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DRAFT RESEARCH PAPER ON
INDIA'S VULNERABILITY TO CLIMATE CHANGE

- BY DR. KIRIT PARIKH

DRAFT
Not to be quoted

India's Vulnerability to Climate Change

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1. Introduction

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1.1 Climate Change - A Threat

The threat of climate change is real. The Third Assessment Report (TAR) of Intergovernmental Panel on Climate Change (IPCC) states clearly as follows:

> "Available observational evidence indicates that regional changes in climate, particularly increases in temperature, have already affected a diverse set of physical and biological systems in many parts of the world. Examples of observed changes include shrinkage of glaciers, thawing of permafrost, later freezing and earlier break-up of ice on rivers and lakes, lengthening of mid- to high-latitude growing seasons, poleward and altitudinal shifts of plant and animal ranges, declines of some plant and animal populations, and earlier flowering of trees, emergence of insects, and egg-laying in birds. Associations between changes in regional temperatures and observed changes in physical and biological systems have been documented in many aquatic, terrestrial, and marine environments."

IPCC further observes that –

> "Natural systems can be especially vulnerable to climate change because of limited adaptive capacity (see Box SPM-1), and some of these systems may undergo significant and irreversible damage. Natural systems at risk include glaciers, coral reefs and atolls, mangroves, boreal and tropical forests, polar and alpine ecosystems, prairie wetlands, and remnant native grasslands. While some species may increase in abundance or range, climate change will increase existing risks of extinction of some more vulnerable species and loss of biodiversity. It is *well-established* that the geographical extent of the damage or loss, and the number of systems affected, will increase with the magnitude and rate of climate change."

Many human systems are sensitive to climate change. These include water resources, agriculture, food security, forestry, coastal zones, marine fisheries, human settlements, energy, industry, insurance and other financial systems and human health. The impact of climate change or these systems can have a severe adverse impact on human well-being in India. Thus it is important to assess India's vulnerability.

India may be particularly vulnerable to climate change as a poor and tropical sub-tropical country, highly dependent on weather for its agricultural output. For India, its freshwater systems, rainfall, rivers and groundwater are critical for its agriculture and food security. Disruptions, draughts and floods induced by climate change can cause great hardship and impose large costs. Similarly, the large coastline of India, millions who live near the sea and depend on coastal ecosystems for their livelihood may also be highly vulnerable to climate change.

It is important to assess India's vulnerability for it can provide guidance for policy actions both at national and international levels.

1.2 Vulnerability - Notions

In any multi-disciplinary area of study, there is a danger that people use common terms with a different meaning in mind. It is therefore, necessary to clearly define at the beginning what is meant by some commonly used terms such as sensitivity, adaptive capacity and vulnerability. We reproduce the IPCC definitions in Box 1. Other terms that need to be defined at the beginning relate to confidence levels and state of knowledge. Box 2 from IPCC shows these.

Box 1: Climate Change Sensitivity, Adaptability and Vulnerability

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. Climate-related stimuli encompass all the elements of climate change, including mean climate characteristics, climate variability, and the frequency and magnitude of extremes. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise).

Adaptive capacity is the ability of a system to adjust to climate change, including climate variability and extremes, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

Box 2: Confidence Levels and State of Knowledge

Quantitative Assessment of Confidence Levels

In applying the *quantitative* approach, authors of the report assign a confidence level that

represents the degree of belief among the authors in the validity of a conclusion, based on their collective expert judgment of observational evidence, modeling results, and theory that they have examined. Five confidence levels are used. In the tables of the Technical Summary, symbols are substituted for words:

Very High (*****)	95% or greater
High (****)	67 – 95%
Medium (***)	33 – 67%
Low (**)	5 – 33%
Very Low (*)	5% or less

Qualitative Assessment of the State of Knowledge

In applying the *qualitative* approach, authors of the report evaluate the level of scientific understanding in support of a conclusion, based on the amount of supporting evidence and the level of agreement among experts about the interpretation of the evidence. Four qualitative classification are employed:

- *Well-established:* Models incorporate known processes, observations are consistent with models, or multiple lines of evidence support the finding.
- *Established but incomplete:* Models incorporate most known processes, although some parameterizations may not be well tested; observations are somewhat consistent but incomplete; current empirical estimates are well founded, but the possibility of changes in governing processes over time is considerable; or only one or a few lines of evidence support the finding.
- *Competing explanations:* Different model representations account for different aspects of observations or evidence or incorporate different aspects of key processes, leading to competing explanations.
- *Speculative:* Conceptually plausible ideas that are not adequately represented in the literature or that contain many difficult-to-reduce uncertainties.

Vulnerability depends not only on the sensitivity of the systems but also its capacity to adapt. Adaptation however, is not costless and the ability to adapt depends on one's resources. Thus a developing country like India and the poor in it have the least capacity to adapt and are most vulnerable. Our purpose in this paper is to assess India's vulnerability to climate change.

To do that we first look at various climate change scenarios in section 2. Section 3 summarizes the impacts of possible climate change scenarios on various sectors and systems to identify key concerns. These are found to be, agriculture and food security, coastal zones, submergence, water resources disruptions and increased vulnerability at local and community levels. These are assessed in sections 4 to 7. Section 10 pulls these together and concludes with policy recommendations.

2. Climate Change Scenarios

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Climate change induced by human activities is now recognized as perhaps the most serious environmental problem and developmental challenge in the world today. The Earth's climate system is likely to undergo significant change over the course of the next century and longer, as a result of forcing due to the increasing atmospheric concentrations of greenhouse gases. The consequences of these changes in the climate system will lead to impacts on natural and social systems. Evaluation of these impacts therefore requires the specification of scenarios or projections of changes in future climate. At the same time, the climate system exhibits significant natural variability on interannual to decadal time-scales. This variability and the occurrence of extremes of weather already poses a challenge to the socio-economic system. Considering that even future climate change will be perceived largely in terms of changes in variability or extreme events, it is important to understand the baseline of impacts that result from current patterns of variability and extremes. Therefore, this section begins with a review of the characteristics of current climate over the Indian subcontinent, with special attention towards extreme weather events. We then summarize some of the recent projections with regard to climate change for the Indian subcontinent.

2.1 Climate characteristics and trends

The climate in the Indian subcontinent, as in most of tropical Asia, is dominated by the two monsoon seasons – the Southwest Monsoon, from June through September and the Northeast Monsoon, from November through March. The monsoons bring most of the region's precipitation and are the most critical climatic factor for the provision of drinking water and water for rain-fed and irrigated agriculture. The Indian subcontinent is also home to some of the largest river basins in the world, including those of the Ganges, Brahmaputra and the Indus. A significant proportion of Indian population and economic activity is concentrated in the deltaic regions of the major rivers of the subcontinent, such as the Ganges, Godavari, Mahanadi and Kaveri.

Over the last 100 years, mean surface temperature has increased by 0.3 – 0.8 degrees C over the tropical Asian region (IPCC, 2001). In India, Rupa Kumar et al (1994) have demonstrated that mean maximum temperatures have increased by 0.6 degrees C for a period from 1901 – 1987. They also observed a decrease in mean minimum temperature of 0.1 degrees C; however, this decrease was not statistically significant. In another study, Srivastava et al (1992) found an increased warming trend in the last two decades (1971 – 1980, 1981 – 1990) as compared to previous decades. Figure 1 plots the annual

average maximum and minimum surface temperatures from 1901 – 1990. For comparison, Figure 1 also illustrates the maximum temperature in the hottest month of the year (May) and the minimum temperature in the coldest month of the year (January).

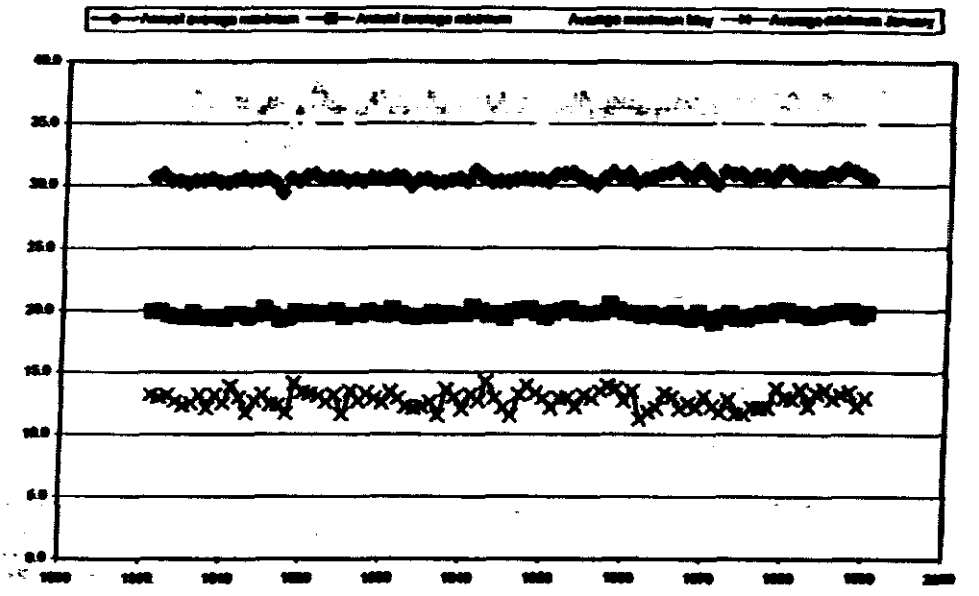


Figure 1: Maximum and minimum surface temperatures[1]

With regard to summer monsoon rainfall, Parthasarthy et al (1993) have shown that there are no significant increasing or decreasing trends over the last 100 years, although there is significant interannual and interdecadal variability. Figure 2 plots the All-India Summer Monsoon Rainfall (AISMR) series, which uses data from an almost uniformly distributed network of 306 stations across the country to obtain an area-averaged estimate of the total monsoon rainfall in the country[2]. This is widely regarded as a reliable index of summer monsoon activity over the Indian sub-continent. Years in which the AISMR exceeds 1 standard deviation above the mean are regarded as "flood" years, while years in which the AISMR is 1 standard deviation below the mean are regarded as "drought" years. Based on this classification, there appear to be 19 flood and 21 drought years in the period from 1981 to 1997. Interdecadal time-scale variability in the monsoon is seen clearly from Figure 2, for example it appears that there have been alternating periods extending to 3-4 decades with less and more frequent weak monsoons over India.

[1] Source: Pant and Rupa Kumar (1997)

[2] For example, see: Mooley et al (1981), Parthasarthy et al (1987), Parthasarthy et al (1995) and Pant and Rupa Kumar (1997).

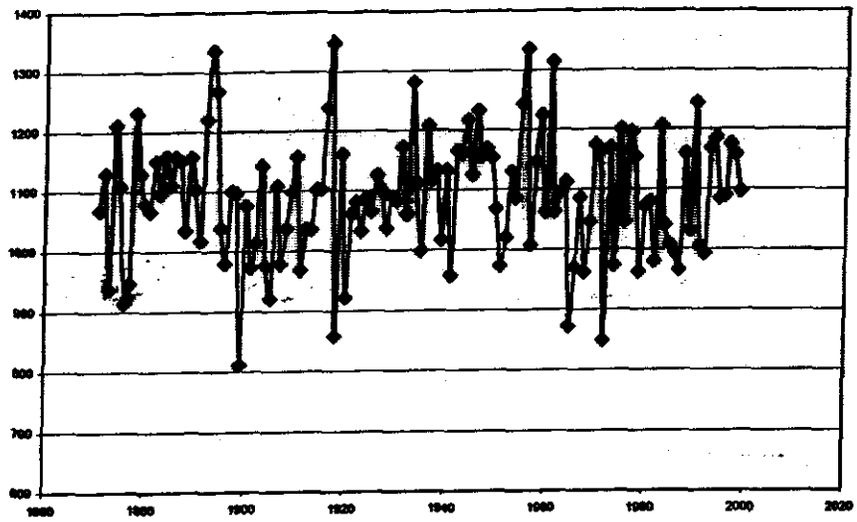


Figure 2: AISMR series

In addition to aggregate rainfall over spatial (regional) or temporal (seasonal) scales, it is also important to examine two other features of the monsoon – wet spells and heavy rainfall. The summer monsoon exhibits a characteristic active and break periods that cause wet and dry spells of varying duration. This intraseasonal variability in rainfall is particularly important for agriculture, and is a key issue in terms of forecasts of future climate change. The India Meteorological Department (IMD) considers days in which rainfall exceeds 7 cms as heavy rainfall days. Heavy rainfall days are important from the perspective of floods. Trends in heavy rainfall have been explored by Sinha Ray and Srivastava (2000), who find a decreasing trend in heavy rainfall during the winter (January – February), pre-monsoon (March – May) and post-monsoon (October – December) seasons, and mixed results during the monsoon itself. They suggest that the decrease in pre and post-monsoon seasons could be related to the decreasing trend in cyclonic activity found by Srivastava et al (2000). Recent decades have exhibited an increase in extreme (or heavy) rainfall events over northwest India during the summer monsoon (Singh and Sontakke, 2001).

2.2 Extreme events

The Indian subcontinent is subject to a wide variety of climate-related extreme events, including, tropical cyclones, floods, landslides as well as heat waves and cold waves. Significant impacts are associated with these events, as can be seen from Figure 3. While tropical storms appear to be the most important, it should be noted that if the numbers for earthquakes and storms are high due to a single very destructive event – the Latur event

in the case of earthquakes, and the Orissa super-cyclone in the case of storms, both of which had mortalities close to 10,000. If one adjusts the data for these two specific events, a more balanced picture emerges, and floods are then the most significant natural hazard in terms of mortality.

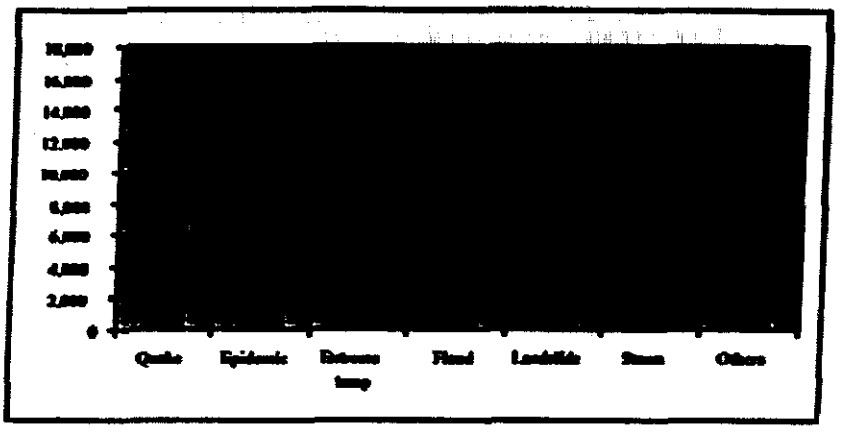


Figure 3: Total mortality from natural hazards over the last decade (1990-2000)[3]

2.3 Tropical cyclones

Tropical cyclones are an important part of the weather and climate in India. The primary area of cyclogenesis of concern for India is the Bay of Bengal, although tropical cyclones originating in the Arabian Sea do affect parts of the Indian coastline, particularly the state of Gujarat. Most analysis of tropical cyclones classifies the events into depressions (wind speed < 62 km/hr), cyclonic storms (wind speed between 62 and 87 km/hr) and severe cyclonic storms (wind speed > 87 km/hr). Severe cyclonic storms correspond to a Category 1 Hurricane on the Saffir-Simpson scale that is commonly used for describing systems in the North Atlantic Ocean. For a 100-year period (1891 – 1990) around 914 events made landfall on the Bay of Bengal coastline (India, Bangladesh and Myanmar), of which about xx were depressions, yy cyclonic storms and zz severe cyclonic storms. Almost 70% of all tropical cyclones originating in the Bay of Bengal eventually make landfall on the coast.

The observational record suggests that no significant changes in the number, frequency, or intensity of tropical cyclones or depressions have been observed in the Northern Indian Ocean cyclone region (Bay of Bengal and Arabian Sea) over the past 100 years, although spectral analysis suggests variability on a range of time-scales. For example, Gadgil

[3] Based on data from the CRED database

(1995) has shown decadal-scale variations—with a rising trend during 1950–75 and a declining trend since that time, and Singh et al (2000) suggest cycles of various periodicities, the most important being 2-5, 10, 13 and 29 years. However, there is some disagreement with regard to the inferences from the observational record, as Srivastava et al (2000) suggest that there is a statistically significant decreasing trend in the frequency of storms when evaluated over a period of 1891 to 1997 for the Bay of Bengal. The same study concludes that there is no significant trend when one examines cyclonic disturbances as a whole.

Tropical cyclones lead to a variety of impacts, some immediate, due to storm surge, high winds and flooding. However, there are also significant impacts due to long-term dislocation of public infrastructure and consequent public and private economic output. Impacts associated with tropical cyclones are discussed further in a subsequent section.

2.4 Floods

Riverine flooding is perhaps the most critical climate-related hazard in India. Flood control has been a key element of national policies for water resource management. There are a variety of types of floods, including flash floods, single event floods, multiple event floods and seasonal floods, all of which are typically caused by heavy rainfall. In addition, there can also be coastal floods caused by storm surge, floods due to dam failure and estuarine floods. In this section we will focus on rainfall-induced floods of rivers. At present there are about 120 major and medium rivers in India that are broadly grouped under 12 major river basins: Indus, Ganga-Brahmaputra-Meghna, Sabarmati, Mahi, Tapi, Brahmani, Mahanadi, Narmada, Krishna, Godavari, Cauvery and Pennar. Flood and river discharge data is collected through a network of about 340 gauge/discharge sites located on the major and medium rivers of India. The rivers are said to be in flood when the water level crosses the Danger Level (DL) at the particular site. Major floods are defined as events when the DL is exceeded by 1 meter and most severe floods are events where the DL is exceeded by 5 meters. For a period from 1987 – 1997 the most flood prone states were Assam and Bihar, followed by Uttar Pradesh and West Bengal. A good source that describes the all-India distribution of flood hazard is the Vulnerability Atlas of India, from the Building Materials Technology Promotion Council (BMTPC, 1997). The maximum number of flood events are experienced in the month of August.

A large part of the Indian subcontinent is exposed to annual floods and droughts. The occurrence of floods and droughts is closely linked to the summer monsoon activity. Variations in heavy rainfall and meteorological floods have been analysed by Chowdhury and Mhasawade (1991), who have used rainfall data to develop a flood index. The average annual flood covers vast areas throughout the region; in India and Bangladesh alone, floods cover 7.7 Mha[4] and 3.1 Mha, respectively (GOI, 1992; Mirza and Ericksen,

[4] Million hectares, or xx sq. km.

1996), while the total flood-prone[5] area in India is of the order of 40 Mha, or about 12% of the total land area of 329 Mha.

Impacts

Floods cause significant damage in India, average flood damage over the period from 1953 – 1987 has been estimated at Rs 298 crores annually, with a mortality rate of around 1318 per year (Roy, 1998). Figure 4 describes the trends in flood damages for a period from 1953 – 1987 (CSE, 1991). As the Figure indicates, the flood damages have increased steadily over a period of time. This is only partly due to changes in the hazard itself – a much larger contribution is perhaps due to the increased exposure to the hazard.

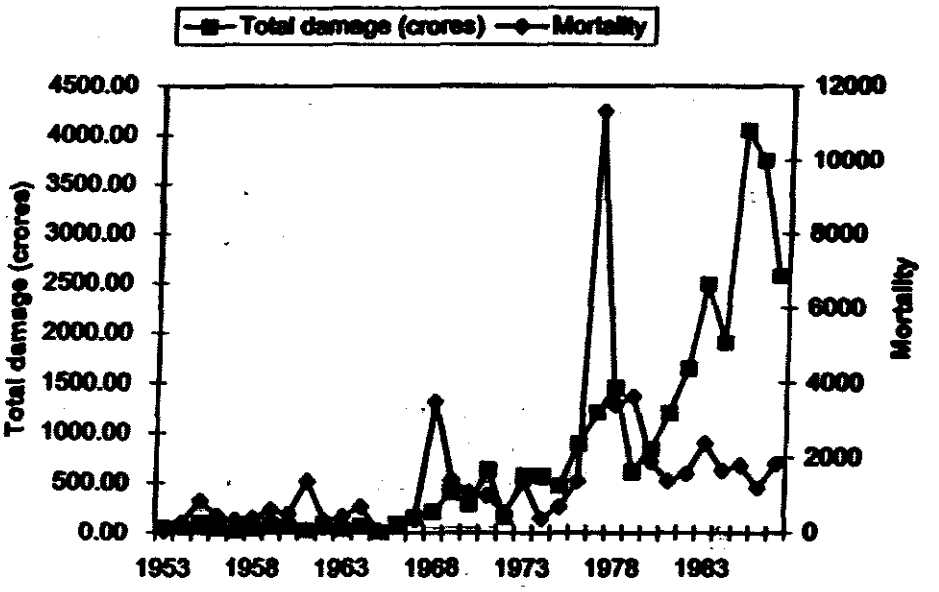


Figure 4: Trends in flood damage

Floods not only cause immediate consequences such as loss of life and property, but are also important in terms of the damage to public infrastructure and utilities. This damage in turn leads to a loss of overall economic activity that depends on the availability of the infrastructure and the utilities. For example, the destruction of roads, bridges and other transport / communication infrastructure needs to be considered carefully while evaluating impacts.

[5] Definition of "flood prone"

Flood damages have risen over the years, as described above (Figure 4). In the outlay on flood protection has also increased consistently, as have the expenditures on relief and recovery. All of these suggest a pattern of increasing vulnerability, which might worsen as a result of climate change. The increase trend in flood damages is suggested even when the data are adjusted to a common year (constant Rupees). This is described in Figure 5 below, which displays average annual damage in different plan periods (including some years when there were only annual plans).

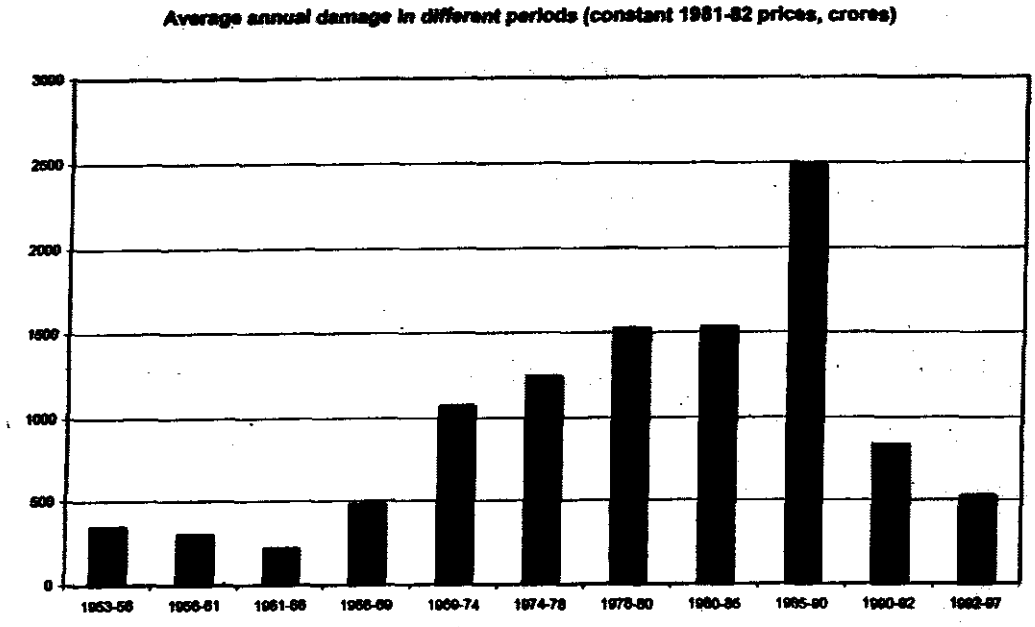


Figure 5:

While a part of the increase in damage might be attributable to the overall increase in the area exposed to the hazard (flood-affected area), it is important to analyze the degree to which systems are also becoming more resilient, particularly in the case of factors such as mortality which can be reduced through a number of policy interventions and adaptation strategies. Figure 6 provides a first attempt at addressing this question by plotting the scaled mortality and damages (i.e. the ratio of total mortality to the total flood affected population, and the ratio of total economic damage to the total flood affected area). While scaled mortality does not appear to have any clear trends, scaled damage does seem to increase in a fashion similar to the overall damage. This suggests that there is perhaps increased concentration of housing, public infrastructure and other capital stock in flood-prone areas.

