[a]

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[a] Dr. El-Raey recommends that a "strategic impact assessment" be required by law such that plans and programs of development on the coastal areas be evaluated on the long term for adaptation to sea level rise.

as indicators, not predictors, of regional climate change

- encouraging countries to use incremental scenarios in addition to GCM scenarios because incremental scenarios are not sensitive to improvements in climate modeling techniques
- refining techniques for developing baseline socioeconomic scenarios and incorporating them into vulnerability and adaptation assessments
- applying state-of-the-art assessment models that can be readily used by analysts
- designing vulnerability assessments to produce results that can feed directly into adaptation assessments.

Future adaptation assessments can be improved by:

- undertaking research on more consistent and reliable techniques for quantifying benefits and costs of adaptation
- developing protocols for assessing adaptation so applications and results are more consistent across countries
- examining implementation of adaptation to determine what types of analyses are useful to decision makers and to assess the accuracy of the analyses
- conducting an assessment of country's adaptive capacity (at the national scale as well as at regional and sector scales) and identifying conditions that enhance or impede adaptive capacity.

Finally, future vulnerability and adaptation assessments can be improved by providing continued technical assistance to analysts throughout the assessment.

Several changes in resource management would lead not only to adaptation to climate change but also to overall improvement of the Egyptian agriculture system. The vulnerability assessment for Egypt found that rice yields could decrease by 11 percent and water demand could increase by 16 percent. Based on this, the Delta (12 Governorates) and Middle Egypt (Fayoum Governorate) are trying to reduce the area under rice cultivation by approximately 40 percent. One set of adaptation measures involves the careful selection and/or breeding of heat-tolerant, salinity-tolerant water conserving crops, as well as controlled environmental production methods that minimize water use while maximizing the production of high-value crops (e.g., planting all-season vegetables and fruits, shifting to more cotton plantation instead of some maize in summer crops and to more planting of tomatoes, onions, and potatoes as winter crops before cotton and instead of wheat). Trials are being done on these options across Egypt through the Agricultural Research Centers and the universities (Eid, 1999).[12]

[12] Dr. Eid recommends that efforts be made to promote the preferential adoption of high-return, specialized and water-conserving crops instead of the presently grown water-profligate crops such as rice and sugarcane and /or reducing the area under cultivation with high water consumer crops and/or using early maturing and high yielding cultivars.