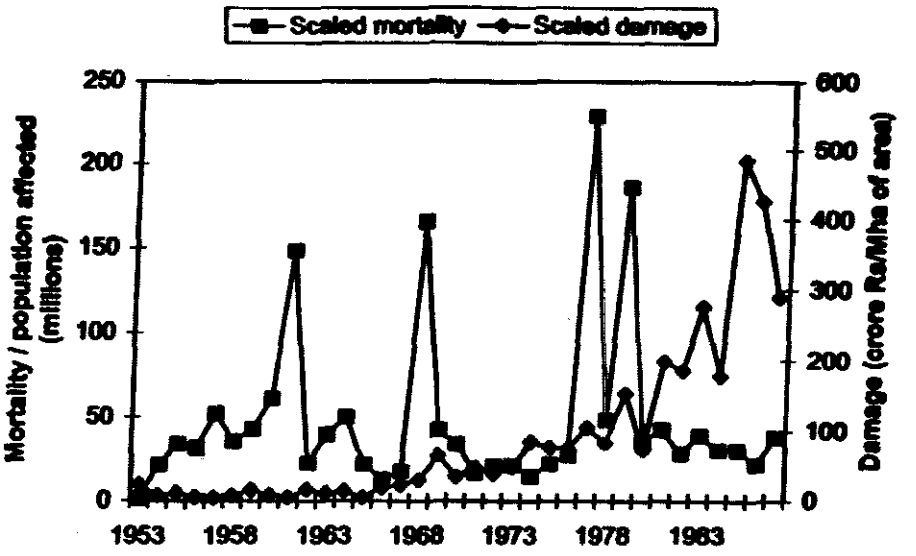
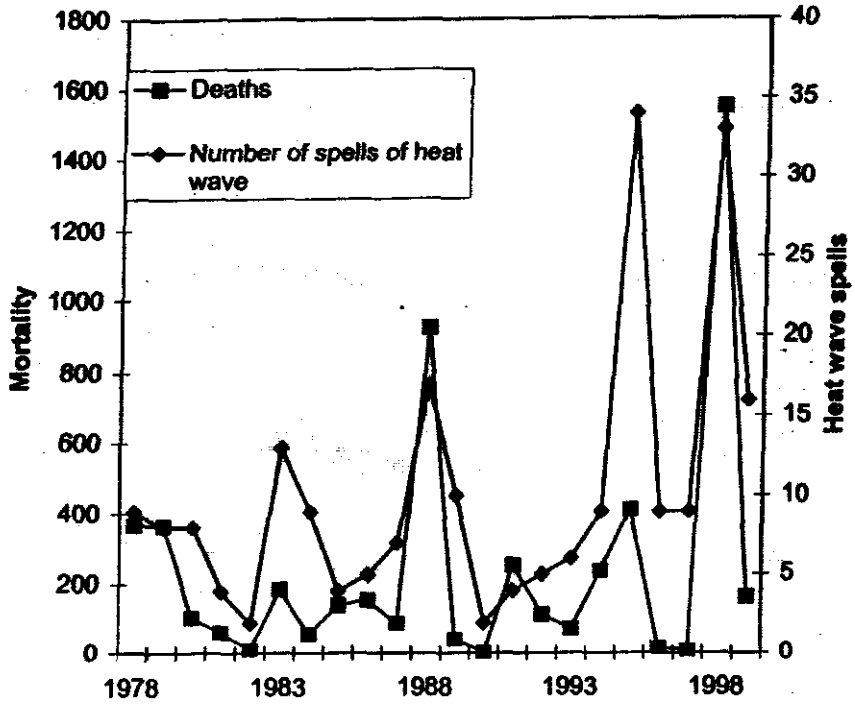


Figure 6:

Temperature extremes

Heat waves are an important route for the manifestation of climate-related impacts. They are also good examples of the role of multiple stresses, for example, mortalities during heat waves are often due to a combination of heat and water stress – heat waves typically occur during the summer months, which are also months of water stress and shortage. The thermo-hygrometric index (THI), which combines temperature and relative humidity is a commonly used discomfort index (Besancenot, 1990). In temperate countries, values of the THI in excess of 28.5 C are considered to be high-discomfort situations. In most parts of the country this value is exceeded for a large percentage of the time. As a result, there is already a greater susceptibility to heat-related health conditions in India. The IMD typically regards a heat wave as occurring if the daily temperature exceeds the normal maximum by 3-4 degrees, and it is considered to be a severe heat wave if the temperature exceeds the normal maximum by 5-6 degrees. The average annual mortality due to heat waves has been estimated at 153 (Sinha Ray et al, 1999). Figure 5 plots the incidence and mortality associated with heat waves over a period from 1978 – 1999. As may be expected the mortality resulting from a heat wave depends significantly on the socio-economic conditions of the exposed population, for example, during the 1978 – 1999 period, while the number of heat waves was roughly equal in Punjab and Orissa (17 and 15, respectively), the mortality in Orissa was more than four times that in Punjab (114 as compared to 529) (Chaudhury et al, 2000). Further cross-sectional and longitudinal analyses of impacts associated with heat waves are likely to provide useful insights into the role and effectiveness of adaptation and adaptive capacity.

Figure 5: Heat waves: incidence and mortality



Projections of future climate change

Scenarios of future climate change are generated starting from projections for the emissions of greenhouse gases. Complex three-dimensional models of the atmosphere, ocean, cryosphere and the biosphere are used to evaluate the effect of the changes in radiative forcing associated with increased concentrations of greenhouse gases. These models also include the effect of factors such as sulfate aerosols. A variety of approaches are then used to develop regional and local scenarios for changes in climate variables. These include, for example, nested models, statistical downscaling and related techniques. Before using a particular climate model for developing regional scenarios of future climate it is necessary to assess the degree to which that model simulates the current climate conditions, including current patterns of climate variability. This is particularly important as impacts are often most sensitive *not* to the climate variables best simulated (such as regionally or globally averaged surface temperature) but to variables such as precipitation or higher order climate statistics, such as exceedences over a threshold, or runs (series) of exceedences (such as a heat wave or a cold wave in the case of temperature). For example, many models do not capture the intraseasonal and spatial variability in the summer monsoon rainfall very well. Model validation exercises of this kind have been carried out (Lal et al, 2000, Lal and Harasawa, 2000). A number of models and model experiments were rated to have some skill in simulating the broad

features of the current climate and its variability (IPCC, 2001). Plausible changes for South Asia in area-averaged surface air temperature and percentage changes in precipitation based on an ensemble of these models are summarized in Tables 1 and 2 (IPCC, 2001).

Table 1: Area-averaged surface air temperature change (degrees C). Numbers in parentheses are changes when direct effects of sulfate aerosols are included

	2020s	2050s	2080s
Annual	1.36	2.69	3.84
	(1.06)	(1.92)	(2.98)
Winter	1.62	3.25	4.52
	(1.19)	(2.06)	(3.25)
Summer	1.13	2.19	3.2
	(0.97)	(1.81)	(2.67)

Table 2: Area-averaged change in precipitation (percentage). Numbers in parentheses are changes when direct effects of sulfate aerosols are included

	2020s	2050s	2080s
Annual	2.9	6.8	11
	(1.00)	(-2.4)	(-0.1)
Winter	2.7	-2.1	5.3
	(-10.1)	(-14.8)	(-11.2)
Summer	2.5	6.6	7.9
	(2.80)	(0.10)	(2.5)

As Table 1 indicates, significant warming is expected over the Indian subcontinent, with greater warming in the winter than in the summer. The direct effect of sulfate aerosols acts to reduce the extent of warming (negative feedback). However, with regard to precipitation, sulfate aerosol appears to produce a deleterious effect – as it tends to lead to a decrease in precipitation rather than an increase. In fact, the inclusion of aerosol forcing can actually change the sign of the expected change, from an increase in precipitation to a decrease. Recent scientific efforts such as the INDOEX project thus great significance in terms of improving predictive capability for the Indian subcontinent. The implications of climate change for the summer monsoon have been explored by Stephenson et al (2000).

With regard to extreme climate events, there is significant uncertainty about the nature of changes expected. The possibility of increased heavy rainfall events has been suggested (IPCC, 2001). Increased heavy rainfall events could lead to increased probabilities of flash floods and floods overall. The intensity and frequency of cyclone storms in the Arabian Sea and the Bay of Bengal could also be affected under changed climatic conditions. While early work (Haarsma et al, 1993) suggested that in the case of the North Indian Ocean, the average number of tropical disturbance days could increase from 17 to 29 per year in a doubled CO2 scenario, the current evidence is still inconclusive.

References

Besancenot, J.P.,1990: Climate and tourism, Masson, Paris

Bhaskaran, B., J.F.B. Mitchell, M. Lal, and J. Lavery, 1995: Climate response of Indian subcontinent to doubled CO_2 concentration. *International Journal of Climatology*, 15, 873-892.

Chaudhury, S.K., Gore, J.M. and Sinha Ray K. C., 2000: Impact of heat waves over India, *Current Science*, 79(2), 153-155

Chowdhury A. and Mhasawade, S.V., 1991: Variations in meteorological floods during summer monsoon in India, *Mausam*, 42(2), 167-170

Dhar, O.N and Nandargi, Shobha, 2001: A Comparative flood frequency study of Ganga nad Brahmaputra river systems of north India – a brief appraisal, *Water Policy*, 3, 101-107

IPCC, 2001: Climate change 2001: Impacts, adaptation and vulnerability, Cambridge University Press, UK

JNU, 1993. Impacts of greenhouse-induced sea-level rise on the islands and coasts of India, Technical Report, School of Environmental Sciences, JNU, New Delhi.

Khole, Medha and De, U.S., 1999: Floods and droughts in associations with cold and warm ENSO events and related circulation features, *Mausam*, 50(4), 355-364

Lal, M. and H. Harasawa, 2000: Comparison of the present-day climate simulation over Asia in selected coupled atmosphere-ocean global climate models. *Journal of the Meteorological Society of Japan*, 78(6), 871-879.

Lal, M. and H. Harasawa, 2001: Future climate change scenarios for Asia as inferred from selected coupled atmosphere-ocean global climate models. *Journal of the Meteorological Society of Japan*, 79(1), 219-227.

Mirza, M.Q. and N.J. Ericksen, 1996: Impact of water control projects on fisheries resources in Bangladesh. *Environmental Management*, 20(4), 527-539.

Mooley, D. A., Parthasarathy, B., Sontakke, N. A., and Munot, A. A 1981 : Annual rain-water over India, its variability and impact on the economy. *J. Climatology*, 1, 167-186.

Muthiah, S. (Ed), 1987: A Socio-economic Atlas of India, Oxford University Press, New Delhi,

Pant, G.B. and Rupa Kumar, K, 1997: Climates of South Asia, John Wiley & Sons, Chichester

Parthasarathy, B., Sontakke, N. A., Munot, A. A. and Kothawale, D. R. 1987: Droughts/floods in the summer monsoon rainfall season over different meteorological subdivisions of India for the period 1871-1984. *J. Climatology*, 7, 57-70

Parthasarathy B., Munot A.A., Kothawale D.R., 1995. All India monthly and seasonal rainfall series : 1871-1993. *Theor. and Appl. Climatol.*, 49, 217-224

Qasim, S. Z., (1998): Glimpses of the Indian Ocean, University Press, Hyderabad, 206pp.

Rupa Kumar, K., K. Krishna Kumar and G.B. Pant, 1994: Diurnal asymmetry of surface temperature trends over India. *Geophysical Research Letters*, 21, 677-680.

Rupa Kumar, K. and S.D. Patil, 1996: Long-term variations of rainfall and surface air temperature over Sri Lanka. In: *Climate Variability and Agriculture* [Abrol, Y.P., S. Gadgil, and G.B. Pant (eds.)]. Narosa Publishing House, New Delhi, India, pp. 135-152.

Sinha Ray, K.C., Mukhopadhyay, R.K. and De, U.S., 1999: Natural disasters, some issues and concerns, Vishwa Bharati, Shantiniketan.

Sinha Ray, K.C. and Srivastava A.K., 2000: Is there any change in extreme events like heavy rainfall? *Current Science*, 79(2), 155-158

Srivastava A.K., Sinha Ray, K.C, and Yadav R.V, 2001: Is summer becoming more uncomfortable over major cities of India? *Current Science*, 81(4), 342-344

Srivastava, A.K., Sinha Ray, K.C, and De, U.S., 2000: Trend in the frequency of cyclonic disturbances and their intensification over Indian Seas, *Mausam*, 51(2), 113-118

TERI, 1996: The economic impact of a one-meter sea level rise on the Indian coastline: Method and case studies, *Report submitted to the Ford Foundation*.

3. Agriculture and Food Security

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3.1 Importance of Agriculture

The importance of agriculture in India is manifold. More than 28 per cent of GDP was generated in agriculture in 2000-01. More than 60 per cent of the workers have their primary employment in agriculture as per the census of March 2001. Agriculture provides the bulk of consumption of India's people. The bottom 50 per cent of India's population spends two thirds of their consumption expenditure on food. Thus when agricultural production system is disturbed it affects everyone in India. It disrupts the livelihood of the poor. It threatens their food security. It aggravates the depth of poverty and enlarges the extend of it as high food prices pushes down those on the margin of poverty line, below the low.

Indian agriculture has made significant progress in the last four decades. Irrigation has expended from 38 million hectares in 1970 to 83.6 million hectares in 1998. Thus, it is now less vulnerable to variability of weather. This, however, does not mean it is less vulnerable to climate change. Climate change can change suitability of different crops, can disrupt ground water tables and supply and also surface water flows. This may change the effectiveness of irrigation systems.

The changes in temperature, monsoon activity and level of carbon dioxide (CO_2) affect the productivity of crops. While higher concentration of CO_2 can increase the rate of photo synthesis and crop yields (Cure and Acock, 1986; Kimball et al, 1993). Recent research suggests that beneficial effect of CO_2 fertilization "may be greater under certain stressful conditions, including warmer temperatures and draught" (IPCC-TS of WGII Report). While this is "well established for some crops under experimental conditions, knowledge about them is incomplete in sub-optimal conditions of actual forms". Acute water shortages combined with thermal stress should adversely affect wheat and more severely, rice productivity in India even under the positive effects of elevated CO_2 in the future.

Other threats to agricultural productivity arises due to increased incidence of pests and diseases, greater frequency of floods and draughts, increased frequency of other extreme events such as cyclones, greater soil erosion due to increased intensity of rainfall and stronger winds.

3.2 Impact of Climate Change

An early global study by Rosenzweig and Parry, 1994 showed that agriculture in developing countries could suffer a larger disadvantage than developed countries due to climate change.

> "The results from climate models predict the average temperature in India to change between 2.3 to 4.8°C following a doubling of ambient concentration of carbon dioxide (CO_2) from their pre-Industrial revolution levels (Lonergan, 1998). The climate models also predict higher monsoonal activity over the Indian sub-continent. The changes in temperature, precipitation, and ambient concentration of carbon dioxide (CO_2)[6] are shown to have an effect on the productivity of crops. These effects, referred as agronomic effects, are assessed using crop simulation models. A number of studies in the past have analysed these physical impacts of potential changes in climate on Indian agriculture. Using a dynamic crop growth model, WTGROWS, Aggarawal and Sinha (1993) have showed that in north India, a 1°C rise in mean temperature would have no significant effect on wheat yields, while a 2°C increase would decrease yields in most places. Rao and Sinha (1994) have assessed the changes in wheat yield using CERES-Wheat crop simulation model under various climate change scenarios. They have estimated that the wheat yields could decrease between 28 to 68 per cent without considering the carbon fertilization effects; and would range between + 4 to –34 per cent after considering carbon fertilization effects. In a study of rice crop in northwest India, Lal et al. (1996) showed that carbon fertilization effects would not be able to offset the negative impacts on yields due to higher temperatures under the changed climatic conditions. More recently Saseendran et al. (2000) studied the impact of climate change on rice production in the southern Indian state of Kerala and showed that for every one degree rise in temperature the decline in yield is about 6 per cent."
>
> Kumar K and Parikh (2001)

These studies have looked at one crop and in a particular region. Kumar K and Parikh J (2001) have used EPIC model to assess the impact on climate change on wheat and rice yields in India. Since they have also used these estimates to assess the consequential impact on production, prices, consumption and welfare of different classes, we look at their assessment of yield impacts in some detail.

> "The EPIC crop model used by Kumar K. and Parikh (2001) is a field-scale model operating on daily time steps. The model has detailed modules on weather, hydrology, erosion, nutrient cycling, soil temperature, tillage,

[6] Higher CO2 concentrations in the atmosphere are expected to increase the rate of photosynthesis and hence the crop yield (Cure and Acock, 1986; Kimball et al., 1993). This phenomenon is referred as carbon fertilization effect in the literature.

crop growth, and farm management. The model was originally developed to study the effect of erosion and Jones et al. (1991) discuss the model structure in detail. Stockle et al. (1992) have subsequently modified the model to study the impacts of climate change on crop output. The model captures the impact of changes in various climate parameters on crop production as follows:

Temperature: Through its influence on rate of plant phenological development, the length of growing period, and the rates of evaporation and transpiration.

Precipitation: Through its influence on soil moisture stress. The moisture stress days during the growing period are accounted while evaluating their effect on plant growth.

Ambient CO_2 concentration: Through increases in radiation use efficiency (which is defined as photosynthesis per unit of solar radiation absorbed). Increase in radiation use efficiency would result in improvement in leaf area index, and also reduction in transpiration. Both these effects would lead to improvement in crop yields.

They have calibrated the EPIC model parameters so that it reproduce observed yields at a number of places in the country for which all the relevant data were available. There were 12 sites for rice and 10 for wheat which covered the important rice and wheat growing areas in the country. The model is then used to generate yields under climate changes scenarios generated by different global circulation models.

The normal climate corresponding to the period 1930-'60 is used as the base climate. The climate change scenarios are generated using the results from the equilibrium experiments conducted at Goddard Institute of Space Studies (GISS) (Hansen et al., 1988), Geofluid Dynamics Laboratory (GFDL) (Manabe and Wetherald, 1987), and United Kingdom Meteorological Office (UKMO) (Wilson and Mitchell, 1987). The predicted changes in climate from these scenarios are expected to manifest by year 2060. The output from these three scenarios varies substantially, with the UKMO scenario projecting maximum temperature change and GFDL scenario projecting minimum change. The average temperature change across India projected by these scenarios ranges from 2.3 to 4.8°C. All the scenarios project the temperature rise in the Northern India to be higher than that in the Southern India. Though all the scenarios predict higher precipitation during monsoon, the projections vary significantly across scenarios.

Their estimated impacts on wheat and rice yields are shown in Table 3.1 and Table 3.2.

Table 3.1. Percentage change in rice yield at different sites under various climate change scenarios

Scenario	Climate change alone								Climate change with CO_2 fertilization effects							
	Nabha		Anantpur		Daryapur		Coimb.		Nabha		Anantpur		Daryapur		Coimb.	
	R	I	R	I	R	I	R	I	R	I	R	I	R	I	R	I
UK	-43.2	-50.1	-38.5	-40.8	-40.1	-48.1	-42.6	-48.2	-24.2	-34.1	-11.5	-24.9	-20.2	-29.1	-23.3	-22.2
GI	-39.1	-48.5	-26.3	-29.2	-36.2	-45.5	-22.6	-33.3	-20.1	-33.4	-6.6	-13.1	-20.1	-30.0	-3.1	-16.6
GF	-24.6	-39.8	-20.7	-28.8	-26.2	-36.3	-21.7	-30.3	-5.2	-23.3	-1.5	-12.1	-6.3	-19.3	-2.8	-13.3

Note: UK – UKMO; GI – GISS; GF – GFDL; R – Rainfed; I – Irrigated.

Source: Kumar and Parikh (2001)

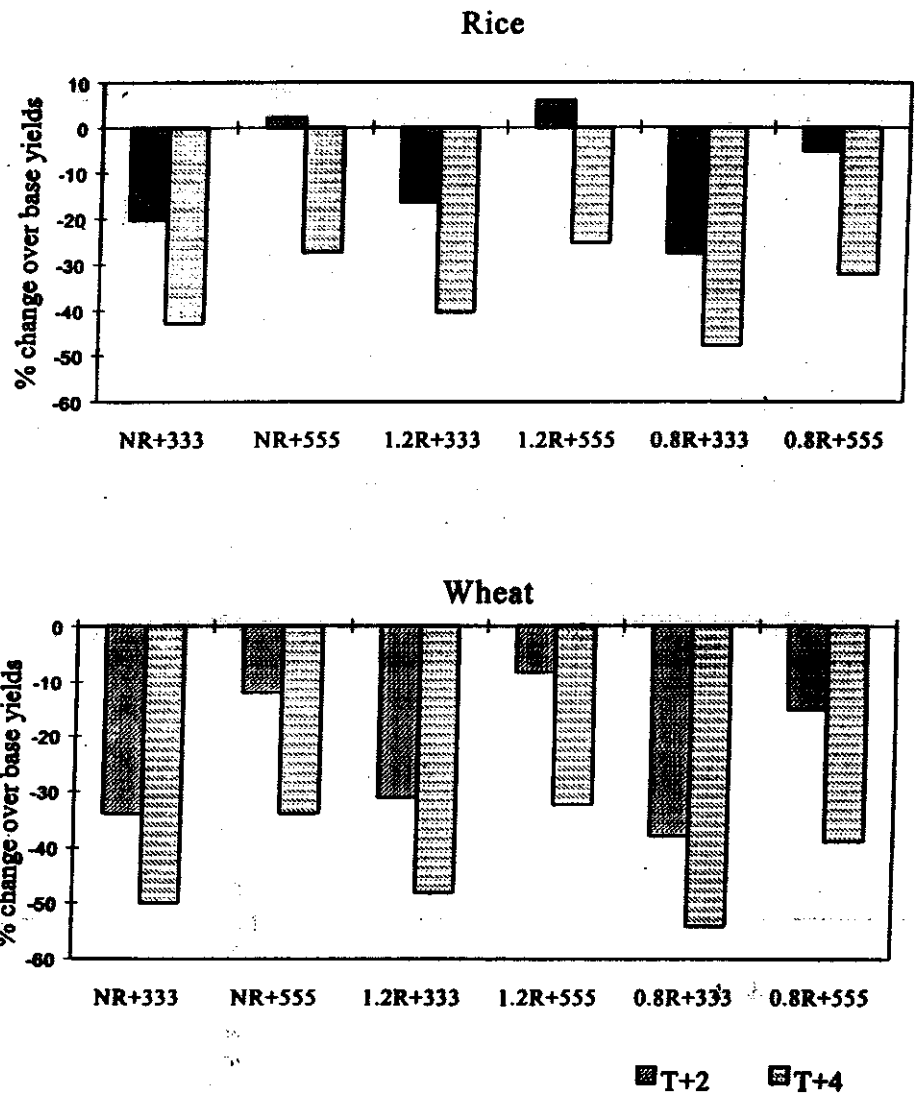
Table 3.2 Percentage change in wheat yield at different sites under various climate change scenarios

Scenario	Climate change alone								Climate change with CO_2 fertilization effects							
	Kalra		Hisar		Fatehpur		Iari		Kalra		Hisar		Fatehpur		Iari	
	R	I	R	I	R	I	R	I	R	I	R	I	R	I	R	I
UK	-36.3	-51.5	-31.7	-57.8	-39.5	-49.7	-43.0	-54.5	-13.3	-32.6	-7.8	-38.3	-11.5	-32.2	-18.0	-33.5
GI	-24.3	-53.2	-27.0	-53.5	-19.5	-43.8	-33.2	-49.0	-0.3	-25.2	-2.3	-23.5	6.6	-24.6	-8.2	-21.5
GF	-34.9	-44.0	-30.5	-45.7	-28.2	-42.5	-33.7	-41.2	-11.5	-19.5	-8.1	-16.2	-7.8	-14.9	-12.3	-16.2

Note: UK – UKMO; GI – GISS; GF – GFDL; R – Rainfed; I – Irrigated.

Source: Kumar and Parikh (2001)

Figure 3.1 from Kumar K and Parikh (2001) shows the sensitivity of EPIC model to changes in climate.



NR : Normal rainfall
1.2R: 20% increase over normal rainfall
0.8R: 20% decrease over normal rainfall
333: Ambient CO_2 concentration
555: Enhanced CO_2 concentration under changed climate

T+2: 2°C increase over base temperature
T+4: 4°C increase over base temperature

Figure 3.1: Sensitivity of EPIC crop model to changes in climate

We can summarize their findings as shown in Table 3.3. These changes are large and can have significant impact on human conditions.

Table 3.3: Range of Impact on Wheat and Rice Yields over Scenarios for Selected Cities

	Rice Yields		Wheat Yields	
	Irrigated	Rainfed	Irrigated	Rainfed
2.3° to 4.8° C increase in average temperature	-20 to -50	-16 to -43	-37 to -58	-19 to -44
Same as above with CO_2 fertilization	–5 to –34	+2 to -24	-8.5 to -38	+6.6 to -22

The national averages are obtained by averaging with the proportions of irrigated and fainfed areas. These are shown in Table 3.4.

Table 3.4: Change in Wheat and Rice Yields: All India Averages

Percent change in yield

	Rice	Wheat
Without CO_2 fertilization	-32 to -40	-41 to -52
With CO_2 fertilization	-13 to -25	-15 to -33

4.3 Economic and Welfare Impacts: Vulnerability

To assess the macroeconomic and welfare consequences of changes in yield levels namely for production, relative prices, incomes, consumption and welfare levels of different groups of people, Kumar and Parikh use the general equilibrium model, AGRIM, developed by Narayana N.S.S., Parikh, K and Srinivasan T.N. (1991).

AGRIM, has as many as 25 crops (16 major and 9 minor crops). Assuming climate change to affect only a few crops would not be appropriate. Hence, out of the 25 crops, the ones under rice group have been assumed to experience similar yield changes as expected for rice, and similarly for the ones under the wheat group. The crops that do not fall into either of these groups are clubbed into two groups – others and small millet group. The yield changes for these two groups are assumed to be 7.5 and 12.5 per cent lower than the average yield change estimated for rice and wheat[7].

The average yield changes obtained through the EPIC model represent shifts in yield-input relationships, i.e., they show by how much the yield would be lower for a given level of inputs. The actual levels of inputs applied will depend on relative prices. AGRIM

[7] In the absence of more accurate estimates of yield changes for other crops, such assumptions are inevitable and somewhat similar assumptions are made by Rosenzweig and Parry (1994) in their study on global food security.

determines cropping patterns and input levels endogenously and thus reflects some adaptation by farmers.

Kumar and Parikh generate scenarios with AGRIM covering the period 1990-2060. The climate change scenarios are compared with a base scenario. Table 3.5 compares some major macro indicators for the termnal year viz. 2060. As the climate change induced yield changes in crops are assumed to manifest fully over the long run, it would be appropriate to study the impacts for the terminal year in the simulation period, viz., 2060.

Table 3.5: Percentage change over base scenario in various macro and welfare indicators under various climate change scenarios

	Base scenario	Climate change alone			Climate change with CO_2 fertilization effects		
		GFDL	GISS	UKMO	GFDL	GISS	UKMO
Macro and Welfare Indicators							
GDPA70	437052	-25.85	-28.69	-32.90	-10.07	-13.02	-18.43
GDPNA70	2871753	1.83	1.52	1.045	-0.05	-0.26	-0.66
GDP70	3308805	-1.83	-2.46	-3.44	-1.37	-1.95	-3.00
INVEST	689264	3.91	3.22	2.15	0.37	0.01	-0.68
PA/PNA	1.1012	107.80	111.73	118.22	25.39	29.69	38.23
UPOP	870037	2.46	2.30	2.05	0.87	0.85	0.79
PARITY	0.868	7.94	7.30	6.30	1.88	1.80	1.61
CAL/CAP	2698.9	-18.23	-19.55	-21.63	-5.38	-6.38	-8.29
AVR.EQY	893.08	-25.16	-27.28	-30.57	-5.02	-6.10	-8.13
Sectoral Production							
WHEAT	93852	-38.31	-43.65	-50.08	-13.98	-20.82	-31.74
RICE	135605	-30.53	-33.56	-38.69	-12.13	-15.77	-24.10
Non-AGRI.	384130	1.72	1.45	0.96	-0.07	-0.30	-0.70

Note: GDP70: Gross domestic product, GDPA70: GDP-agriculture, GDPNA70: GDP-non-agriculture, INVEST: Investment, all in 1970-'71 prices, in 10^6 Rs.; PA/PNA: Ratio of agricultural to non-agricultural price deflator; UPOP: Urban population, in '000 persons; Parity: Rural-urban income parity; CAL/CAP: Food energy calorie intake/capita, in Kcal/person-day; A.EQY: Average equivalent income (income needed at 1970-71 prices to provide same utility as provided by current consumption at current prices), in Rupees; Wheat and Rice: Wheat and Rice production, respectively in '000 tons; Non-Agri: Non-agricultural production in million US $ in 1970-'71 prices. The figures correspond to the terminal period of the simulation.

Depending on the climate change scenario under consideration expected decline in agricultural GDP ranged from 26 to 33 per cent. The overall effect of climate change has resulted in loss in GDP under all scenarios, with the decline ranging between 1.8 to 3.4 per cent. (The losses are greatest under UKMO scenario and least under GFDL scenario.) The impacts on agricultural GDP are substantially reduced after considering the CO_2 fertilization effects. Nonetheless they are sizeable. This gain in agricultural sectors under the scenarios with CO_2 fertilization effects result in only a marginal loss in non-agricultural sectors' performance.

The agricultural production losses are compensated somewhat by higher agricultural prices and the results show higher losses in urban income as against the rural income under climate change scenarios.

Table 3.6: Proportion of people across income groups under various climate change scenarios

Expenditure Class (Rupees)	Base Scenario	Climate change alone			Climate change with CO_2 fertilization effects		
		GFDL	GISS	UKMO	GFDL	GISS	UKMO
Rural							
Less than 216	0.091	0.169	0.177	0.191	0.118	0.124	0.135
Less than 336	0.092	0.114	0.117	0.120	0.100	0.102	0.106
Less than 516	0.143	0.140	0.142	0.143	0.143	0.145	0.149
Less than 900	0.261	0.241	0.239	0.237	0.257	0.258	0.257
More than 900	0.412	0.336	0.326	0.310	0.382	0.372	0.353
Urban							
Less than 216	0.004	0.013	0.014	0.015	0.007	0.007	0.008
Less than 336	0.030	0.058	0.060	0.065	0.040	0.042	0.047
Less than 516	0.111	0.137	0.140	0.146	0.124	0.127	0.134
Less than 900	0.304	0.290	0.291	0.293	0.304	0.305	0.307
More than 900	0.551	0.503	0.495	0.481	0.526	0.519	0.504

Note: The expenditure classes are defined in 1970-'71 prices. The figures correspond to the terminal period of the simulation.

The population distribution by levels of total consumption expenditure are shown in Table 3.6. The bottom two classes correspond to those below poverty line and the bottom most class shows the abject poor. We see that climate change increases the number of rural poor from 18.3 per cent to as much as 31.1 per cent. The abject poor increases by 10 percentage points in rural areas. The number of urban poor increases from 3.4 per cent to 8 per cent and abject poor by 1.0 percentage point. Even with carbon fertilization effect the number of rural and urban poor increases by as much as 6 and 2 percentage point respectively.

This means that climate change could increase the number of poor in India by more than 130 million persons in 2060. Indian agriculture and India's food security are highly vulnerable to climate change.

One should emphasize that Kumar and Parikh analysis has not fully accounted for many other threats to agriculture from climate change. Thus the damage due to land loss, irrigation capacity loss and higher incidence of draughts and floods have not been factored in.

References:

Aggarwal, P.K., Sinha, S.K. 1993. Effect of probable increase in carbon dioxide and temperature on wheat yields in India. Journal of Agricultural Meteorology 48, no. 5:811-814.

Cure, J.D. and Acock, B. 1986. Crop responses to carbon dioxide doubling : A literature survey. Agriculture and Forest Meteorology 38:127-145.

Fischer, G., Frohberg, K., Keyzer, M.A. and Parikh, K.S. 1988. Linked national models: A tool for international food policy analysis. Dordrecht: Kluwer Academic Publishing.

IPCC (2001), *Climate Change 2001: Impacts, Adaptation and Vulnerability Summary for Policy Makers and Technical Summary of the Working Group II Report*, UNEP, WMO,

Kumar, K.S.K. 1998. Modeling and analysis of climate change impacts on Indian agriculture. Unpublished Ph.D. dissertation. Mumbai: Indira Gandhi Institute of Development Research.

Kumar K. S.K., and Parikh Jyoti (2001), "Socio-Economic Impacts of Climate Change on Indian Agriculture" *International Review for Environmental Strategies*, Forthcoming.

Kumar, K.S.K. and Parikh, J. 2001. Indian agriculture and climate sensitivity. Global Environmental Change (forthcoming).

Lal, M., Singh, K.K., Rathor, L.S., Srinivasan, G., Saseendran, S.A. 1996. Vulnerability of rice and wheat yields in northwest India to future changes in climate. Technical Report No. A/TR/1-96, Centre for Atmospheric Sciences. New Delhi: Indian Institute of Technology.

Narayana, N.S.S., Parikh, K.S. and Srinivasan, T.N. 1991. Agriculture, growth and redistribution of income. New Delhi: North-Holland/Allied Publishers.

Rao, D.G. and Sinha, S.K. 1994. Impact of climate change on simulated wheat production in India. In Implications of climate change for international agriculture: Crop modeling study, edited by C.Rosenzweig and A. Iglesias. Washington D.C.: Environmental Protection Agency.

Rosenzweig, C. and Parry, M.L. 1994. Potential Impact of Climate Change on World Food Supply. Nature 367:133-138.

Saseendran, S.A., Singh, K.K., Rathore, L.S., Singh, S.V., Sinha, S.K. 2000. Effects of climate change on rice production in the tropical humid climate of Kerala, India. Climatic Change 44:495-514.

World Population Prospects. 1988. New York: United Nations.

4. Coastal impacts of climate change

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4.1 Basic characteristics

The coastal zone is an important and critical region for India, which is endowed with a coastline of over 7500 km. 3 of the 4 major Indian metropolitan areas are located in the coastal region (Mumbai, Kolkata and Chennai). The total area occupied by coastal districts is around 457000 sq. km, with an average population density of 425 persons / sq. km, which is almost twice the national average of 267. While the average decennial growth rate over the 1981 – 1991 period was similar for the coastal zone as compared to the country as a whole (26.4% vs 23.86%), this hides a significant asymmetry between the East and West coasts. According to the data from the 1991 census, there are 21 cities in the coastal zone with a population in the range of 100,00 – 500,000, 7 in the range from 500,000 – 8 million and two (Mumbai and Kolkata) with a population exceeding 10 million.

The Indian coastal zone exhibits a number of geomorphologic features, including shorelines with coastal cliffs, dune and beach ecosystems, mangroves, coastal wetlands and estuaries. Coastal cliffs are prominent in many locations, for example, Chilka Lake in Orissa, Tiruchendur and Nagercoil in Tamil Nadu; all on the East Coast, extensive parts of the shoreline south of Trivandrum, and the Konkan coast in Maharashtra; all on the West Coast.

India has an estimated total brackish water area of 1.2 million hectares (Mha). The maximum area is in West Bengal (0.4 Mha) with Gujarat (0.37 Mha) close behind. Andhra Pradesh, with 0.15 Mha, has a network of 172 brackish water bodies in 9 coastal districts. The brackish water areas are important for a variety of economic activities including aquaculture. However, the penetration of aquaculture is still somewhat low, as the total area under brackish water aquaculture in the country is only around 68,000 hectares.

4.2 Key climate-related issues in the coastal zone

The coastal zone is one of the most climate-sensitive regions, as it is subjected to a range of climate-related forcing drivers, including sea level change, local precipitation, ocean currents as well as local ecosystems. Future climate change is likely to be manifested through the worsening of some of the existing coastal zone issues. Therefore, some of the main issues in the context of the Indian coastline are discussed below:

Erosion: Gully erosion and the formation of badlands is developed to a high degree in the coastal zone round the Gulf of Cambay in the valleys of Tapti, Narmada, Mahe and Sabarmati, particularly north of the Narmada. Sheet wash of soil and sediments also occurs to be a marked degree in the region of the Western Ghats. A good deal of these sediments pass in to the sea and contribute to the building of the beaches and other shore features in the region of their discharge. Coastal erosion problem are also severe along the coastline of Central and North Kerala, and Southern Tamil Nadu. Erosion due to cyclonic storms takes place all along the coast.

Flooding: Coastal flooding is a problem in all the coastal states that experience tropical cyclone incidence – these include states on the East coast such as West Bengal, Orissa, Andhra Pradesh and Tamil Nadu, as well as Gujarat on the West coast. River flooding (i.e. temporary inundation of the coastal zone by river water) also occurs in coastal areas, estuary formations, deltaic areas of major rivers. This particularly happens in case of rivers Godavari, Krishna, Ganges, Mahanadi, Subernarekha, Cauvery, Tapi & Mahi.

Subsidence: Coastal subsidence is a serious problem in the Ganges – Brahmaputra delta in West Bengal, as well as regions in the Gujarat coast, such as Kathiawar and the Gulf of Cambay.

Ecosystems: The Indian coastline is richly endowed with a range of coastal ecosystems, including mangroves, salt marshes and other wetlands, lagoons, coral reefs, dunes and sand / mud flats. For example, lagoon formations like Chilka (Orissa), Pulicat (Tamil Nadu), Vembanad (Kerala), and near Tuticorin are well known. These are threatened by various activities related to industrial production (effluents), new construction (dredging) and sedimentation. Virtually all the rivers flowing into the Arabian Sea, including the Narmada, Mahi, Tapti, Sabarmati and others have extensive mud flats and salt marshes. Extensive mangrove forests are found in the Sunderbans, as well as the Orissa coast, North Andhra Pradesh coast, and Southern Gujarat. Many of these ecosystem regions are under severe pressure as a result of rapid development of the coastal zone. Climate change is likely to lead to further deterioration of the ecosystems.

Salinisation: Salinisation of agricultural land is commonly associated with tropical cyclone occurrence on the East Coast. Districts that are particularly affected include: Sundarbans, South 24 Parganas, Balasore, Puri, East & West Godavari, Krishna, Ongole and Nellore. Many coastal regions also suffer from longer-term saline intrusion into coastal aquifers and groundwater, including the coastal districts of Nellore and Prakasam in Andhra Pradesh, Northern Tamil Nadu and the Saurashtra region of Gujarat.

4.3 Sea level rise

Sea level rise at a particular location is the combination of global (or eustatic) sea level rise and local trends. In many coastal regions where subsidence or uplift are important, local factors can often dominate the global signal. Therefore, while assessing the impacts of sea level rise it is important to account for the long-term local sea level trends. Traditionally, observations of local (or relative) sea level are made using tide gauges, and there are around 24 stations on the Indian coast for which relative sea level data from tide gauges are available. Studies of historical rates of relative sea-level rise in the South Asia Seas region, reported by Gable and Aubrey (1990), indicate an average annual relative sea-level rise of 0.67 mm/yr. In addition, during the past half-century or so, relative sea-level changes in the region have ranged from a fall (i.e., land emergence) of 1.33 mm/yr to a rise (i.e., land submergence) of 2.27 mm/yr. Relative sea level trends as inferred from these tide gauges on the Indian East coast are summarized in Figure 1. These trends indicate a relative sea level rise throughout most of the coast, excepting in the South.

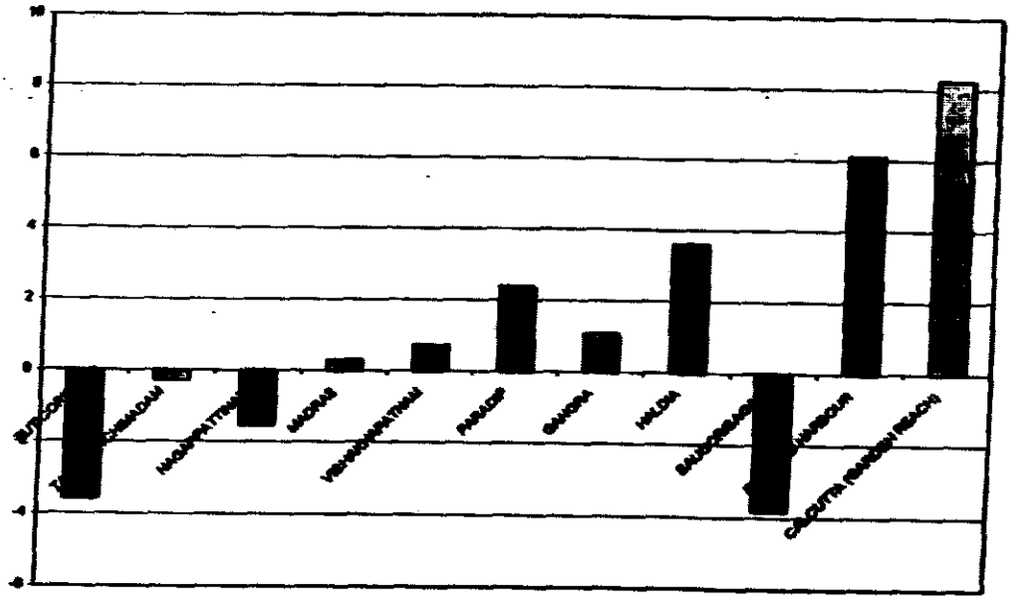


Figure 1: Relative sea level trends on the East coast (mm/year)

A variety of impacts are expected as a result of sea level rise. These include:

- Land loss and population displacement
- Increased flooding of low-lying coastal areas
- Agricultural impacts (e.g., loss of yield and employment) resulting from inundation, salinization, and land loss
- Impacts on coastal aquaculture

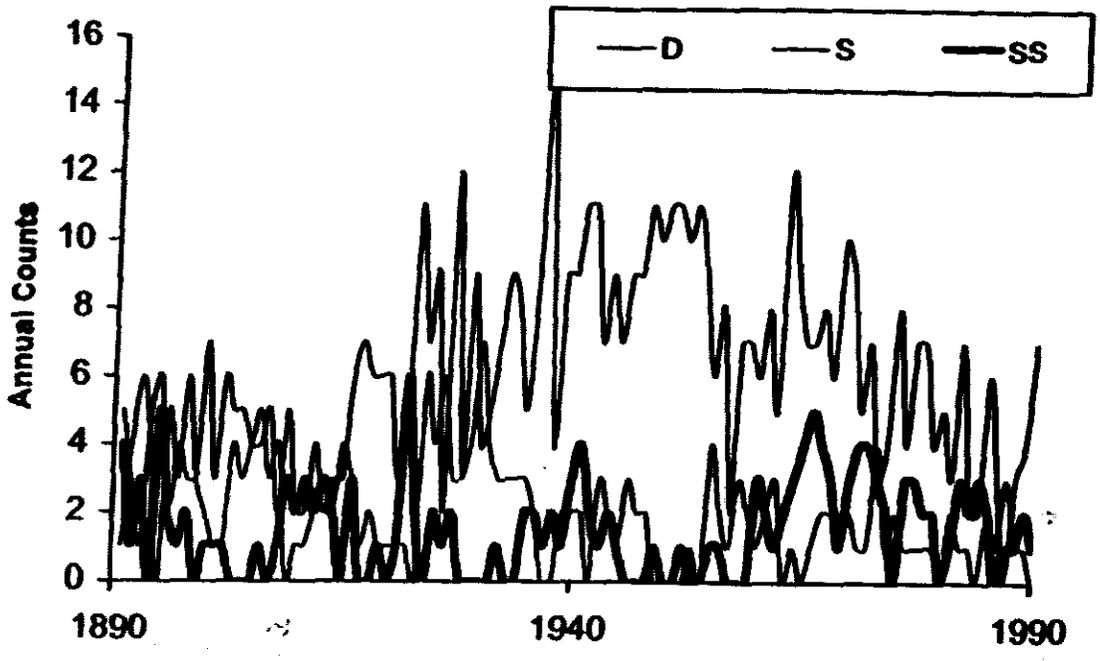
- Impacts on coastal tourism, particularly the erosion of sandy beaches.

The first of these impacts is considered the most serious for a number of regions in South Asia by Nicholls et al (1995). They estimate that a 1-meter rise in sea level could lead to a land loss of 6000 sq. km and displace over 7 million people in India. There have been a few other studies that have explored sea level rise impacts for India. One of the first studies was done by the Jawaharlal Nehru University (JNU, 1993), in which the consequences of a 1-meter sea level rise scenario were evaluated. The study concluded that, in the absence of protection, approximately seven million people would be displaced, and 5764 km^2 of land and 4200 km of roads would be lost. The dominant cost estimated was that due to the loss of land. Table 1 summarizes the results of the study. A subsequent study by the Tata Energy Research Institute (TERI, 1996) explored the relative vulnerabilities of different coastal regions, the effect of adaptive responses on the sea level rise impacts and the value of coastal protection for selected regions.

Table 1 Effect of 1-m sea-level rise (source: JNU, 1993)

	Coastal area (million hectares)			Population (million hectares)		
State/Union territory	**Total**	**Inundated**	**Percentage**	**Total**	**Affected**	**Percentage**
Andhra Pradesh	27.504	0.055	0.19	66.36	0.617	0.93
Goa	0.37	0.016	4.34	1.17	0.085	7.25
Gujarat	19.602	0.181	0.92	41.17	0.441	1.07
Karnataka	19.179	0.029	0.15	44.81	0.25	0.56
Kerala	3.886	0.012	0.3	29.08	0.454	1.56
Maharashtra	30.771	0.041	0.13	78.75	1.376	1.75
Orissa	15.571	0.048	0.31	31.51	0.555	1.76
Tamil Nadu	13.006	0.067	0.52	55.64	1.621	2.91
West Bengal	8.875	0.122	1.38	67.98	1.6	2.35
Union territory						
Andaman and Nicobar Islands	0.825	0.006	0.72	0	0	0
India	**139.594**	**0.571**	**0.41**	**416.74**	**7.1**	**1.68**

Figure 2: East coast storm incidence (1891-1990)



Tropical cyclones

Historical trends and impacts

Tropical cyclones are a key climate-related factor for determining the vulnerability of coastal regions. As was mentioned earlier, the Indian East coast is most susceptible to cyclone impacts. Figure 2 plots the incidence of depressions, cyclonic storms and severe cyclonic storms for the East coast. While there are no long term trends, there is significant variability on interannual and interdecadal time scales. In addition to temporal trends, spatial patterns of incidence are also important. While depressions are often concentrated around the West Bengal coastline, cyclonic storms and severe cyclonic storms are distributed more evenly throughout the East coast. However, it is important to note that the spatial distribution is not stationary – there are shifts in the spatial distribution on decadal time scales. This is quite significant in terms of coastal development – a region that has experienced a moderate storm climate in the past could experience a more severe storm climate in the future, and there may be a lack of adequate planning for this purpose. Similarly, while there is no significant relationship between the number of events and phenomenon such as ENSO, the spatial patterns of incidence appear to depend on the phase of the El Nino oscillation.

Assessment of vulnerability to cyclone hazard requires an evaluation not only of the hazard, but also the exposure to the hazard, coastal geomorphology and complementary factors such as sea level rise and the extent of adaptive capacity and adaptation potential in the region. A detailed examination of the vulnerability process is likely to yield a number of insights with regard to the impacts of future climate change.

Data for tropical cyclone impacts are quite scanty and scattered. Annual summaries are available in Mausam, however, there is considerable variation in terms of classifying and systematically reporting damage data. Mortality is one of the variables that is commonly report, and Figure 3 plots the variation in mortality for the last three decades. A slight increase in mortality may be seen. The actual consequences of cyclones are critically dependent on the exposure and on the overall adaptive capacity for the region. Figure 4 plots the mortality with storms affecting Andhra Pradesh, to give an indication of the possible advantages of building adaptive capacity and improving the overall developmental baseline of the region.

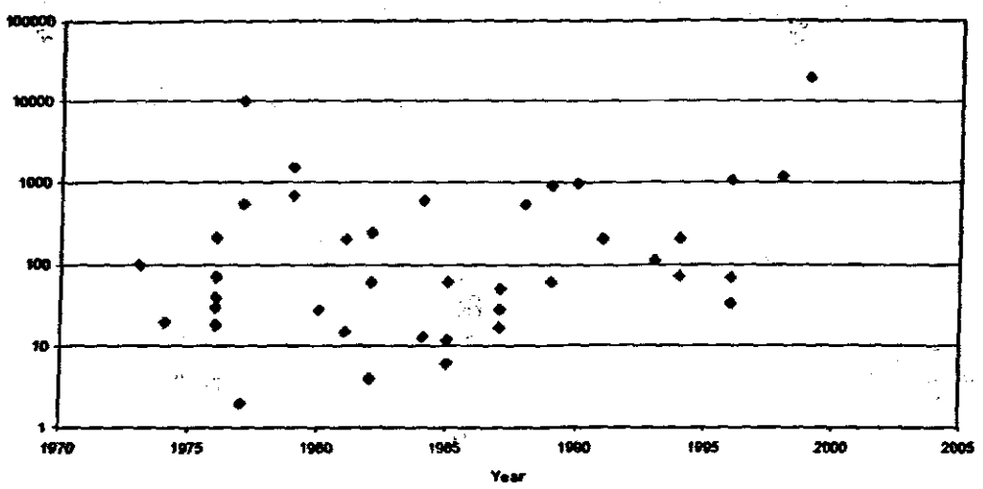


Figure 3: Tropical cyclone mortality (all-India)

Projections

Current atmosphere-ocean general circulation model (AOGCM) simulations have limited ability to suggest likely changes in tropical cyclone activity; until high-resolution GCM simulations are available, it is not possible to say whether the frequency, area of occurrence, time of occurrence, mean intensity, or maximum intensity of tropical cyclones will change in Tropical Asia. However, more recent studies with models of

higher resolution appear to be able to simulate tropical cyclone climatology (Bengtsson et al., 1995). Bengtsson et al. (1995) found a decrease in the number of tropical cyclones under enhanced greenhouse scenarios, especially in the Southern Hemisphere, although their geographical distribution remained unchanged.

A study by Holland (1997) indicated that tropical cyclones are unlikely to be more intense than the worst storms experienced under present-day climate conditions—although some potential exists for changes in cyclone intensity in tropical oceanic regions, where sea-surface temperature (SST) is betwen 26°C and 29°C. According to Henderson-Sellars and Zhang (1997), recent studies indicate that the maximum potential intensities of cyclones will remain the same or undergo a modest increase of up to 10–20%; they add that these predicted changes are small compared with observed natural variations and fall within the uncertainty range in current studies. Lal et al. (1995a), in their ECHAm^3-T106 experiment, found no significant change in the number and intensity of monsoon depressions in the Indian Ocean in a warmer climate. Similarly, likely changes in the ENSO phenomenon under enhanced greenhouse conditions and their possible impact on the interannual variability of the summer monsoon are not known.

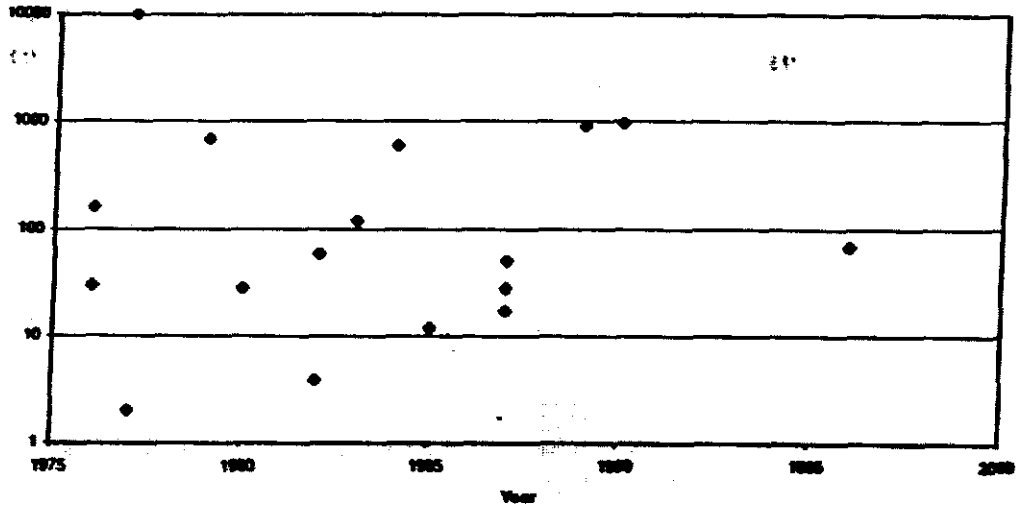


Figure 4: Tropical storm mortality (Andhra Pradesh)

5. Water Resources of India

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5.1 India's Vulnerability to Global Warming

The vulnerability of the Indian sub-continent to the impact of climate change is most relevant in the tropics, for the majority of people in India and its neighbouring countries depend on agriculture for their livelihoods and the agricultural production depends a great deal on the Asian Summer monsoon and its variability on a variety of time scales.

A study of the rainfall data from 25 meteorological sub-divisions of India for 81 years (1875-1955) did not reveal any major changes in rainfall, except the bulk of the rainfall over India shows a pattern similar to that of the annual rainfall. However analysis of revealed an increase in the mean annual surface temperature over India. The relative dominance of the increased concentrations of greenhouse gas, as a result emissions of ghgs from fossil fuel burning, deforestation and land use change in India, as in the rest of the world, may have contributed to the observed temperature trend. Based on atmospheric General Circulation Model projection, the best estimate of surface warming for the IPCC's B-a-U scenario is warming of 1 to 2^0C over the Southern Asian Region by the year 2030. The precipitation changes over South Asia are likely to increase throughout the region by 5 to 10% in Summer, while marginal changes are expected during winter. The projected largest warming of > 3.5^0C occurs over the north west particularly over Rajasthan and adjoining areas. Relatively uniform warming of approximately 2.5^0C occurs over both the Arabian Sea and the Bay of Bengal. The most pronounced greenhouse gas induced warming over the land mass of the Indian sub-continent is expected to be during the pre-monsoon season. The simulated changes in annual as well as seasonal surface temperature over the entire study area are found to be statistically significant at 95% confidence level.[8]

Vulnerability of Indian Coasts to Sea Level Rise (SLR) due to Greenhouse Gas induced Global Warming

[8] *Actual And Anticipated Changes In India's Climate : M.Lal Et Al In The Book Global Warming Ed. M. Lal, P117, Tata Mcgraw Hill, 1993.*

Global Warming is expected to meet the polar ice caps, and land ice and glaciers and increase water-level in the oceans. In addition warming of the sea water due to global warming will also add to the sea level rise due to thermal expansion.

India has a long coastline - the total length of the coastline of the India maintained is 5700 km (from the Sunderbans in West Bengal to Rann of Kutch in Gujarat) - however with the coastlines of Lakshadweep and Minicoy and the Andaman and Nicobar Group of Islands are taken into account, the total Indian coastline comes to over 7510 km.

Some studies conducted recently,[9,10] reveals that most of the coasts in India are vulnerable to sea level rise due to climate change - the very high risk coastal zones are along the deltaic areas of West Bengal, Orissa coasts, and Gujarat coasts. The coasts along the eastern and western ghats near Vishakapatnam and Bombay respectively are projected to be least vulnerable to sea level rise. The population density along the coasts is very high (Table 5.1). This will mean that a large population will be vulnerable to SLR due to global warming, requiring rehabilitation and resettlement (R & R).

TABLE 5.1: POPULATION DENSITY IN THE DIFFERENT COASTAL BELTS IN INDIA

STATE	NO. OF POPULATION / KM^2
WEST BENGAL	616
ORISSA	165
ANDHRA PRADESH	196
TAMIL PRADESH	372
A & N ISLANDS	23
KERALA	655
KARNATAKA	194
MAHARASHTRA	2040
GUJARAT	174
LAKSHADWEEP	1258
PONDICHERRY	1229

The projected vulnerability of the Indian coasts to SLR is considerable causing inundation of low lying coastal areas, accentuated by storm surges, intrusion of saline water into the coastal groundwater aquifers and loss of ecologically fragile and important mangroves and wet lands. Sea Level Rise will not only displace people, disrupt the

[9] *Impact of Rising Sea Level along the Indian Coastline : M Bandyopadhyay in the book "Global Warming" Ed. M. Lal, p 153, Tata Mcgraw Hill, 1993.*

[10] *Sea Level and Climate Fluctuation during the Quaternary Period : V. Asthana & Pawan k. Srivastava in the book "Global Warming" E. M. Lal, p 136, Tata Mcgraw Hill, 1993.*

coastal economy and demolish coastal eco systems but also make the entire area vulnerable to water resources particularly for drinking and agricultural purposes. Adaptation to sea level rise by constructing dykes to prevent sea to inundate coastal areas is beyond the means of the poor communities. In the Indian situation, the communities are to be provided with facilities for increasing their resilience to cope with such disasters : Some of the ways to increase coping capacity of the community through sustainable livelihood practices such as "Grameen Banks" and "Entrepreneurship" that increase community resilience to adverse impacts like floods, droughts, cyclones and other natural calamities.

Water is essential for human civilisation, living organisms, and natural habitat. It is used for drinking, cleaning, agriculture, transportation, industry, recreation, and animal husbandry, producing electricity for domestic, industrial and commercial use. Due to its multiple benefits and the problems created by its excesses, shortages and quality deterioration, water as a resource requires special attention. Table 5.2 gives land & water resources of India. On a global scale, total quantity of water available is about 1600 million cubic km. The hydrologic cycle moves enormous quantity of water around the globe. However, much of the world's water has little potential for human use because 97.5% of all water on earth is saline water. Out of the remaining 2.5% freshwater, most of which lies deep and frozen in Antarctica and Greenland, only about 0.26% fish in rivers, lakes and in the soils and shallow aquifiers which are readily usable for mankind.

TABLE – 5.2 : LAND AND WATER RESOURCES OF INDIA[11]

PARTICULARS	QUANTITY
Geographical Area	*329 million ha.*
Flood Prone Area	*40 million ha.*
Ultimate Irrigation Potential	*140 million ha.*
Total Cultivable Land Area	*184 million ha.*
Net Irrigated Area	*50 million ha.*
Natural Runoff (Surface Water and Ground Water)	*1869 Cubic km.*
Estimated Utilisable Surface Water Potential	*690 Cubic km.*
Groundwater Resource	*432 Cubic km.*
Available Groundwater resource for Irrigation	*361 Cubic km.*
Net Utilisable Groundwater esource for irrigation	*325 Cubic km.*

Source: National Institute of Hydrology

[11] *Water Resource India, National Institute of Hydrology. Website : www.nih.ernet.in*

5.2 Water Resources[12]

Surface Water

India's average annual surface run-off generated by rainfall and snowmelt is estimated to be about 1869 billion cubic meter (BCM). However, it is estimated that only about 690 BCM or 37 per cent of the surface water resources can actually be mobilised. This is because (i) over 90 per cent of the annual flow of the Himalayas rivers occur over a four month period and (ii) potential to capture such resources is complicated by limited suitable storage reservoir sites.

Rainfall

The average annual rainfall in India is about 1170 mm. This is considerable variation in rain both temporarily and spatially. Most rain falls in the monsoon season (June-September), necessitating the creation of large storages for maximum utilisation of the surface run-off. Within any given year, it is possible to have both situations of drought and of floods in the same region. Regional varieties are also extreme, ranging from a low value of 100 mm in Western Rajasthan to over 11,000 mm in Meghalaya in North-Eastern India. Possible changes in rainfall patterns in the coming decade, global warming and climate change and other predicted or observed long-term trends on water availability could affect India's water resources.

Ground Water

India's rechargeable annual groundwater potential has been assessed at around 431 BCM in aggregate terms. On an all India basis it is estimated that about 30 per cent of the groundwater potential has been tapped for irrigation and domestic use. The regional situation is very much different and large parts of India have already exploited almost all of their dynamic recharge. Haryana and Punjab have exploited about 94 per cent of their groundwater resources. Areas with depleting groundwater tables are found in Rajasthan, Gujarat, most of western Uttar Pradesh and in all of the Deccan states.

Occurrence of water availability at about 1000 cubic meters per capita per annum is a commonly threshold for water indicating scarcity (UNDP). Investment to capture additional surface run-off will become increasingly more difficult and expensive in the future. Over time, both for surface and groundwater resources, a situation where resources were substantially under utilised and where considerable development potential existed, has transformed in little more than a generation to a situation of water scarcity and limited development options.

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[12] *Initiating and Sustaining Water Sector Reforms : A Synthesis World Bank in collaboration with the Government of India, Ministry of Water Resource.*

India faces an increasingly urgent situation : its finite and fragile water resources are stressed and depleting while various sectoral demands are growing rapidly. Historically relatively plentiful water resources have been primarily for irrigated agriculture, but with the growth of Indian economy and industrial activities water demands share of water is changing rapidly. In addition increase in population and rapid urbanisation also put an additional demand on water resources. Summing up the various sectoral projection reveals a total annual demand for water increasing from 552 billion cubic meter (BCM) in 1997 to 1050 BCM by 2025 (Fig 5.1).

Under current sectoral trends, precious little water will remain for environmental and other needs. This is untenable

At Independence population was less than 400 million and per capita water availability over 5000 cubic meter per year (m^3/yr). With the population crossed 1 billion mark, water availability has fallen to about 2000m^3/yr per capita. By the year 2025 per capita availability is projected at only 1500 m^3/yr or 30% of availability levels at Independence.

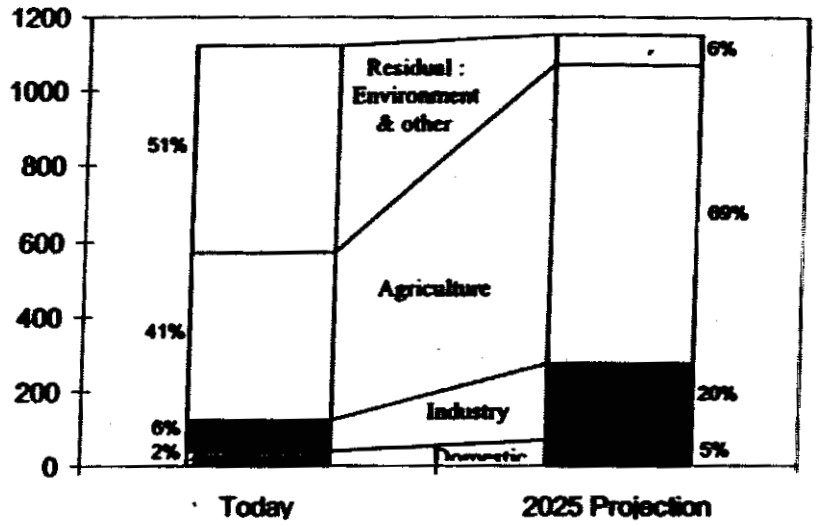

Figure 5.1 : Sectoral Water Demand Trends

Note : Government projections; Increasing sectoral demands planned to be met through new construction.
Source : GOI (1997d).

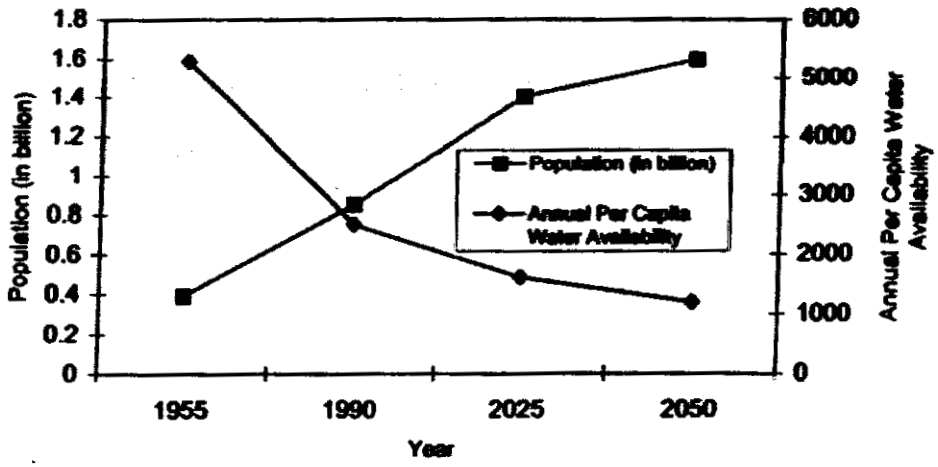

Figure 5.2 : Population and Water Availability Trends in India

Sources : Population Action International, 1995; World Bank, 1997a.

The water availability index includes surface water only, yet groundwater is an important component of water availability that factors significantly in the Indian economy. Ground water is an important source of drinking water and food security for India, supplying about 80 per cent of water for domestic use in rural areas and about 50 per cent of water for urban and industrial uses. Ground water provides a very significant percentage of water supply for irrigation, and contributed significantly to India's agricultural and overall economic development. With more than 17 million energised wells nationwide, groundwater now supplies more than 50 per cent of irrigated area.

5.3 Populations Food Grain Requirement

In India the food grain availability is at present **around 525 gms per capita per day whereas the corresponding figures** in China & USA are 980 gms and 2850 gms respectively. If small raise is made in per capita consumption to 650 gms the food grain requirement will be about 390 MT of food grain. Taking the projections of about 1800 million by 2050 AD as reasonable, it would require about 430 MT of food grain annually at the present level of consumption. This will mean a much greater use of available inputs. First input is water, the second input would be fertilizers and third input would be much larger emphasis of research. This would also need increasing area under irrigation from present 28% to roughly 40% by the year 2050 and adopting drip and sprinkler irrigation in India.

The total geographical area of land in India is 329 mha which is 2.45% of the global land area. The total arable land is 165.3 mha which is about 50.2% of total georgraphical area against the corresponding global figure of 10.2%. India possesses 4% of the total average run off in the rivers of the world. The per capita water availability of natural run off is at least 1100 cu.m per year.

Water availability of both surface and groundwater is further reduced due to water pollution and in appropriate waste disposal practices. There are now few states or river basins in India where water quality issues are not present. Environmental problems include water quality degradation from agro-chemicals, industrial and domestic pollution, groundwater depletion, water-logging, soil salinization, siltation, degradation of wetlands, ecosystem impacts and various health related problems. Though India is facing various serious water constraints to-day, India is not on the whole a water scarce country. The present per capita availability of water in India of approximately 2200 m^3 per annum, actually compares quite favourably with a number of other countries.

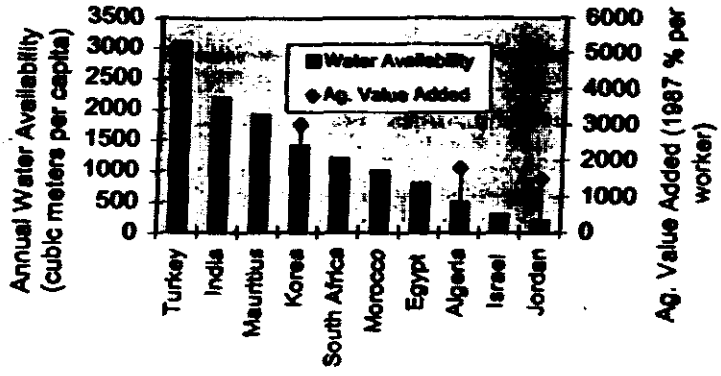

Figure 5.3 : Water Availability and Agricultural Value Added - Selected Countries

Note : Israel Ag. Value Added not available.
Sources : World Resources Institute (1997) and World Bank (1998).

5.4 Policies

Current water resource constraints in India, in terms of both quality and quantity, can be expected to manifest themselves even more rapidly in the coming years. In the past, with lower population and development levels, there was still substantial room for each sector to satisfy its water needs and concerns independently. Now as the gap between the availability of water resources and the demands on such resources narrows, the past approach to water management pursued in India is no longer tenable. Competition for water between urban and agricultural sectors will be a major challenge in the forthcoming century. Provision for environmental and ecological concerns will have to be made.

Water should be treated as both a Social and Economic Ground

Water management in India in future must shift its emphasis from social good as at present to economic good, and use of market mechanisms with the participation of the business sector. Such a change will achieve a more efficient and effective allocation, use and management of water, and their roles of both public and private sectors in managing water resources must be defined.

Decentralisation of operation will be critical

Achieving sustainable use and management of water in India will further require a shift from the traditional top down centralised approach towards a more decentralised approach. While government has an important role to play, it is only one among many stakeholders involved. These stakeholders include Government of India, State

Government, every household in India as a consumer of water, business sector, industries, larger community aggregates such as water uses association, villages.

Policy, Legislative and Regulatory Framework

The Central Government plays an important role in framing policy guidelines, legislative and regulatory framework. The most comprehensive Government of India (GoI) statement on water is the National Water Policy (NWP) adopted by the National Water Resources Council in 1987, which calls for a holistic, and integrated basin-oriented approach to water development, promoting combined use of both the surface and groundwater, water conserving crop patterns as well as irrigation and production technologies. The National Water Policy in its present form appears to be a statement of intentions as it is not supported by any legislation and does not have an action. The NWP is undergoing revision.

Water Sharing Issues

The existing Constitutional provisions and legislation in India do not provide an appropriate framework to deal with water sharing issues between states, sectors and individuals. In the present set up (i) primary powers are vested at state levels which do not correspond to river basin boundaries; (ii) surface water rights are not clearly defined and such rights cannot be commercially transferred; (iii) ground water rights are purely private, and; (iv) environmental laws have not been comprehensively operationalised and regularly standards are either not enforced or do not exist.

The legal and absolute right to groundwater rests with the owner of the overlying land, irrespective of the social and environmental consequences.

Institutional Arrangements and Mechanisms

The present institutional arrangements in India, including central, state and local institutions, and both formal and informal structures, do not enable comprehensive water allocation, planning and management. The main problems that exist are : (i) inadequacies in necessary institutions for comprehensive water allocation, planning and management, particularly at state and basin levels where they are frequently absent; (ii) lack of co-ordination between institutions, duplication of responsibility and accountability gaps; (iii) inadequate fostering of grass-roots institution; and (iv) lack of involvement of civil society - local communities, NGOs, the business sector and academia.

Mechanism for **conflict resolutions** in matters of sharing of water resources and utilisation is weak and needs to be looked into and strengthened at various levels.

In the matters of water resources management the civil society has a very crucial role to play but unfortunately their contribution, and the contribution of the business sector has been greatly neglected. A substantial reason for their limited involvement to date is the limited efforts of government to inform the public on issues pertaining to water resources. In particular, outreach to women has been neglected, yet women are the most interested and involved in rural water supply, domestic urban water consumption, health and sanitation issues and are at least equally concerned as men in agricultural production.

Water Sector Investment

Being a vital resource for the lives and livelihoods of all Indian citizens, and having contributed significantly to India's economic growth since independence, water sector investments have rightly been accorded high priority in India's development plans.

With a massive resource commitment for irrigation since independence of Rs. 576 billion the gross irrigated area increased four-fold from 23 million hectares in 1951 to about 90 million ha in 1997, substantially increasing and stabilising the incomes of millions of farmers throughout the country. Significant achievements in drinking water coverage have also been realised. About 85 per cent of India's urban population have access to public water supplies and over 75 per cent of the rural population are now provided with public water supply. It may be mentioned here that more than 1000 million of people in India, about 70% live in the rural areas.

In all the sectors however there is a considerable scope for conserving water resources. Such conservation can be a reality if the subsidies in water pricing is gradually removed, particularly in the agricultural sector.

Reforms in the Water Sector

Various reforms in the management of water resources are necessary but by its nature water is multidimensional - it involves users from different sectors with widely different needs. India's task is made all the more difficult by its enormous population and its federal administrative structure.

The role of government needs to be more of a facilitation from a provider and financier of services, and an enabling environment to be put in place for the different stakeholders to play their role, with necessary incentive framework.

As the reform programme is implemented a long-term vision needs to be conceived through a public debate and participatory process.

References

1. Website: www.nih.ernet.in; National Institute of Hydrology

2. Initiating and Sustaining Water Sector Reform: A Synthesis; World Bank in Collaboration with the Govt. of India, Ministry of Water Resources. Allied Publishers, 1999.

6. Community Level Case Studies on Vulnerability and Adaptation to Global Warming

6.1 Community level case studies on Water Harvesting to cope with extreme climate events like drought in various drought prone areas in India

In India community level water harvesting efforts in regions vulnerable to droughts / severe droughts due to lack of adequate rainfall and infrastructure for storage of rainwater during the rainy season has made the water harvesting process a very powerful technology for an effective adaptation at the community level to cope with such natural disaster which may be exacerbated due to human induced climate change. Though adequacy of rainfall is a very important factor to consider in discussing impacts of droughts, but it is important to remember that it does not matter how much rain a place gets, if there is no infrastructure to capture rain water, the place will still to short of water. It is unbelievable that Cherrapunji which gets 11,000 mm annual rainfalls still have serious drinking water shortages. The CSE Report titled "Making Water Everybody's Business" assert that every village in India that can meet the basic drinking and cooking needs through community level activities including rain water harvesting. The community-based case studies that have been reported in this chapter are primarily based on material taken from the published literature (Making Water Everybody's Business - edited by Anil Agarwal etal) and media reports.

6.2 Community Level Case Studies : Western Coastal Plains

Out of the total of about 18,500 villages in Gujarat, at least 12,000 - 18,000 villages can be categorised as 'no source' villages. 'No source' villages ate those who do not have dependable source of drinking water. A number of problems like salinity, sea water incursion, high fluoride content and depletion of ground water sources lead to severe drinking water shortage. The State Government response has been to introduce usual solutions such as utilising groundwater sources, constructing large irrigation dams, and introducing piped water supply and tanker services during the dry season when water availability is under stress. These solutions however did not take into account specific problems of individual areas, and were not therefore very successful.

Large areas along the coastal parts of **Dhandhuka block** (in Ahmedabad district) used to be thickly covered with mangroves and piloo trees till about 30 - 40 years ago. But with increasing water scarcity and environmental degradation local people have been forced to migrate. Introduction of piped water supply raised hopes about quality water becoming easily available and in sufficient quantity. But both the quality and the quantity of water fell short of the expectations of the community.

Local communities took initiatives to find better solution to the chronic drinking water shortages. Local communities in villages Rajpur, Mingalpur, Mahadevpura and Khun villages of Dhandhulka block were quite divided among men and women on the foremost reason for migration of people from the area - men cited the 'unproductive saline wasteland' as the main reasons, on the other hand women insisted that the severe drinking water problem as the foremost reason for all difficulties in the area. The local communities were of the view that the water resources must be augmented at common property by desilting existing ponds and building new ones for drinking purposes to benefit the whole village. Villagers suggested the use of some sort of lining material on the bed and inner walls of new ponds to prevent salinity seepage from below and of the harvested rainwater in the pond.

Villagers contributed both in terms of labour and other resources. Success of the project inspired villagers to putforth new proposals to Gujarat Water Supply and Sewerage Board (GWSSB) for obtaining support for such ponds, sowing the seeds of a long-battle. The demonstration of lined ponds in these villages has resulted in the setting up of a Samiti, a people's organisation comprising villagers from various village organisations who help in promoting such ponds. Some 50 percent of the 94 members were women.

6.2 Community Level Case Study : In Alwar district of Rajasthan

Communities from 650 villages took the initiatives to rejuvenate about 3000 traditional water harvesting structures (TWHS) called 'Johads'. Johads are small earthen check dams that capture and conserve rainwater, improving percolation and groundwater recharge. The results have been spectacular - rising groundwater level by six meters and increasing forest cover by 33 percent. The most spectacular effect has been on the five rivers that used to go dry immediately following the monsoon - have now become perennial.

For every Rs. 100 invested in Johads, the agricultural production has risen by Rs. 400 per capita per annum, income of the rural population has increased annual migration of the male population to cities in search of livelihood practically stopped and the people are in a position to address issues like health and education. At the core of this success lies the emergence and proper functioning of popular and local institutions like the gram sabha at village levels.

This is another example how a community level effort can tackle problem like water scarcity / drought and ecological degradation, to bring back water in their rivers, forests cover that had completely disappeared.

These community level activities was inspired by an Alwar based organisation called Tarun Bharat Sangh (TBS).

In rejuvenating about 8000 traditional water harvesting structures no qualified engineers were involved.

All the construction work-right from planning, site selection, design and execution of about 3000 Johads was undertaken by the villagers themselves, and most assuring fact is that all the structures are working fine, and none collapsed.

6.3 Community Level Case Study : In the Central Highlands of Bundelkhand Region

Bundelkhand region comprising seven districts of Lalitpur, Jhansi, Jalaun, Hamirpur, Mahoba, Banda, Shahiinagar in Uttar Pradesh and six districts of Datiya, Tikamgarh, Chattarpur, Panna, Sagar and Damoh in Madhya Pradesh. Poverty, illiteracy, unproductive agriculture and an acute lack of infrastructure are the main issues that the development processes in the region must address on a priority basis. Environment degradation is increasing with soil erosion and widespread deforestation.

This region receives an average rainfall of only 750 mm annually. Traditionally, groundwater resources in Bundelkhand are meager due to the presence of hardrocks like gnesis and granite. Availability of water in the Bundelkhand region varies from season to season. In this region agriculture is highly dependent on rainfall and only 20% of the total area under agricultural activity is irrigated.

Against this backdrop, Development Alternatives (DA) with the active participation of the local communities, and in close consultation with the district administration of Tikamgarh has surveyed villages of Niwari Block which were facing acute drinking water problems. Five villages were selected for interventions. The main objectives of the intervention were[13, 14] :

- to provide adequate quantity of drinking water for these villages
- to increase availability of ground and surface irrigation in the area by constructing innovative water harvesting structures by constructing Check Dams

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[13] *Water Management Practices for Bundelkhand : Water for life : Air Vice Marshal S. Sahni (Retd.), DA N.L. March 1997.*

[14] *Check Dam - A Tool for Sustainable Development : Sanjay Vashist, DA N.L. April 2001.*

[**Check Dams.** There are small barriers built across the direction of water flow on shallow rivers and streams for the purpose of water harvesting. The small dams retain excess water flow during monsoon rains].

- upgradation of wells and handpumps to minimise / eliminate stagnant water in close proximity of wells and hand pumps
- to increase drinking water availability in these villages

With these objective two check dams were constructed across the Gurari river in the area. These water harvesting structures created opportunities for the community to raise their income by increased agricultural outputs, and the awareness of the community on the benefits of safe drinking water and sanitation around the wells and handpumps.

The project resulted in improving the quality of life of the villagers by providing them with the scarce resource - water. The check dams on the Gurari river have resulted in recharging the groundwater supply within a radius of 2-3 km around the structures with the result that farmers can now take up at least two crops a year from only one crop earlier. The water reservoir also made available adequate water for lift irrigation to cater for 300-400 ha of crop land.

6.4 Community Level Case Study in Decan Plateau : Anantapur District, Rayala Seema Region, Andhra Pradesh[15]

Out of the eight districts declared as drought - prone in Andhra Pradesh, the four districts of Kurnool, Ananthapur, Cuddapah an Chittor with a population 110 lakh, comprise the Rayalseema region. Located in the rain shadowzone, Rayalseema has been facing droughts almost every alternate year for nearly a century. About 50 per cent of the average rainfall 550 mm are received over only 5-7 days and the number of rainy days with 25mm and above are less than 10. Nearly 75 per cent of the population is engaged in agriculture despite inadequacy of rainfall coupled with infertile land and poor moisture retention capacity of the soil. The only rivers are Pennar, originating in the Nandi Hills of Karnataka, and Chitravathi. The rainfall in the district is meagre, untimely and erratic and the entire area is drought prone.

To deal with the situation, local communities in the district had devised traditional water harvesting systems to meet drinking water needs, and to a certain extent irrigation needs. These include water harvesting systems in the district community tanks (1091), spring channels (1221), river channels (243) and wells (58,483) in the district as **collective property**. This community activities have greatly improved the water availability in the region and improved their economic level.

[15] *In Harmony with Nature : Koda Ramakrishna Reddy, Srikrishnadeva Ray University, Ananthapur in "Making Water Everybody's Business", Eds : Anil Agarwal, Sunita Narain and Indira Khurana, March 2001.*

6.5 Community Level Case Study in the Eastern Ghat Region : Saora Hills of Orissa

Saoras one of the oldest tribes in India, harvest rainwater to turn stream beds into paddy fields and thus an inhospitable environment into a habitable one. The Saoras who live in the Saora hills of Orissa practice terraced paddy cultivation. Conservation of rainwater and improvement of water regime in hill slopes are the main objectives of terracing. Using stone-packed contour bunding, saoras layout small terraced fields on the hilly slopes and grows paddy. By means of water channels they regulate water flow from natural hill streams and irrigate the terraced fields. As flow irrigation is not possible in an undulating topography, the runoff water is stopped at different levels and allowed to soak deep into the soil. This results in availability of adequate moisture at root levels, which helps in better crop production.

6.6 Community Level Case Studies in the Central Highlands : Jhabua District, Madhya Pradesh

Jhabua is an upland region of western Madhya Pradesh. Once a heavily forested area, Jhabua lost its natural wealth over the last 45-50 years. Almost 80 percent of its forest is severely degraded. The reasons are all man made - unauthorised clearing of forests by contractors for agricultural activities and population pressure. As the uplands were used for cultivation without terracing, the humus and fertile layer of soil was lost and soil erosion accelerated. Free grazing further accelerated the vegetative cover. The district was dotted with rock exposed hillocks. The intensive cultivation on uplands led to an ecological disaster, resulting in loss of land productivity, decline in employment opportunities and distress out migration of people.

The situation changed in the mid - 1990s, when the Madhya Pradesh government launched the Rajiv Gandhi water shed Development project (RGMWD) in October 1994. A decentralised and time bound mission, it started with the objective of improving 1.2 million hectares (mha) of land and several watersheds by the year 2000. It envisaged greening more than 2.9 mha - approximately one percent of the country's total land area - spanning 6,691 villages through 5024 watersheds.

The Madhya Pradesh government is now looking a mid-course strategy shift. The strategy is to build a community based water security system that would be controlled and monitored by the village level Paani Roko Samities. Under the system it is envisaged to create 8-10 lakh water harvesting structures and at least 25,000 water tanks in the villages. In the Kallipara Panchayat of Jhabua block the village community through its initiative constructed 613 check dams. They have also completed the task of recharging a large number of handpumps by constructing the recharging pits. The villages in most of

the villages are now very happy that hand-pumps installed in their villages after March 2001 are in working condition. In most of the villages water table has gone up.[16]

Combining the principles of Joint Forest Management (JFM) and watershed treatment was a new approach that was adopted in Jhabua and helped in the formation of 20 village forest committees, the executive body used JFM that protects forests with the help of the forest department. Of Jhabua's total forest area, 60 percent (100,950 ha) is now under JFM and the 344 village committees cover 420 villages.

Management of watershed development finances in Jhabua District

The total government expenditure till min 1998 for watershed development was 16.48 crore. Of the Rs. 16.48 crore, Rs. 4.53 crore (about 30 percent) was spent by the project implementation agencies, out of which a substantial amount was spent (about 60 percent) to build up the credibility particularly of the community organisation, for their training and capacity building to build institutions and social mobilisation at the village level.

A saving scheme programme encourages villagers to save a part of their wages as a Watershed Development Fund (WDF), for future use for the management of the watershed. This is a mandatory fund developed through contribution from all the users groups who are land owning people. Self-help groups (groups of landless people) do not normally contribute to this fund. The fund is entirely controlled by the community, and neither the panchayat not the officials of the rural development have any control over it. Savings are also encouraged through a village fund for use by the villages for collective activities of the communities and a women's thrifts and credit fund which women can use to help each other with soft loans. The watershed management programme, thus not only helped in improving the local ecology, but also in an improvement of the collective and individual financial security of the local communities and improved their coping capacity with drought and other natural calamities.

6.7 Community Level Case Study in Western Coastal Plains : Saurastra

Gujarat faces severe water shortage every year. The potential for surface irrigation being particularly low in the Saurastra region of Gujarat, harvesting rainwater through recharge wells is providing welcome relief. Over the years, ground water has been excessively extracted leading to large scale salinisation of coastline due to the incursion of sea water. Drop in groundwater in North Gujarat is also increasing fluoride concentrations, a serious health hazard. About 78 percent of the total irrigated area in Gujarat is served by wells alone which has caused severe groundwater depletion. In view of this harvesting of rainwater becomes a necessity.

[16] *M.P. Focus on Water Conservation : Lalit Shastri, The Hindu, June 19, 2001*

The farmers in the region felt the need for more check dams to store river water during rainfall, and the existing but unused / failed wells may be utilised for staring rainwater. Further the farmers suggested that village level committees be formed to develop programmes for recharging both private and public wells and handpumps and construct check dams and percolation wells on river beds. An effective information centre to assist farmers in water harvesting and management techniques in co-odination with government and non-governmental organisation were also envisaged.

The case study made it clear that well recharging activity is becoming popular in Saurastra, per capita and household water consumption are increasing with better availability of water resources.

Farmers are already optimising yields by using stored water during poor monsoon or failure of monsoon. This has increased their per capita income as evinced by increased use of fertilisers and pesticides.

6.8 conclusion

a) The present study and analysis have clearly brought out that developing countries like India are most vulnerable to the impacts of climate change due to resource constraints, lack of capacity and adequate funds. This vulnerability is further exacerbated due to large-scale poverty in these countries.

b) The case studies bring out the efficacy of community level responses to address to acute water scarcity. The community level responses can be channelised and further strengthened, by creating an enabling environment in the country / society by developing sustainable livelihood practices and entrepreneurships among the people and society. Such practices will not only increase the capacity of community to cope up and increase their resilience to such natural calamities like droughts, floods, cyclones etc., but will check migration of people to other states / regions.

c) The traditional community level practices to cope with situation like droughts in water scarcity / drought prone areas / region can be integrated into Government Policies and Responses to cope with such calamities and for adaptation to hydrological resources in India.

d) Such community level efforts must be encouraged by governments to start activities like Grameen Bank / Co-operative Banks on a co-operative basis by all the stakeholder. Such a mechanisms can provide small loans to the affected communities to enable them to cope with the adverse situations. Such a mechanism will also help in community based adaptations to water resources in water scarcity areas. The Co-operative Banks initiated from small contributions from communities increases the community resilience to face such climatic vagaries and extreme weather events.

e) Technological responses to adapt to climate change is most suitable for rich countries. Such adaptations in developing countries however may face technology, transfer barrier, financial barrier, and capacity building barrier. Solutions to such barriers must be put in place in developing countries before adopting technological options to adapt to climate change. Such solutions must be found from a participatory process among the communities and not transplanted from other countries / regions.

References

1. Intergovernmental Panel on Climate Change (IPCC), Second Assessment Report on the Impacts, Adaptation and Mitigation of Climate Change, WMO / UNEP, 1995

2. Climate Change Science : An Analysis of Some Key Question, National Research Council, National Academy of Science, Washington, D.C,2001

3. Actual And Anticipated Changes In India's Climate : M.Lal Et Al In The Book Global Warming Ed. M. Lal, P117, Tata Mcgraw Hill, 1993.

4. Impact of Rising Sea Level along the Indian Coastline : M Bandyopadhyay in the book "Global Warming" Ed. M. Lal, p 153, Tata Mcgraw Hill, 1993.

5. Sea Level and Climate Fluctuation during the Quaternary Period : V. Asthana & Pawan k. Srivastava in the book "Global Warming" E. M. Lal, p 136, Tata Mcgraw Hill, 1993.

6. Vulnerability and Adaptation Assessments : An International Handbook : Ed. by Ron Benioff, Sandra Gull and Jeffrey Lee, Kluwer Academic Publishers, April 1996

7. Vulnerability and Adaptation to Climate Change in Latin America, Ed. Cecilia Ranns Mane, C.R. Special, Vol. 9, Nos. 15211992

8. Water Management Practices for Bundelkhand : Water for life : Air Vice Marshal S. Sahni (Retd.), DA N.L. March 1997.

9. Check Dam - A Tool for Sustainable Development : Sanjay Vashist, DA N.L. April 2001.

10. In Harmony with Nature : Koda Ramakrishna Reddy, Srikrishnadeva Ray University, Ananthapur in "Making Water Everybody's Business", Eds : Anil Agarwal, Sunita Narain and Indira Khurana, March 2001.

11. M.P. Focus on Water Conservation : Lalit Shastri, The Hindu, June 19, 2001

7. Summary, Conclusion and Policy Recommendations

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The consensus of scientific community is that the available observational evidence indicates that regional changes in climate, particularly increases in temperature, have already affected a diverse set of physical and biological systems in many parts of the world. Many human systems are sensitive to climate change. The impact of climate change or these systems can have a severe adverse impact on human well-being in India. Thus it is important to assess India's vulnerability.

India may be particularly vulnerable to climate change as a poor and tropical sub-tropical country, highly dependent on weather for its agricultural output. For India, its freshwater systems, rainfall, rivers and groundwater are critical for its agriculture and food security. Disruptions, draughts and floods induced by climate change can cause great hardship and impose large costs. Similarly, the large coastline of India, millions who live near the sea and depend on coastal ecosystems for their livelihood may also be highly vulnerable to climate change.

A review of climate variability in India over nearly 120 years shows that there were 19 flood and 21 drought years. Excepting extreme events like earthquakes or cyclones, floods are the most important cause of mortality. Any increase in the frequency of floods thus increases vulnerability.

The economic costs of damage due to flood is rising steeply, mainly due to greater exposure. In future because of the much higher population with India's land scarcity, the damages could be much larger. Vulnerability would be high.

It is also noticed that mortality due to heat spells is increasing. This, however, depends on the nutritional status of the population.

It is expected that annual average surface air temperature will increase in 2050 by 2.7°C. Increase in winter would be higher at 3.25°C. Annual average precipitation will increase by 6.6 per cent. When effects of sulphate aerosols are accounted for annual average temperature increase will be lower by 1.9°C but rainfall would fall by 2.4 per cent. Thus significant warming is expected over the Indian subcontinent.

Indian agriculture and food security are highly vulnerable. Agriculture generates 28 per cent of GDP, employs 60 per cent of work force and the poor spend 2/3rd of their income on food. Any disruption, thus can cause much misery.

Analysis using a crop production model, the EPIC model, whose parameters were calibrated to reproduce Indian data on wheat and rice, shows that with a temperature increase of 2.3°C to 4.8°C, rice yields would decrease on the average by 32 per cent to 40 per cent. For wheat yields the fall would be 41 per cent to 52 per cent. Even when carbon fertilization effect is accounted for, rice and wheat yields will fall by 13 per cent to 25 per cent and 15 per cent to 33 per cent respectively.

These yield changes would lead to changes in the structure of production, prices, incomes and consumption. When these are analyzed in a consistent general equilibrium model, depending on the climate change scenario under consideration, expected decline in agricultural GDP ranged from 26 to 33 per cent. The overall effect of climate change has resulted in loss in GDP under all scenarios, with the decline ranging between 1.8 to 3.4 per cent.

The welfare impact are also very serious. Climate change increases the number of rural poor from 18.3 per cent to as much as 31.1 per cent. The abject poor increases by 10 percentage points in rural areas. The number of urban poor increases from 3.4 per cent to 8 per cent and abject poor by 1.0 percentage point. Even with carbon fertilization effect the number of rural and urban poor increases by as much as 6 and 2 percentage points respectively.

This means that climate change could increase the number of poor in India by more than 130 million persons in 2060. Indian agriculture and India's food security are highly vulnerable to climate change.

These estimates have not fully accounted for many other threats to agriculture from climate change. Thus the damage due to land loss, irrigation capacity loss and higher incidence of draughts and floods have not been factored in.

Sea level rise due to climate change can cause land loss, population displacement, increased flooding, salinity infusion, loss of agricultural yields, impact on aquacultures, tourism and beach erosion and property loss.

It is estimated that a 1 meter rise could lead to a land loss of 6000 sq. km and displace over 7 million people. Increased frequency of tropical cyclones could lead to that much more loss. Moreover, it is estimated by one study that they will be more intense than the worst storms experienced under present day climate conditions.

Other impacts on the coastal system are not assessed.

India's freshwater resources are limited and scarce even today. With population growth the scarcity will increase. It is projected that under current trends only 6 per cent of water would be left for environmental and other uses by as early as 2025. The impact on climate change could aggravate the problem. Salinity ingress with sea level rise could affect ground water supply. Increased frequency and intensity of flooding would mean more run off and less water for use – apart from the damage due to flood. The possible increase in rainfall may not compensate for this. It will depend upon its geographical and spatial distribution.

In India community level water harvesting efforts in regions vulnerable to droughts / severe droughts due to lack of adequate rainfall and infrastructure for storage of rainwater during the rainy season has made the water harvesting process a very powerful technology for an effective adaptation at the community level to cope with such natural disaster which may be exacerbated due to human induced climate change. Though adequacy of rainfall is a very important factor to consider in discussing impacts of droughts, it is important to remember that it does not matter how much rain a place gets, if there is no infrastructure to capture rain water, the place will still to short of water. It is unbelievable that Cherrapunji which gets 11,000 mm annual rainfalls still have serious drinking water shortages.

A number of case studies of community-based approaches show the vast scope and effectiveness of concerning water and making it go further.

What kind of policy conclusions can one draw from theses?

(a) Even when India is not responsible for the threat of climate change it is quite vulnerable. India has the right to seek adequate compensation.
(b) It would be in India's interest to work to reduce the threat of climate change.
(c) To ensure food security India should promote research to develop more climate tolerant crop varieties.
(d) Water conservation and use techniques should be followed.
(e) Development in flood plains and coastal regions may be controlled.
(f) Ground water recharge through community participation should be encouraged and be a national programme as it has also many short-run benefits.
(g) India should step up its economic growth to reduce its dependence on agriculture and acquire the ability to import as much food as needed.

DRAFT RESEARCH PAPER ON
MITIGATION IN SELECT SECTORS-TRANSPORTATION SECTOR

- BY DR. JYOTI PARIKH

Sustainable Urban Transport Sector and Possibilities for CO_2 Mitigation

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1. Introduction

In urban areas especially, transportation systems determine efficiency of the cities, economic growth and the feeling of well-being and quality of life for millions of residents.

Transport is a critical infrastructure for developmental process. It accounts for a major share of consumption of petroleum products in India. Transport is responsible for an appreciable share of pollution, both local and global. Problems due to the emissions of local pollutants get concentrated in urban areas. Transport activities thus occupy central concerns of local pollution in many urban areas of developing countries. The emission of global pollutants, especially of Carbon dioxide (CO_2), from transport is a problem of increasing concern in the global environmental scenario.

Managing transport sector while minimizing externalities such as local pollution, congestion and global pollution is a major challenge. Rapidly urbanization is taking place in developing countries. Efficient transport system is a key ingredient for cities to be economically productive and for quality of life.

In this paper, first a preliminary a review of the performance of the Indian transport sector by rail and road with particular emphasis on urban transport in the past few decades is carried out with a view to identify the changing patterns of use of different modes and fuels, and to assess emission of local and global pollutants. Later, depending on the data availability, specific information on four megacities of India, namely Mumbai (formerly Bombay), Delhi, Kolkatta (formerly Calcutta) and Chennai (formerly Madras), on pollutant emissions are estimated. Important macro-economic variables responsible for these changes are econometrically identified. Econometric models are used to generate future transport scenarios for passenger and freight traffic in India. Energy consumption and CO_2 emissions also increase from this sector at an equivalent rate. The effects of various policy options aimed at mitigating the CO_2 emissions are analyzed.

2. Review of Transport Characteristics

Main faces of this work is on urban transport for mainly passengers. However, when possible, we first take an overall review of the transportation in terms of both passenger and freight transport to see the magnitude of the urban transport.

A gradual transformation from rail-dominated transport to road-dominated transport has been witnessed in the last few decades. As can be seen in Table 1, the share of railways has decreased from 36.4% of the total Passenger Kilometres in 1980-81 to 16.4% in 1993-94. During the same period, the share of railways for freight transport (Tonne-Kiometres) declined from 61.8% to 42.3%. Note that the values do not sum to unity, the reminder being the share of domestic air transport.

Table 1: Trends in Modal Split (%)		
	Rail	Road
Passenger traffic		
1993-94	16.4	83.4
1980-81	36.4	61.5
Freight traffic		
1993-94	42.3	57.6
1980-81	61.8	38.1
Sources: Based on the values in Tables 2 and 3.		

The total passenger kilometres (PKM) and Tonne Kilometres (TKM) by Indian railways were 296.2 and 257.1 billions respectively in 1993-94 (Table 2). The growth rate in rail passenger transport during 1980-94 has reduced to nearly half of the growth rate of 1970-80, whereas the rate has nearly doubled for freight traffic. Bulk commodities (dominated by coal) have constituted about 85-90% of the total revenue originating tonnage in railways.

Suburban rail traffic has grown at a slightly higher rate than the non-suburban segment during seventies and eighties. Suburban rail travel in Mumbai constitutes more than 68% of this traffic, while other metropolitan cities, namely, Calcutta, Chennai (formerly Madras) and Delhi constitute about 25%, 6% and 0.6% respectively.

With the exception of the coal traction, which is on the way out, railways have consumed the least direct fuel energy per PKM or TKM (Figures 1 and 2). They have also emitted the least carbon di-oxide per PKM or TKM (Figure 3 and 4).

Table 2: Salient Features of the Transport by Indian Railways				
Details	1993-94	1980-81	Change % pa	
			1980-94	1970-80
Non-suburban PKM (Billion)	233.2	167	2.58	5.96
Suburban PKM (Billion)	63	41	3.36	5.95
Total TKM (Billion)	257.1	159	3.77	2.31
Sources: Data compiled and analyzed by Ramanathan and Parikh from Indian Railway Yearbooks.				

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2.1 Roadways

It is estimated that the roadways have accounted for 1500 billion PKM during 1993-94, which was more than five times that of railways (Table 3). Road passenger transport has recorded very high growth in recent years, especially since 1980-81. Such a tremendous growth in road transport can be attributed to a rapid growth in the population of vehicles. The growth rate was the highest for two wheelers (16.22% p.a.), which constituted more than 67% of total vehicles in 1993-94. While the total number of passenger buses is estimated to have more than doubled during the last decade, the share of public sector buses in the country has declined from about 44% in 1980-81 to 29.9% in 1993-94.

Table 3: Salient Features of the Performance of Indian Road Transport

Details	1993-94	1980-81	Change % pa	
			1980-94	1970-80
Passenger Transport				
PKM (Billion)	1500	353	11.77	7.43
No. of all vehicles ('000)	27227	5391	12.26	10.35
No. of Two wheelers ('000)	18338	2599	16.22	16.22
No. of cars, Jeeps and Taxis ('000)	3617	1147	9.24	5.01
Share of Two wheelers (%)	67.35	48.71		
Share of public buses in total number of buses (%)	29.91	44.03		
Freight Transport				
TKM (Billion)	350	98	10.29	3.08
No. of Trucks ('000)	1650	542	8.94	3.76

Sources: Data compiled and analyzed by IGIDR from Annual Reports of the Ministry of Surface Transport, and Motor Transport Statistics.

Figures 1 and 3 show that the energy consumption and CO_2 emissions per PKM effected by personalized vehicles has been more than twice the corresponding values for public transport modes.

The freight traffic handled by road in 1993-94 was about 350 billion TKM. The annual growth rate has increased by more than three times in the eighties compared to the seventies. Such a tremendous growth can be correlated to the growth in the number of trucks, which has registered nearly double growth rate in the eighties compared to the seventies. The energy consumption and CO_2 emissions per TKM effected by trucks has been nearly five times more than the corresponding values for rail transport (Figure 2 and 4).

2.1.1 Urban road transport

India has witnessed a tremendous growth in urbanization since independence. The urban population has increased from 62.4 million in 1951 to 217.2 million in 1991, nearly 3.5 times. Just 8.2% class I town (cities) accounted for 65.2% of the urban population in 1991 (NCU, 1988; Census, 1991).

While the population in major metropolitan cities in India doubled in about twenty years in the past, the travel demand increased by four to eight times. An increase of 66-200% increase in travel demand in five major metropolitan cities in India is projected for the period 1985-2001 AD (NCU, 1988). While population growth is an important determinant of this travel demand, at least two more factors are responsible for high growth. First, the urban physico-socio-economic environment, lay off and design which provides a variety of opportunities for a person, increases his mobility. Second, the continuous physical expansion of the city results in spatial distribution of activities causing the trip length to grow.

The share of Mass transport in total passenger traffic was less than 55% in major Indian cities during 1980 (NCU, 1988). The important exceptions are Bombay, Calcutta and Madras, where the suburban rail traffic plays a very important role in the passenger traffic. It must be noted that with the voluminous increase of personalized vehicles since 1980, the share of mass transport would have still reduced.

A more disaggregated analysis has shown that the composition of personalised vehicles in Indian cities is very high. In the four major metro cities, they form nearly 83% (two-wheelers 52% and cars 31%) of the total number of vehicles. The share of public transport buses are only 2%. The share of Passenger Car Units (PCU)[1] of the personalized vehicles is quite out of proportion to the share of traffic fulfilment. Their average number of trips served in some of the principal cities is 21%, while in terms of PCUs these vehicles have accounted for 87%. This is to be contrasted with the public transport vehicles (Buses). While they fulfill 79% of the trips, their share of PCUs is only 13% (Patankar, 1991).

Such a disproportionate growth of the personalised vehicles has many implications: increased energy consumption, severe road congestion, reduction in speed, increase in accidents, and emission of local and global pollutants. For example, in Bombay, the average speed of vehicles was about 38 kmph in 1962, which has reduced to about 26 kmph in 1979. The average speed in Calcutta was about 17 kmph in 1963, which has reduced to about 12 kmph in 1981.

While no time series data are available to identify the transportation changes with urbanization, certain trends can be observed with the cross sectional data on mobility and congestion indicators for selected cities (Table 4). With the exception a general reduction in the per capita road length is observed as the size of the city increases. There is also an increase in the PCUs and an increase in number of PCUs per km of road length as the city grows. These indicate the improvements in road structure have not been in tune with the growth of vehicles.

The growth of registered motor vehicles in various cities of India are shown in Table 5. Metropolitan cities account for about one-third of total vehicles in India. Note that the growth rate of vehicles in metropolitan cities has been slightly lesser than that of All India vehicles.

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[1] Bus = 3 PCU; Two Wheeler = 0.5 PCU; Three Wheeler = 0.75 PCU

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Table 4: Mobility and congestion indicators for selected cities					
Cities	Population in lakhs	Road Length per 1000 people (km)	PCU's per km of road	Trip Length (km)	PCU ('000)
Kolkatta	91.94	0.09	256	5.8	205.9
Mumbai	82.43	0.17	230	10.8	318.6
Delhi	57.29	0.28	331	13.4	508.8
Chennai	42.89	0.39	56	7.6	91.9
Bangalore	29.22	0.41	150	10.6	225.9
Amdavad	25.48	0.35	127	7.3	106.7
Pune	16.86	0.31	195	7.9	149.0
Kanpur	16.39	0.58	51	5.7	107.5
Coimbatore	7.50	0.92	77	9.8	100.1
Source: Patankar (1991), *Urban Transport in India in Distress*, CIRT, Pune.					

It can be seen from Table 5 that the growth rate of all registered vehicles was more than 10% per year in the big cities of Amdavad, Bangalore, Delhi, Hyderabad, Lucknow, Chennai, Nagpur and Pune in the eighties, which dropped to about 8% per year or less for the period 1991-94. However, the growth rate has been quite high (about 13% or more per year during 1991-94) for the next level cities of Bhopal, Cochin, Coimbatore, Madurai, Surat and Vadodara (which are recognised as metropolitan cities according to the 1991 census). In fact Coimbatore has recorded a very high growth rate of 20.33% per year during the period 1991-94. The only important exception to this trend has been Mumbai, which has recorded a negative growth rate of -1.13% per year during the period 1981-94. These trends indicate that the growth rate of vehicles could be high as the city grows. As a number of towns in India are growing very rapidly, a very high level of vehicle growth can thus be expected in the future.

Table 5: Registered Motor Vehicles (in '000) in Metropolitan cities in India (Year on 31st March)					
	1981	1991	1994	Change per annum 1981-'91	Change per annum 1991-'94
Amdavad	103	374	478	13.76%	8.52%
Bangalore	175	577	716	12.67%	7.46%
Bhopal	—	130	188	—	13.08%
Mumbai	307	629	608	7.44%	-1.13%
Kolkatta	—	475	544	—	4.62%
Cochin	—	29	42	—	13.14%
Coimbatore	—	66	115	—	20.33%
Delhi	536	1813	2239	12.96%	7.29%
Hyderabad	89	443	543	17.41%	7.02%
Indore	—	214	267	—	7.65%
Jaipur	48	266	339	18.68%	8.42%
Kanpur	56	169	209	11.68%	7.34%
Lucknow	53	216	266	15.08%	7.19%
Ludhiana	—	202	258	—	8.50%
Chennai	120	544	689	16.32%	8.19%
Madurai	—	38	57	—	14.47%
Nagpur	45	167	185	14.01%	3.47%
Patna	—	180	197	—	3.05%
Pune	107	280	331	10.10%	5.74%
Surat	—	197	271	—	11.22%
Vadodara	—	162	212	—	9.38%
Varanasi	—	112	146	—	9.24%
Visakhapatnam	—	142	165	—	5.13%
Total for the metropolitan cities*	1639	7392	9070	12.76%	7.06%
Total for India	5391	21374	27227	14.77%	8.40%
Share of metropolitan cities	30.40%	34.58%	33.31%	—	—

Source: Motor Transport Statistics of India, 1991-94, by Transport Research Wing, Ministry of Surfact Transport, Year: 1995
Note: * Columns 2 and 5 in the last three rows pertain only to the 11 cities for which information is available for the year 1981.

A more detailed data on vehicular growth in the four mega cities of India is shown in Table 6. The growth of three wheelers as important intermediate public transport modes for passengers is highlighted in this table. Both Mumbai and Chennai have recorded high growth of these vehicles. Chennai has recorded highest growth of two wheelers during the period. Mumbai has shown a favourable trend in passenger transportation by recording high growth in the number of buses, and a negative growth in the number of cars, jeeps and taxis.

Table 6: Vehicles Data as on 31 March 1994							
	All India	Mumbai	Delhi	Kolkatta	Chennai	4 Metropolitan	
						Total	Share
Two Wheelers	18338000 (8.90)	258960 (2.28)	1492201 (6.93)	233634 (6.21)	497640 (8.78)	2482435 (6.69)	13.54%
3 Wheelers - Pass.	A	35567 (13.11)	72102 (4.60)	6973 (6.65)	28282 (23.79)	134044 (9.85)	A
3 Wheelers - Goods	A	8633 (-16.40)	B	16874 (5.10)	1912 (9.36)	27419 (-3.77)	A
Cars, Jeeps and Taxis	3617000 (6.98)	253047 (-5.44)	534110 (9.34)	227736 (3.48)	134829 (5.24)	1149722 (3.79)	31.79
Buses	419000 (8.18)	11394 (12.67)	24211 (8.69)	13457 (8.75)	8716 (3.70)	57778 (6.52)	13.79
Trucks	1650000 (6.76)	33110 (-1.73)	116379 (4.55)	35969 (8.90)	19517 (6.83)	204975 (2.91)	12.42%
Others[C]	3283000 (8.14)	51785 (5.31)	72102 (4.60)	33961 (8.87)	28441 (17.59)	186289 (7.22)	5.82%
All Vehicles	27227000 (8.40)	608296 (-1.88)	2239083 (7.29)	544757 (4.67)	689143 (8.20)	4081199 (5.65)	14.99%

Note: A- Included in Others and separate All India information is not available; B- Included in trucks; C- Includes 3Wheelers, tractors, trailers and other vehicles.
Figures in parenthesis indicate annual growth rate, 1991-'94.

Source: Based on data from Motor Transport Statistics of India, 1991-94, by Transport Research Wing, Ministry of Surface Transport, Year: 1995

As highlighted in Ramanathan (1997), Data on the performance of individual modes of road transport in India are generally not available. However, a part of the performance of passenger transport effected by public bus services is regularly reported (CIRT, 1994). A number of state-run transport undertakings operate bus services in various urban centres and other parts. Table 7 provides data on salient features of their performance. The share of urban PKM to total PKM by public buses has decreased from 12.5% in 1990-91 to 11.4% in 1992-93. Note that the actual share of urban PKM by road transport considering all modes would be higher because most of the PKM by two wheelers, three wheelers and taxis would be effected in urban areas. On the basis of the available fuel consumption data by these buses, the total CO_2 emission has been estimated and shown in Table 7 itself. Note that, in spite of registering a lower KMPL, the share of urban transport in total CO_2 emission is lower than the share in PKM because of higher capacity utilisation of urban buses. On an average, there were 55 persons per urban bus compared to the overall value of about 41 persons.

Table 7: Urban and long distance passenger transport performance by State Road Transport Undertakings (STU) in India		
Details	**1990-91**	**1992-93**
I. Total Urban PKM (in millions)	45511	44368
Selected Urban Centres		
Delhi (DTC City)	16091	12963
Mumbai (BEST)	9205	9765
Chennai (PTC)	10114	10748
Kolkatta (STC City)	2040	2013
Amdavad MTS	1514	1709
Pune MT	1504	1864
II. Long distance PKM in millions	317330	344496
Selected State Operations		
Maharashtra	50280	53708
Gujarat (Mofussil)	30767	33932
Karnataka (Mofussil)	28351	30830
Kerala (Mofussil)	12173	12956
Uttar Pradesh (Mofussil)	22326	22363
III. Share of Urban PKM in total PKM by STUs	12.54%	11.41%
IV. HSD consumption (KMPL)		
– Urban	3.49	3.54
– Overall	4.3	4.41
V. CO_2 Emission (mtC) by the operation of the STUs		
– Urban	0.17	0.19
– Overall	1.51	1.65
Source: Based on CIRT (1994)		

3. Energy consumption trends

During the year 1993-94, Indian transport sector consumed 1.93 million tonnes of coal, 5538 million kWh of electricity, 38,40,000 tonnes of gasoline, 17,40,000 tonnes of aviation turbine fuel (ATF), 2,30,59,000 tonnes of High Speed Diesel (HSD), 82,000 tonnes of Light Diesel Oil (LDO), 4,05,000 tonnes of Fuel Oil and 12,000 tonnes of Low Sulphur and Heavy Stock. Table 8 provides the details for the last few years. During the period 1989-94, coal consumption has reduced by nearly three times. Consumption of all other fuels have increased, with electricity registering the highest increase at the rate of 8% per annum.

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Table 8: Energy consumption for transport in India
(Units for liquid fuels: '000 Tonnes)

Year	1989-90	1990-91	1991-92	1992-93	1993-94
I. Road and Other Transport (incl. Agri. Retail Trade)					
Gasoline	3491	3545	3570	3620	3[illegible]
HSD	16691	17156	18621	20114	21[illegible]
LDO	16	14	15	16	1[illegible]
Fuel Oil	88	121	76	84	9[illegible]
II. Railways					
Coal (MT)	5.73	5.01	4.42	3.19	1.3[illegible]
Electricity (million kWh)	4070.00	4112.00	4520.00	5068.00	5530.0[illegible]
HSD	1455	1453	1459	1417	144[illegible]
LDO	5	4	3	2	[illegible]
Fuel Oil	24	22	21	15	1[illegible]
III. Aviation					
HSD	11	11	11	12	1[illegible]
LDO	1	1	1	1	[illegible]
Fuel Oil	3	4	1	5	[illegible]
ATF	1775	1677	1500	1590	170[illegible]
IV. Shipping					
HSD	184	193	191	183	19[illegible]
LDO	76	67	61	66	6[illegible]
Fuel Oil	346	300	245	235	29[illegible]
V. LSHS	8	13	22	10	1[illegible]
Total Energy Consumption (TJ)	1237647	1240791	1287208	1331975	138797[illegible]
Share of:					
Petroleum fuels	89.10%	90.31%	91.48%	93.59%	95.62%
Road and Other transport	74.39%	76.21%	78.54%	81.16%	82.84%
Rail transport	16.28%	15.02%	13.65%	11.24%	9.09%
Air transport	7.13%	6.72%	6.02%	5.95%	6.25%
Shipping	2.17%	2.00%	1.78%	1.61%	1.78%

Source: India's Energy Sector, 1996, Centre for Monitoring Indian Economy, Mumbai.

An analysis of the above data indicates that petroleum products account for the major fuel consumption in the transport sector (95.7% in 1993-94). Road and other transport (including agricultural retail trade) is the dominant consumer (82.8% in 1993-94), followed by rail (9%) and air (6%).

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4. Environmental implications

Air pollution due to road transport is of high significance in terms of the quantity of pollutants emitted. In India, it is estimated that vehicular emissions alone account for about 60% of the total pollution from all sources (Patankar, 1991). An international study has indicated that the emission of selected local air pollutants (such as the carbon monoxide, nitrogen dioxide, etc.) in the megacities of India is above the WHO guidelines (Grubler, 1993).

4.1 Emissions of local pollutants

The emissions of local pollutants due to road transport have been obtained using the emission factors estimated by the Indian Institute of Petroleum (IIP, 1985) for Indian vehicles. The emissions have been computed using the procedures outlined in the same report. In 1993-94, fuel consumption in the transport sector has accounted for about 17,58,756 tonnes of Carbon Monoxide (CO), 6,48,025 tonnes of hydrocarbons (HC), 10,39,374 tonnes of nitrogen oxides (NOx), and 32,974 tonnes of particulate matter. A detailed break-down in terms of different vehicles is shown in Table 9. These trends indicate that emissions are increasing at a very high rate. While gasoline vehicles account for a large part of CO and HC emissions, diesel vehicles account for a majority of NOx, and all the particulate emissions.

Table 9: Emissions Summary (KT per Year) (All India)

	CO	HC	NOx	Part.
Gasoline vehicles				
- 2 Wheelers	426.9411	266.4524	0	—
- 3 Wheelers	119.1835	74.4289	0	—
- Cars, Jeeps and Taxis	696.8867	103.5325	45.53109	—
Diesel Vehicles	525.7452	203.611	993.8429	32.97437
Total	1768.756	648.0247	1039.374	32.97437

Source: Values computed from data on Indian vehicles using the procedure suggested in IIP (1985).

Concentrations of selected local environmental pollutants for the four megacities of India are shown in Table 10. Note that Calcutta recorded a very high concentration of NO_2 during 1985. Chennai recorded the least variability in concentrations.

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Table 10: Annual mean concentration of some local pollutants in four megacities of India ($\mu g/m^3$)												
Year	Mumbai			Delhi			Calcutta			Chennai		
	SPM	SO_2	NO_2	SPM	SO_2	NO_2	SPM	SO_2	NO_2	SPM	SO_2	NO_2
1980	190	30	20	440	38	38	405	38	20	150	14	14
1985	205	22	78	350	60	42	320	50	140	120	8	10
1990	200	40	28	480	20	52	330	50	40	120	12	23
1991	230	28	26	540	34	46	390	62	40	110	8	13
1992	330	18	28	520	22	32	405	38	30	90	10	12
1993	280	24	28	440	16	28	550	46	44	80	8	8

Source: Based on graphs in the Annual Report of the National Environmental Engineering Research Institute, Nagpur, India for the year 1992-93.

4.2 Emission of global pollutants

CO_2 emissions have been computed using the past energy consumption data presented in previous sections, and emission factors available in previous studies (Parikh and Gokarn, 1993; Parikh, Panda and Murthy, 1994). The emissions corresponding to electricity consumption are obtained as the emissions of equivalent coal after assuming 30% electricity generation efficiency in coal based thermal power plants. Two-thirds of the total electricity generation in India is assumed to be from coal based thermal power plants, while the remaining is assumed to be from non-CO_2 emitting technologies, namely hydro and nuclear power plants.

Table 11 shows the estimates for direct (*i.e.* fuel related) CO_2 emissions due to transport in India for the last few years. The direct CO_2 emissions in 1993-94 due to the fuel consumption in transport sector works out to be about 27.85 million tonnes of carbon equivalent (mtC). Road and other transport (including agricultural retail trade) is responsible for more than 80% of the emissions, followed by rail (13%) and air (6%).

Table 11: CO_2 emission by different transport modes (mtC)					
Year	Road and Other	Rail	Air	Shipping	Total
1989-90	17.852	5.284	1.575	0.533	25.251
1990-91	18.336	4.896	1.490	0.493	25.225
1991-92	19.608	4.662	1.384	0.437	26.111
1992-93	20.974	4.062	1.415	0.426	26.886
1993-94	22.308	3.494	1.550	0.489	27.852

Note: CO_2 coefficients used are 0.546 t of carbon per ton of Indian coal and 0.88 t c/t of liquid fuels (Parikh and Gokarn, 1993).

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Emissions due to the transport operations of four megacities of India are shown in Table 12. These values have been estimated based upon the share of each of the cities in the registered number of vehicles. For example, gasolene consumption of Mumbai in a year is estimated from the All India data for gasolene consumption assuming the same proportion as the number of gasoline vehicles. Electricity consumption in Mumbai's suburban operation is estimated as follows. From the annual report of Indian Railways, the average share of electricity consumption for suburban operations (which includes the operations in all the four megacities) in total electricity consumption of all electric traction has been estimated. Once this value is available, the share of Mumbai is estimated as proportional to the share of PKM of Mumbai's suburban operations in the total suburban PKM. Electricity consumption due to the rail freight operations originating from each of these cities could not be estimated owing to lack of data, and the CO_2 emissions of Table 12 do not include these rail freight operations. Similarly, the estimates of this table do not consider air and shipping operations.

Table 12: CO_2 emissions due to urban transport in four megacities in India (1993-94)

	Mumbai	Delhi	Calcutta	Chennai	Total
CO_2 emissions	1.70	1.40	1.94	1.34	6.38
Share in All India Transport Emissions	6.11%	5.03%	6.98%	4.81%	22.92%

Thus, it can be seen that transport operations in Mumbai are responsible for about 1.7 mtC of CO_2 in 1993-94, which forms about 6.1% of the all India transport emissions in that year. The four megacities accounted for about 23% of the total direct CO_2 emissions due to transport operations. Note that this share has been increasing over the years. For example, in 1990-91, urban transport in Mumbai was responsible for about 1.38 mtC, which was about 5.5% of the total CO_2 emissions in that year.

5. Projecting future transport requirements

The projections of future PKM are carried out using the econometric models. A detailed analysis with data has revealed that simple multiple regressions do not provide satisfactory models. Finally, an approach using cointegrating econometric models (Charemza and Deadman, 1992; Engle and Granger, 1987) has been found to be satisfactory. The relevant models are given below. A more detailed discussion of the validity of cointegrating regressions is available in Ramanathan (1998a).

$$PKM_t = \underset{(0.114)}{0.684} + \underset{(4.105)}{1.147}\, Y_t + \underset{(2.606)}{4.414}\, NR_t - \underset{(-1.381)}{0.209}\, P_t + V_{1t} \qquad (1)$$

$$\Delta PKM_t = \underset{(2.20)}{0.060} + \underset{(0.66)}{0.122}\, \Delta Y_t + \underset{(0.29)}{0.464}\, \Delta NR_t - \underset{(-0.09)}{0.010}\, \Delta P - \underset{(-2.46)}{0.345}\, V_{1(t-1)} + \underset{(0.48)}{0.098}\, \Delta PKM_{t-1} + U_{1t} \qquad (2)$$

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where the notations PKM, Y, NR, I and P stand for passenger kilometres, gross domestic product, ratio of urban to total population, index of industrial production and price of mineral oils respectively. Figures within parentheses are the t-values. Data for the period 1956-89 were used in the construction of the model. We could not use data till 1993-94 because a regular time-series data on PKM are not available beyond 1988-89.

Model (1) and (2) are normal econometric models for PKM. They could not be used as such for making projections as they suffered from severe autocorrelation. On the basis of usual tests for cointegration, the cointegrating relationships given in Models (1) and (2) have been established. First, the stationarity of the variables have been checked and all of them have been found to be non-stationary with order 1. Then, the residuals V_1 and V_2 of models (1) is used to verify the existence of cointegration. Models (2) is called the Error Correction Models (ECM) for models (1). Note that the residuals V_t was used in the error correction models with a unit lag.

The values of coefficients in Models (1) and (3) give the long-run elasticities for PKM. The long-run income and price elasticities of PKM are 1.147 and -0.209 respectively. Further its elasticity with respect to the ratio of urban to total population is quite large, at 4.414.

The short run elasticities for PKM is obtained as the values of the coefficients in Model (2).

Two different cases are considered for projecting the PKM requirements. A growth rate of 10% in the prices of mineral oils has been considered for Case I, while Case II has considered a growth rate of 12%. The urban population projections have been obtained by using the macro-economic model reported in Majumdar and Parikh (1994). The resulting PKM projections are shown in Figure 1. The actual growth in PKM over the past years are also shown for comparison. PKM projections for Case II show a declining trend after 2010 AD, indicating their sensitivity to the mineral oil price index.

For analysing the implications of these projections on the sustainability of this sector in India, a scenario analysis has been performed. The details are presented below.

6. Energy requirements and Carbon di-oxide emissions upto 2020-21: A scenario analysis

For policy purposes, it is necessary to identify the implications of alternate courses of action so that the future can be shaped to ensure sustainable development. The impact of the Indian transportation sector will be greatly felt on two important areas - the future energy requirements and the CO_2 emissions. Assuming that the PKM projections made in the previous section will materialise, their likely impacts and the effects of alternate courses of action have been analysed using four scenarios. Table 13 describes the scenarios in terms of growth rates. The results of the scenarios (corresponding to Case I) are also plotted in Figure 2 (for energy requirements) and Figure 3 (for CO_2 emissions).

Table 13: Growth rates obtained for the scenarios (in % p.a. during 1990-2021)		
Details	**Case I**	**Case II**
PKM	6.96	3.69
TKM	7.05	5.72
Energy requirements		
Business as usual	6.46	4.40
Efficiency increase	5.38	3.35
CNG and Electric vehicles	5.38	3.35
High share of mass transport	3.62	1.42
CO_2 emissions		
Business as usual	6.25	4.21
Efficiency increase	5.17	3.16
CNG and Electric vehicles	5.17	3.16
High share of mass transport	3.85	1.63
Source: Values computed by IGIDR		

Scenario 1: Business As Usual (BAU)

In this scenario, existing historical patterns have been assumed to continue in future. A logistic substitution model has been used to capture the trends in the modal split. Based on their performance in the previous decade, an increase in the efficiencies of road transport equipment by 2% per annum over the the prevailing values in 1988-89 has been assumed.[1] Based upon these assumptions, the energy requirements and CO_2 emissions till 2020-21 have been projected. The energy requirements in 2020-21 is projected to be about 7884 Peta Joules (PJ) (Figure 2), which is about 6.54 times the consumption in 1990-91. CO_2 emissions have also recorded a similar rise (Figure 3). Such a sharp increase is obvious considering the fact that the energy and carbon intense modes of transport (gasoline vehicles and trucks) have been assumed to satisfy the additional transport demand during 1990-2021 (see Table 16). It is necessary to reduce such a high growth using available policy options. An analysis of such options is presented below.

Scenario 2: Emphasis on Efficiency Improvements (EFFICIENCY)

The assumptions of the previous scenario have resulted into a huge increase in energy requirements and CO_2 Emissions. Emphasis on efficiency improvements can reduce the demand. About 4% per annum (2% over and above the expected efficiency improvements which normally takes place) for road transport[2] have been assumed. Energy requirements and CO_2 emissions in 2020-21 have been estimated to be about 5814 PJ and 111 million tonnes of carbon equivalent (MTC) respectively. These values represent a significant (about 26%) reduction compared to the corresponding figures of the previous (BAU) scenario.

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Scenario 3: Introduction of alternative transport fuels (ALTFUEL)

In addition to efficiency improvement, introduction of alternative transportation fuels can further reduce energy requirements and CO_2 emissions. In this scenario, the effect of introducing these fuels *over and above efficiency improvements* has been examined.

At present virtually all (99%) fuels consumed in road transport in the world are being produced from crude oil. The market share of other non-oil transport fuels such as bio-ethanol, methanol and Compressed Natural Gas (CNG) is very minor (Okken, 1991). Other non-oil alternative fuels (hydrogen and electricity) are still in the research and development stage (OECD, 1993).

Of these non-oil fuels, the most revelant one for India is the CNG. CNG vehicles are more efficient and cleaner compared their gasoline counterparts. It has been estimated that the CNG vehicles will emit only 80% of CO_2 (full fuel cycle) compared to gasoline engines (Okken, 1991). A technology assessment has identified fruitful utilization of the natural gas available in India for transportation purposes (Parikh and Painuly, 1991; Painuly and Parikh, 1993). Calculations using available data from the above sources reveal that CNG vehicles are expected to consume about 0.4683 MJ and emit 7.8 grams of Carbon equivalent of CO_2 for every PKM. CNG decreases local emissions significantly but not global emissions.

Pressure on cleaner environment especially in urban areas is expected to stimulate the introduction of electric vehicles in India. Both Battery Powered Electric Vehicles (BPEV) and Hydrogen Fuel Cell Electric Vehicles are not yet commercially available (Williams, 1993), with the former being in a relatively more advanced stage of development. Hence, except for a few studies (Wang and DeLuchi, 1992; MacKenzie, 1994), details on their technical performance is not available. The US trials show that their performance vary from 0.3 to 0.4 kWh per mile (Wang and DeLuchi, 1992). A battery powered EV (BPEV) emits only 56% of greenhouse gases compared to a gasoline vehicle, if the battery is charged using the average general mix in the USA. The corresponding CO_2 emissions for a fuel cell powered electric vehicle is quite low and depends upon the fuel used in the fuel cell (Williams, 1993). It is usually as low as 8% of the corresponding value for gasoline vehicles (Okken, 1991). The electric vehicles are expected to consume about 0.2283 MJ/PKM. BPEVs emit about 5.9 grams of Carbon equivalent of CO_2, while fuel cell powered electric vehicles are expected to emit about 0.8 grams.

For the purpose of this scenario, a diffusion of CNG and electric vehicles in 2020-21 along the S-shaped logistic pattern has been assumed. It is assumed that both the CNG vehicles and EVs will diffuse to account for 10% share in the new vehicles registered in 2020-21.[3,4] The level of market penetration has been assumed to be uniform for both these EVs.

Expectedly, the results do not show much variation from those of the previous scenario (EFFICIENCY). This is because, under the stated assumptions, the share of the alternative fuel vehicles in the total number of vehicles expected in 2020-21 has been quite low (1.14%). Moreover, both CNG and BPEV rely on fossil fuels and the gain is not much. This means that if the alternative fuel vehicles are to make any appreciable effect on reducing energy consumption and the CO_2 emissions, they have to be encouraged very vigourously. Otherwise, their likely impact is expected to be very minimal in Indian transport scenario.

Scenario 4: Desired Modal Split (MODSPLIT)

The modal split employed in the previous three scenarios is the expected pattern based on past trends. The modal split is shown in Table 14 for the years 1990-91 and 2020-21. This modal split is however highly undesirable as it favours energy inefficient and CO_2 intensive modes. For example, in 2020-21, gasoline vehicles have been assumed to meet 35% of the PKM demand. The share of rail has been assumed to to be less than 5%.

Table 14: Modal Splits (%) for Passenger Transport

Mode	Passenger Transport		
	1990-91	2020-21 (projected)	2020-21 (desired)
Road			
- Gasoline	16.99	35.53	3.38
- Diesel	60.56	53.86	50.62
- CNG	0.00	1.14	6.75
- EV	0.00	1.14	6.75
Road Total	77.55	91.67	67.50

Source: Values computed by IGIDR

However, the analyses in earlier sections indicate that railways, especially suburban railway in terms of energy per passenger kilometer are highly energy efficient and less carbon intensive. Hence, there is a strong case for increasing the share of railways in the modal split. Many planning studies on Indian transportation sector have also opined that railways should account for a major share of PKM and TKM as they are more energy efficient. The National Transport Policy Committee (NTPC, 1980) has recommended that the railways should plan to carry 72% of the total land freight traffic by 2000 AD.

Hence, this scenario has been constructed to identify the effects of encouraging more desirable travel modes in terms of energy consumption and CO_2 emissions. The details are also provided in Table 14. Specifically, this desired modal split assumed a more share for rail in total PKM and TKM, for buses and alternative fuels in passenger road transport, and for electric traction in railways.[5]

The results have shown a much larger reduction (nearly 50% of BAU) in energy requirements and CO_2 emissions (3504 PJ and 76 MTC respectively). Thus this scenario has shown that it is possible to have a reasonably low increase in energy requirements and CO_2 emissions, and hence points to the best strategy for sustainable transport development in India.

6.1 Scenarios of Case II

A similar analysis has been conducted for the PKM projections of Case II. As expected, the results have indicated a much larger reduction in energy requirement and CO_2 emission (at 4392 PJ and 84 MTC respectively). The results indicate about 45% reduction in energy requirement and CO_2 emission compared to the corresponding scenarios of Case I. This proves that opportunities for sustainable development will be stronger if future travel demand can be reduced.

7. Summary and Recommendations

Transport sector is vital for economic growth and quality of life, especially in the urban areas.

It is shown that during 1980-94, road transport has grown at a very high rate (more than 11% p.a.). Thus the present transportation trends, especially road transport, are unsustainable in future.

Mass transport systems provide the least energy consumption, CO_2 emissions, and cost per PKM. For example, per PKM electric traction of railways consumes about 0.115 MJ, and buses consume 0.212 MJ, which are much lower than the corresponding values for gasoline vehicles. Modal splits in their favour can significantly reduce the energy requirement and carbon emission. They also reduce the level of congestion in cities. For example, buses fulfill 79% of the trips in cities, while they form only 13% of the share of the total Passenger Car Units.[6] Hence, they should be encouraged wherever possible.

We have found that modal split has been changing in favour of road both for passenger and transportation in India. Road is expected to account for nearly 87% and 65% of passenger and freight transport respectively by the turn of this century. Non-suburban and suburban rail PKM grew at 2.5% and 3.4% per annum respectively during 1980-94, which is quite low compared the growth of road PKM (11.4%). Travel demand in many Indian cities is projected to grow by 66-200% during the period 1985-2001. It has been pointed out, using data, that vehicle population is expected to grow rapidly in urban India, and that the improvements in road structure have not been in tune with the growth of vehicles. Electricity consumption in rail transport has registered the highest growth at 8% per annum during 1990-94. Petroleum products constituted more than 95% of the transport fuel consumption in 1993-94. In that year, road and other transport (including agricultural retail trade) accounted for 82.8% of the total energy consumption, followed by rail (9%) and air (6%). It has been estimated that, in 1993-94, fuel consumption in the transport sector has accounted for about 17,58,756 tonnes of Carbon Monoxide (CO), 6,48,025 tonnes of hydrocarbons (HC), 10,39,374 tonnes of nitrogen oxides (NOx), 32,974 tonnes of particulate matter, and 27.85 million tonnes of Carbon equivalent of Carbon di-oxide. Four megacities of India accounted for about 22% of the CO_2 emissions. Econometric models indicated that urban population, prices of crude and gasoline, and the index of industrial production are likely to be major factors affecting traffic growth in India. An analysis with traffic projections has indicated that transport energy requirements would be about 7884 PJ in 2020-21, which is more than 6 times the actual consumption in 1990-91.

Corresponding CO_2 emission would be more than 140 mtC.

The following recommendations emerge:

- Efficiency improvements can meet the future traffic demand with reduced energy consumption and CO_2 emissions. Savings as high as 26% is possible. Hence, the best available technologies should be commercialized at the earliest. Vehicles should be made to run at optimal speeds, and at full capacities.

- The first and foremost requirement is to improve the speed, comfort, and reliability of public transportation. However, many of the government owned road transport undertakings which provide public transportation are financilly ill, and very badly equipped to provide superior services. Their main drawback is that pricing their services are controlled by the government. In majority of cases, the prices do not cover even a part of their expenditure. This makes capacity augmentation and improvement of the quality of existing services very difficult. The solution lies in making these undertakings autonomous so that they can price their services based on economical principles.

- For the same population and gross domestic product, Mumbai requires only 40% of energy and emissions compared to Delhi because of suburban railways. International investment opportunities should be explored in mass transit in India as a means to reduce the problems associated with energy consumption and CO_2 emissions. Hence, mass transit seems to be a strong contender for joint implementation (JI) or CDM.

- Alternative transport fuels could provide energy security and healthy urban environment. Vigorous promotion is needed in order that their benefits can be reaped in the foreseeable future. Hence efforts must be made to promote them as fast as possible. Subsidies may be provided on the capital and fuel costs of these vehicles, and exclusive roads and parking spaces may be constructed. To provide the required impetus, it is necessary to create an exclusive department in the government, or a special institution. This institution should work in tandem with the existing industries involved in alternative vehicles development to spread the know-how to the extent possible, provide R&D support and mobilise the necessary funding from suitable sources.

- A more prudent move to achieve a sustainable future would be to reduce the volume of travel demand itself. Scenarios using Case II (section 5.1) have shown that nearly 50% savings in energy and reductions in emissions are possible by reduced travel demands. This can be done by many options, such as planning smaller cities, raising the occupancy ratios of vehicles, substituting motorised travel by non-motorised travel by providing sufficient cycling tracks, and, improving the telecommunication facilities. The most important long term option is to instill an awareness of *sustainable development* among the travelling public. They should be encouraged to change their lifestyles to ensure availability of resources and safe living conditions to future generations. It involves using vehicles only for very important needs and avoiding luxury travels, and choosing the most energy efficient equipment.

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References

1. CIRT (1994), *Performance statistics of State Transport Undertakings 1991-92 & 1992-93*, Central Institute of Road Transport, Pune.

1. Grubler,A. (1993), The transportation sector: growing demand and emissions, *Pacific and Asian Journal of Energy*, Vol.3, December, 179-199.

2. MacKenzie,J.A. (1994), *The Keys to the Car: Electric and Hydrogen Vehicles for the 21st Century*, World Resources Institute.

3. Majumdar,Saumen and Jyoti Parikh (1994), *Macroeconomic Consistency in Energy Planning*, Discussion Paper No. 102, Indira Gandhi Institute of Development Research, Mumbai.

4. NCU (1988), *Report of the National Commission on Urbanization*, Ministry of Urban Development, Government of India, New Delhi.

5. NTPC (1980), *Report of the National Transport Policy Committee*, Planning Commission, New Delhi.

6. IIP (1985), *State of Art Report on Vehicle Emissions*, Report prepared by The Indian Institute of Petroleum, Dehradun, for the Department of Environment, Government of India, New Delhi.

7. Okken, P.A. (1991), A case for alternative transport fuels, *Energy Policy*, Vol.19, No.4, 400-405.

   OECD (1993), *Cars and Climate Change*, Organisation for Economic Co-operation and Development, Paris.

8. Painuly,J.P., and Jyoti Parikh (1993) Policy analysis of oil substitution by Natural Gas in India: Transport and Industry Sectors, *Energy Policy*, Vol.20, No.1, January, 43-52.

9. Parikh, Jyoti K. and Subir Gokarn (1993), "Climate Change and India's energy policy options: New perspectives on sectoral CO_2 emissions and incremental costs", *Global Environmental Change*, September, pp: 276-291.

9. Parikh,J., and J.P.Painuly (1991), *Compressed Natural Gas (CNG) in Transport Sector: Techno-economic Assessment for India*, Discussion Paper No.49, Indira Gandhi Institute of Development Research, Mumbai.

10. Parikh, Jyoti K., Manoj K. Panda and N. S. Murthy (1994), *Consumption Pattern Differences and Environmental Implications: A Case Study of India*, Discussion Paper No. 116, Indira Gandhi Institute of Development Research, Mumbai, October.

76

10. Patankar (1991), *Urban Transport in India in Distress*, CIRT, Pune.

10. R. Ramanathan (1996), "Indian Transport Sector: Energy and Environmental Implications", *Energy Sources*, **18**(7), 791-805.

11. R. Ramanathan (1997), "Transport: A Crucial Infrastructure", in: Kirit S. Parikh (Ed.), *India Development Report - 1997*, Oxford University Press, New Delhi, pp: 219-238.

12. R. Ramanathan and Jyoti K. Parikh (1996), "Indian transportation sector: An analysis in the context of sustainable development." In *Structural Transformation Processes towards Sustainable Development in India and Switzerland: Synthesis and Case Studies*. Zurich: INFRAS.

13. RITES (1993), *Study on Productivity Optimization on Indian Railways* (Vol. I and II), Railway Fare and Freight Committee, New Delhi.

14. Williams,R.H. (1993), *Fuel Cells, their fuels and the US automobile*, Paper prepared for the First Annlual World Car 2001 Conference, University of California at Riverside, Riverside, California.

15. Wang,Q. and DeLuchi,M.A. (1992), Impacts of electric vehicles on primary energy consumption and petroleum displacement, *Energy - The International Journal*, vol.17, No.4, 351-356.

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Notes:

1. From the data available for road transport, it appears its efficiency has increased. The total energy consumption of this transport has increased at a rate of about 8% per annum during 1980-89, whereas PKM road have risen at about 11%. Fuel efficiency of road transport, on an average, may therefore have increased by about 4.5% per annum. Hence assumption of 2% efficiency increase is quite conservative.

2. The average specific fuel consumption of cars at present in developing countries in Asia is about 9 to 10 litres per 100 kilometres. For developed countries the value is about 8. However, new technological improvements have resulted in small cars which have a fuel consumption as low as 5 litres per 100 km. If one assumes that these types of cars will be commercially available in developing countries in about 30 years (Okken, 1991), it amounts to a cumulative efficiency increase of about 2.5% per year. Hence, the assumption of 1% in efficiency increase in road transport (which also includes buses) is not unrealistic. For other transports, the assumption of 1% efficiency improvement per year is quite conservative.

3. The share of CNG vehicles may be optimistic because as per the present Indian natural gas policy, fertiliser has the first priority use for natural gas. In fact, its use as CNG for transportation has a much lower priority. However, we assume a high level of use of CNG for transport as we hope that there will be a change in the natural gas policy towards transportation. Our optimism is based upon two facts. We feel that the pressure to reduce local emissions will force the government to encourage the use of CNG vehicles. Also, with the new joint ventures for setting up Indian fertilizer plants in West Asia coming up, the need for fertilizer production in India using indigenous natural gas is expected to decline.

4. Electric vehicles are expected to occupy 25% share in the Total Motor Vehicle sales in the United States in the year 2010 AD (MacKenzie, 1994). Hence, this assumption seems to be conservative. Due to the large amount of uncertainty regarding the development of EVs, a more optimistic assumption may not hold the realistic view.

5. All these assumptions have their own financial implications. However, we do not analyse this aspect further here.

6. Passenger Car Unit (PCU) is a uniform measure of the space occupied by different vehicles on the road. The following are the equivalents. Bus = 3 PCU; Two Wheelers = 0.5 PCU; Three Wheelers = 0.75 PCU.

DRAFT RESEARCH PAPER ON
MITIGATION IN SELECT SECTORS-POWER SECTOR

- BY DR. AMIT GARG

Carbon Mitigation for the Indian Power Sector

A research paper by

Amit Garg
P. R. Shukla
Debyani Ghosh

For
The Louis Berger Group, Inc.

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Executive Summary

Power sector mitigation in India covers a wide spectrum of economic, technological, environmental, institutional and socio-political issues. The present research paper assesses policies and measures under alternate mitigation scenarios and provides an assessment for the future of the Indian power sector. Results show that power generation capacity increases by 1.5 times in the next 10 years, doubles in the next twenty years and reaches 395 GW in 2035. Some specific insights provided from the research are indicated below.

Coal dominates in the long-term future generation capacity mix, but its use becomes more sustainable with clean coal technology penetration. Gas technologies penetrate fast in medium term (till 2020), mainly to meet peak load requirements. In this context, building of gas supply infrastructure is an important issue. In later periods (beyond 2020), its penetration slows down due to build up of large peak reserve capacity in the system. Expectations about improved performance of nuclear plants increase nuclear penetration, but its capacity is restricted due to socio-political and environmental considerations. Despite large hydro being competitive, socio-environmental constraints cause a decline in its capacity share. Among renewable, small hydro, co-generation and biomass technologies are highly competitive and penetrate rapidly. For wind penetration, strengthening of local manufacturing capabilities and push policies to promote investment in wind power projects enhance technology competitiveness. Solar technologies penetrate in the medium term due to capacity building through demonstration projects that enhance learning experiences, but long-term penetration will depend largely on international lowering of costs.

Indian power sector has substantial potential for greenhouse gas (GHG) emission mitigation by changes in the energy and technology mix. In the short-term, demand side technologies have a large contribution in emission reduction due to low inertia of technological stock along with improvements in transmission and distribution efficiency. In the medium and long term, supply side contribution increases due to significant shifts in technology mix. Gas and renewable technologies substitute coal in the medium term, while in the long-term, there is high penetration of carbon-free technologies like large hydro and nuclear. A hedging strategy, therefore, is to keep the energy and technology mix diverse and flexible.

Electricity supply cost declines due to autonomous technological advancements and better management practices (load management) that lower peak to off-peak cost ratio from 2.5 to less than 1.5 in next 35 years. Carbon mitigation policies lead to more substantial rise in electricity costs, especially in the long-term, as compared to local pollution mitigation policies. However, recycling of carbon revenue can bring down electricity costs. Therefore, climate change mitigation policies for the Indian power sector will have to be crafted for their own sake.

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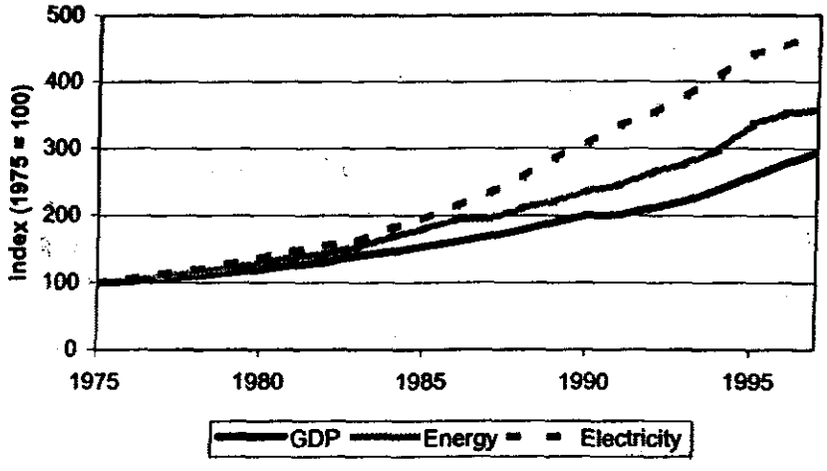
1. Overview of the Indian Power sector

The energy consumption in India is rapidly rising due to growing industrialization, rising incomes, expanding urbanization, and modernization of agriculture. Most notable increase has been in the electricity sector, where consumption has doubled over the last decade (CMIE, 2000). In past two decades, electricity consumption has grown at a rate higher than GDP and energy (Figure 1) and this trend has become remarkably pronounced in the present decade. Electricity demand, growing at 8.7% annually during the present decade, has outstripped the economic growth rate of 6.2% (Economic Survey, 1990-2000). Electricity consumption per person, which was 90 kWh in 1972, increased to almost 400 kWh in 2000 (TEDDY, 2000). However in global comparison this is still very low, six times below the global average, 5% of that in the U.S.A and, nearly a half of that in China (WRI, 2000).

Figure 1. Growth of energy, electricity, emissions and the Indian economy



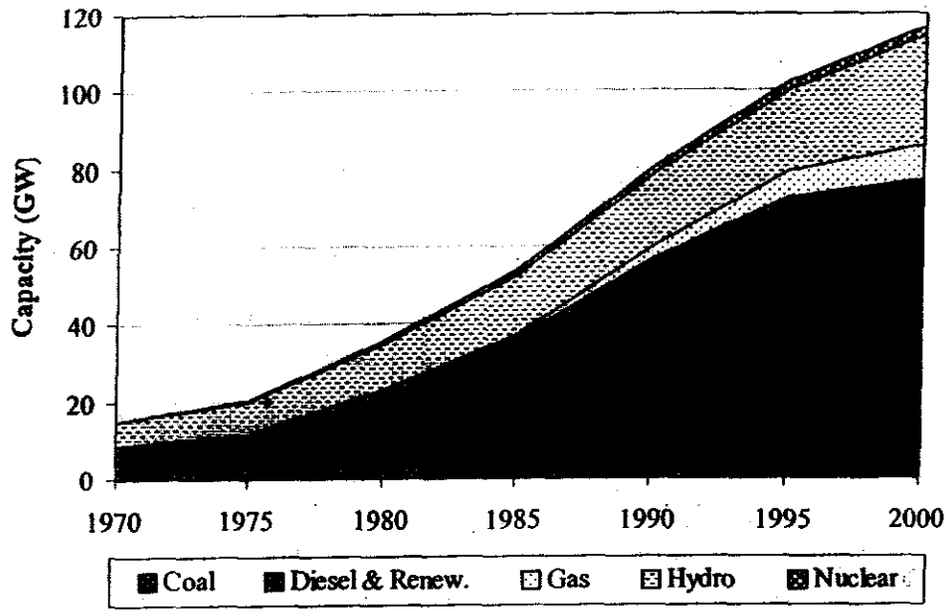
Source: Government of India, Ministry of Finance. *Economic Survey (1990-1998).*

1.1 Growth trends in capacity and generation

Growth in power generation capacity (figure 2), which increased by almost seven folds between 1970 and 2000, was accompanied by a greater diversity of technology mix (CMIE, 1990 to 2000). The present capacity mix (2000) includes a substantial share of coal (61%) and a significant but declining share of large hydro (24%). Almost all the coal plants use sub-critical pulverized coal technology. Gas based power, which has come up mainly during the nineties, has gained an 8% share. Nuclear power has 2% share and renewables around 1.5%. In the last decade, generation capacity grew at 4.4% annually, whereas electricity generation has grown at 7% due to improved plant utilization (CMIE, 2000). There has been a decline in the hydro-thermal ratio for power generation. Thermal power share expanded due to shorter lead time relative to hydro plants, increasing opposition to large hydro projects on social and environmental grounds and higher political risks of hydro projects due to inter-state disputes on power and water sharing. This has added to the peak power problem. India has a hydro potential of 84 GW and only about one third of it has been exploited so far (CEA, 1997).

Gas-fired power has grown from almost nothing to one-twelfth of total generation in the last decade (CMIE, 2000) due to the low risk associated with lower capital requirements, shorter construction periods and higher efficiencies. Compared to the use of coal for power generation, gas use has much lower environmental impacts. With increase in private participation in the power sector, plants are being built in coastal areas near ports with terminals capable of handling liquefied natural gas (LNG). However, inland use of imported LNG remains expensive compared to coal, so natural gas is competitive in these regions only if transported by pipeline directly from the production field. Nuclear power contributes less than 3% to total generation from India's ten nuclear reactors. There has been a considerable improvement in capacity factor of these plants during the last five years and they now operate above 80% as compared to 60% earlier (http://www.npcil.org). Renewables have a small share in the capacity presently. However India has a significant program to support renewable power targeting 12 GW by 2010 (http://mnes.nic.in).

Figure 2. Power Generation Capacity



1.2 Energy consumption

Electricity generation has the largest share in the primary energy consumption in the country with 40% of primary energy and 70% of coal use (CMIE, 1999). Despite enhanced competition from other fuels, coal remains the mainstay of power generation. Domestic availability helps coal to retain competitive advantage over imported fuels that have associated risks from fuel security and exchange rate uncertainties in the long run. A sizable infrastructure of mining and manufacturing industries and transport has evolved around the coal-based power. But lately, certain factors have influenced the investment in power generation to shift to other fuels. The slow additions to domestic coal mining capacity, inadequate coal transportation linkages, relaxation of fuel imports and investments by international power companies who import own fuel needs have been responsible for a preference to gas. This shift has been enhanced by the low risk associated with gas-fired power: it enjoys lower capital requirements and shorter construction periods. Gas based generation has high operational efficiencies and reduced environmental impacts. The long term power purchase agreements, which are based on the

cost plus principle and operating efficiency incentives, have also aided penetration of gas based power.

1.3 Growth in captive power

Faced with an unreliable external power supply, many energy-intensive industries such as aluminum, steel, and fertilizer have invested in on-site power generation, which is growing at an annual rate of 8% (CMIE, 2000). Captive power generation has grown from about 1.6 GW in 1970 to almost 14 GW in 2000 with almost half being coal based. Many captive generating plants have excess capacity that could supply power to the grid given the right policy incentives. Some steps have been taken in this direction regarding wheeling of power and allowing third party sale.

1.4 Transmission and distribution system

Transmission and distribution (T&D) losses now amount to over one-fifth of generated electricity (CMIE, 2000). Commercial losses on account of theft, non-metering and non-billing account for about one-quarter of these losses. Government still maintains monopoly over power transport. Power quality suffers from widening frequency and voltage fluctuations and frequent grid disruptions. Inadequate capacity, inefficient operations, and predominance of low voltage lines (low to high line ratio is above 16) and technological obsoleacence cause these problems. High losses cripple the financial viability of state owned power transport system resulting in a persistent lack of funds for expanding and improving the network.

1.5 Inter-regional transfer of electricity and grid integration

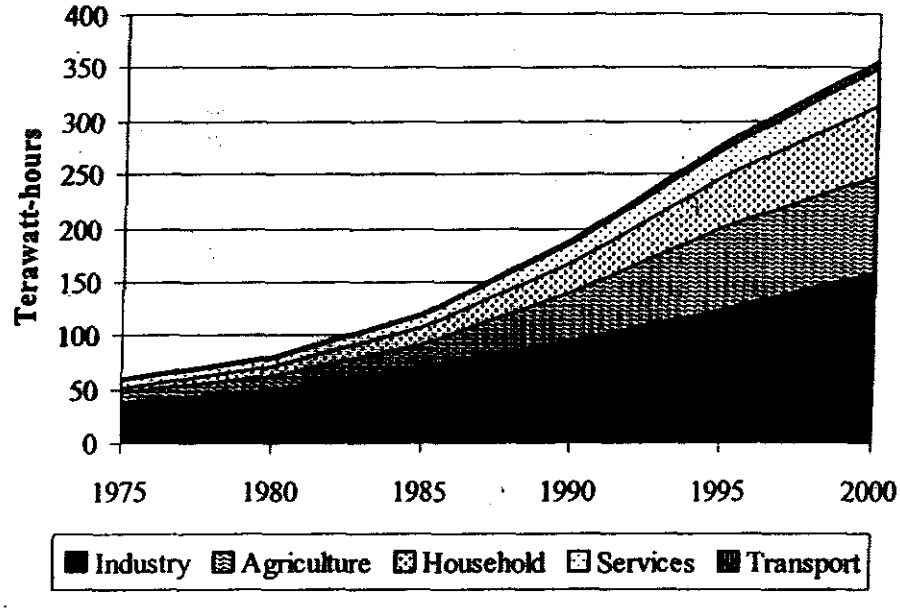
The country is divided into five regional grids with very little trading among the regions. Regional distribution of power generation in India varies significantly due to uneven electricity demand and endowment of resources across the country. Balancing economic advantage of transporting fuels versus transmission of electricity has therefore remained an important issue before national planners. There are opportunities for latter through regional grid integration, which will help in power supply from surplus to deficit regions. This will help reduce T&D losses, peak shortages and overall capacity requirements by

better load management among regions. Despite co-ordination, financial and technical bottlenecks, *grid strengthening* is already underway with plans for completion of the national grid by 2012 (CEA, 1999). Power trading with neighboring countries like Nepal, Bhutan, Pakistan and Bangladesh is also assuming increasing *significance (IE, 1999a and* 2000a).

1.6 Electricity consumption trends

The sector consumption profile has undergone substantial change in past two decades. The agricultural and household sector consumption has grown over 12% annually while total power use grew at 8.6% (figure 3). Industry's total share of power use over the period therefore fell from almost 60% to just under 45% (TEDDY 1995/96 to 2000/01). The phenomenal rise in energy consumption from agricultural activities is due to greater irrigation demand by new crop varieties, very low price of electricity for farmers, and booking some T&D losses as agriculture sector consumption to show better T&D performance by state utilities.

Figure 3. Final electricity consumption by sector



Source: TEDDY, 2000/01.

1.7 Electricity costs and tariffs

The electricity tariff structure in India is the main cause of investment disincentives and widespread demand side inefficiencies. Average tariff has remained below the average cost of supply by almost 20% resulting in a net drain on public funds (TEDDY, 2000/01) (Table 1). The gap mainly arises from subsidized rates to agricultural and domestic consumers. In 1997, the electricity subsidy to agriculture and domestic sector consumers amounted to over Rs. 200 billion which was equivalent nearly to half of new investments in electricity sector in that year (TEDDY 1998/1999). Nearly 80% of this subsidy goes to agriculture with industrial consumers cross-subsidizing half of the total subsidy. The abnormally high rates for industrial consumers erode their competitiveness. Early rationalization of the tariff structure should therefore be an important agenda of the reform process.

Table 1. Average cost of power supply and tariffs (at 2000 prices)

Year	Cost (Rs./KWh)	Tariff (Rs./KWh)	Gap (Rs./KWh)	Tariff/cost ratio
1990	2.19	1.63	0.52	0.75
1994	2.19	1.72	0.47	0.78
1997	2.41	1.93	0.47	0.80
2000	2.81	2.08	0.73	0.74

Source: TEDDY, 2000/2001.

1.8 Environmental Concerns

A number of environmental concerns are associated with power generation in India, mostly with coal and large hydro projects. Over the past three decades, surface mining of coal has increased in India. Poor mining practices have caused significant deforestation, land degradation and contamination of water bodies. While reducing the dependence on coal may seem environmentally sound, it can significantly impact the socio-economic dynamics in coal producing regions of India. The revenues of states like Jharkhand, Bihar, Orissa, Madhya Pradesh and Chhatisgarh, which supply almost 70% of India's coal, depend considerably on the royalties earned from coal extraction. These regions are also among the poorest areas of the country with coal mining being a major source of employment. Any major shift away from coal will have serious socio-economic

implications for these regions. Ironically coal mining has also remained the major source of land degradation and deforestation in these regions. GHG mitigation choices have to take into consideration all these aspects to be consistently integrated within the long- term sustainable national development strategy.

Coal used in Indian power plants has an average ash content of 40% (ESMAP, 1998; Biswas, 2000). This coupled with low combustion efficiencies of around 33% generates large amounts of ash, particulate, sulfur dioxide (SO_2), nitrogen oxides (NO_X), carbon dioxide (CO_2) and heavy metals. Social and environmental impacts of hydro projects have been a cause of major controversies and have lead to massive delays in project completion. Dam construction has caused resettlement and rehabilitation problems (CBIP, 1998b). Managing environmental and social impacts has therefore drawn considerable attention in policy-making, project development and operations.

1.9 Institutional structure

Government has assumed a predominant role in electricity supply, with more than 50% of the generation under the state electricity boards (SEBs) (CMIE, 1999; CEA, 1995b). There are a few central utilities like National Thermal Power Corporation (NTPC) and National Hydro Power Corporation (NHPC). SEBs in particular are wide open to political influence and tariff distortions. Their performance is far from satisfactory, with most of them making huge losses. Recent power sector reforms are aimed at changes in the institutional structure. Rising power shortages, declining efficiencies, poor financial performance and investment shortfalls spurted the reform process. The accompanying institutional changes can be broadly categorized into- corporatization of SEBs, private sector participation, unbundling and regulatory changes.

Corporatization is expected to increase professionalism, reduce political interference and financial accountability. The Regulatory Commissions Act set up the Central Electricity Regulatory Commission (CERC) in July 1998. The proposed functions of CERC include proposing tariff for central government owned utilities and other generating companies selling power to more than one state, regulate inter-state transmission, aid and advise central government in tariff policy and arbitrate in disputes between generation and transmission entities. Regulatory changes have also been undertaken by the states with

most of the states having already set up or in the process of setting up SERC (State Electricity Regulatory Commissions). Its functions include tariff setting, regulate power purchase and procurement for transmission utilities, investment, approval and arbitration of disputes, issue of licenses for T&D and regulating working of licensees, setting quality, continuity and reliability standards and promotion of competitiveness and private sector participation.

2. Power sector future

The future assessment of Indian power sector is based on the current official policies of the government and expert forecasts of macro-economic, demographic and energy sector indicators. It does not attempt to precisely predict the future course of the Indian power sector; it rather indicates general trend under business-as-usual scenario. The reference case is a dynamic representation and includes many pro-environmental measures, such as structural changes in the Indian economy, technology improvements, increased penetration of cleaner technologies and fuels, development of renewable energy, and adoption of end-of-the-pipe environmental technologies (e.g. flue gas de-sulfurisation). Some of these measures are already visible on the ground and the reference scenario merely assumes the dynamics to proceed as usual in future.

2.1 Methodology

The analysis presented here spans four decades and examines a reference scenario and a few carbon mitigation scenarios. It provides insights into the implications of mitigation commitments on Indian power sector fuel-technology mix, carbon emissions, power tariffs, mitigation costs and potential, and investment requirements. Power sector analysis forms an integral part of the integrated analysis of Indian energy system, both demand and supply side. Therefore an integrated modeling framework for Indian economy, energy, electric power and emissions analysis is used (Garg et. al, 2001). This framework has three modules integrating ten independent models; the top-down models, the bottom-up models and other models (figure 4). The models are soft-linked through consistent and similar assumptions for all the models, a shared database and talking between the models. Multiple feedback is required among the models to ensure consistency of results and policy analysis. For the present analysis, we mainly use the results from the bottom-up

module (figure 5). It integrates five individual models:

i) MARKAL - an energy systems optimization model (Berger et al, 1987; Fishbone and Abilock, 1981; Loulou et al., 1997) which is used for overall energy system analysis,

ii) AIM/ENDUSE model (Morita et al, 1994; Morita et al, 1996; Kainuma et al, 1997) which is a sectoral optimization model used to model fourteen end-use sectors,

iii) A demand model which projects demands for each of the thirty seven end-use services,

iv) Stochastic MARKAL model for uncertainty analysis,

v) Power sector linear programming (LP) model for regional analysis.

2.2 Reference scenario results

Reference scenario analysis shows that the all India carbon emissions continue to rise from 212 to about 740 million tons of carbon between 1995 and 2035. The emissions grow very rapidly in the short-term, at an annual average rate of four and a half percent in the next decade. The growth rate slows down in the medium term (3.5 percent between 2010 and 2020) while in the long-term it declines to an annual growth rate of about 1.7%. Power sector emissions also grow at the same rate, maintaining a steady share in the total emissions at about 45 percent.

In the reference scenario, while the economy grows about 6 times in the next 35 years, the demand for electricity grows by only 4 times resulting in a decline in the elasticity of electricity demand from more than 1 at present to about 0.65 in 2035. The growth in the demand for electricity outpaces the growth in energy demand in the economy. While there is a 60 percent decline in the overall energy intensity in the next 35 years, the electrical energy intensity declines by only 25 percent. The decline in the elasticity of electricity demand is due to advancements in technological stock, structural changes in the economy, changing consumption patterns, and demand side management interventions. The per capita electricity consumption becomes three times the present value in the next 35 years, but still remains at about one-fifth of the present per capita electricity consumption in the United States. The power generation capacity increases by 1.5 times in the next 10 years, doubles in the next twenty years and reaches more than three and a half time (395 GW) the

present capacity in 2035. Improvements in the performance of generation technologies cause the electricity generation to grow at a faster rate than the capacity. The average Plant Load Factor (PLF) of base load generating plants increases from about 60 percent at present to more than 70 percent in the next 35 years due to advancements in technologies, improvements in operation and management practices, better grid management practices leading to higher grid availability, and increase in fuel supply reliability. Some specific insights for the technology mix are provided below.

Coal: Coal dominates in the long-term future generation capacity mix, but its use becomes more sustainable with clean coal technology penetration. The coal capacity share declines but improvements in its performance enables it to maintain a high share in generation. Advanced coal technologies like Super-critical Pulverized Coal (PC) technology and Integrated Gasification Combined Cycle (IGCC) penetrate in the medium (2020) and long-term (2035), but their overall share in the coal capacity remains just 10 percent even in 2035. Conventional Sub-critical PC technology penetrates with Flue Gas Desulfurisation (FGD) units, lowering local pollutant emissions from coal power plants considerably. In the medium term, around ten percent of the Pulverized coal plants are fitted with FGD, with their share increasing to as high as 60 percent in the long-term.

Natural Gas: There is an already existing peak demand gap in the power sector. Advancements in gas technologies and rapidly rising peak power requirements increase gas penetration in the medium term. The low investment costs for plants employing combined cycle gas turbine (CCGT) technology, coupled with high conversion efficiencies and availability, make base load power generation using gas competitive with coal at locations far away from the pithead (example, coastal locations) where inadequate coal linkages exist and coal transportation costs are high. There are energy security implications for increasing use of natural gas, as most of the gas requirement has to be supplied by imports due to limited domestic reserves. The gas pipelines from Oman, Iran and Turkmenistan have been under consideration for quite sometime now. The recent gas findings in Bangladesh could also find a natural market in India. In this context, building of gas supply infrastructure like development of ports for imported compressed natural gas, and setting up of reliable and secure transnational and domestic pipeline networks are important issues for India. The foreign exchange requirements for total natural gas imports

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in 2020 is projected to be about US$ 10 billion[1], with the power sector having a 50 percent share in the total consumption. Gas penetration slows down in later periods (beyond 2020), due to lowering of the growth rate in peak demand due to better load management practices and increase in system reliability due to large peak reserve capacity build up. Beyond medium-term, gas share lowers in base load generation with rise in natural gas prices and increasing competitiveness from coal technologies due to advancements in their technological stock and better operating and management practices.

Nuclear: At present, nuclear power plants in India operate at very low capacity utilization, mainly due to highly unstable grids that necessitate very frequent shutdowns. The competitiveness of nuclear power plants is very sensitive to the plant load factor due to a very high fixed cost component and low variable costs. Expectations about improved performance of nuclear plants due to indigenous technological advancements and better grid management practices leading to substantial increase in their capacity utilization increase nuclear penetration from the present 2 to 5 percent in the long-term. There is a nine-fold increase in its capacity in the next 35 years, with socio-political and environmental considerations restricting further capacity increase.

Large Hydro: Large hydro capacity doubles in the next two decades, and reaches about 90 percent of its present estimated economic potential in 2035. Despite the high competitiveness of large hydro technology, its share is restricted to about one-fifth in the total capacity due to the large risks associated with hydro projects caused by long gestation periods, uncertainties in site identification and testing, socio-environmental and political constraints.

Other Renewables: Capacity of other renewable technologies including small hydro, cogeneration, biomass based power generation, wind and solar increase their capacity by more than three times in the next decade with a three and a half percent share in the capacity mix from the present 1 percent. In the long-term, their capacity share increases to 6 percent. Among these renewable technologies, small hydro, cogeneration and biomass technologies are highly competitive and penetrate rapidly, mainly as decentralized power options. Penetration of wind based power generation in the initial years will depend upon a

[1] The cost of infrastructure is not included in it. All cost figures in this paper are in 2000 prices and assume an exchange rate of Indian Rs.47 per US $

technology push policy, targeted at attracting investments, development and strengthening of local manufacturing capabilities. These push policies in initial years, will enhance technology competitiveness in the medium and long-term. Internalization of the environmental costs associated with fossil fuel based power generation will give wind a competitive edge over these technologies. On the other hand, solar technologies penetrate in the medium term due to capacity building through demonstration projects that enhance learning experiences, but long-term penetration will depend largely on international reduction of costs, lowering of their capital intensity and establishing institutions for co-operative R&D and technology transfers.

3. Carbon mitigation scenario analysis

India does not have any GHG reduction commitments presently. However rising emission trends necessitate an understanding and analysis of policy induced mitigation measures such as carbon emission reduction commitments and carbon tax. These policies prompt technology and fuel substitution by changing the relative costs of competing fuels in favor of those with lower carbon contents.

Climate change occurs due to increase in cumulative GHG emissions over long run (SAR, 1996, 1996a). Carbon mitigation targets should therefore be based on cumulative mitigation over long term and annual targets should dovetail into optimum long-term mitigation targets. Cumulative carbon emissions in India are estimated at around 20 billion tons (BT) between 1995-2035 under the reference scenario. A 5% cumulative carbon reduction amounts to about one BT carbon mitigation in forty years. We analyze the impact of cumulative carbon mitigation commitments of 5, 10, 15, 20 and 25% (that is 1, 2, 3, 4 and 5 BT respectively). These are termed as low, moderate, high, extra high and excessive (table 2). The marginal cost of carbon is a model output and it indicates the optimum carbon tax trajectories as MARKAL spreads cumulative mitigation across years and sectors in a cost-effective manner.

Table 2: Carbon Mitigation Scenario Assumptions

Mitigation scenario	Cumulative mitigation over Reference case (1995-2035)		Cumulative carbon emissions 1995-2035 (Billion ton)
	Percentage mitigation	Billion ton of carbon	
Reference	0	0	20
Low	5	1	19
Moderate	10	2	18
High	15	3	17
Extra high	20	4	16
Excessive	25	5	15

Carbon mitigation in India is complicated by the fact that India has large coal reserves, but limited oil and gas reserves. The substitution away from coal will make the country dependent on imported energy, which has energy security implications. While India has experience with emerging renewable technologies, the capital and foreign exchange constraints are likely to restrict a shift away from coal, unless the economic and fiscal policies to relax these constraints are instituted.

Carbon mitigation would require technological transformation of Indian energy system. This will need investments in infrastructure to support new technologies, and reforms to remove the barriers for penetration of advanced technologies and cleaner fuels. Societies with strong reduction commitments would therefore have to start thinking differently. These are captured through different sets of assumptions for each mitigation scenario, as compared to the reference case in the model. For example, in the Excessive mitigation scenario, the average transmission efficiency for electric power in India in 2035 improves to 93% (as against 88% in the reference case), the technological gaps in various sectors between best international practices and India reduce faster, and natural gas supply increases at higher prices.

3.1 Energy consumption and emissions

Some important results for the Indian energy system are indicated in table 3. Inertia of existing technological stock in the energy system prevents significant fuel substitution till the year 2010 for meeting carbon mitigation targets and coal continues to dominate the energy system. However coal consumption declines drastically in the long-term for meeting high mitigation targets. Decline in gas consumption in medium and long term in high and

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excessive mitigation cases is due to increasing penetration of carbon free technologies like renewables and nuclear for power generation. However coal is mainly substituted by natural gas in power sector. While natural gas exhibits early penetration, renewable penetration is late due to their high initial investment costs. Due to the rising gas prices with higher use of gas in later years, the renewable energy penetration becomes higher with rising mitigation targets. Comparing SO_2 elasticity of carbon emission reduction across mitigation scenarios also reflects this. It first increases and then reduces for each carbon mitigation target since gas emits no sulfur while biomass emits sulfur.

Table 3: Results of climate change policy scenarios for Indian energy system

Parameter	Low			Moderate			High			Excessive		
	2010	2020	2035	2010	2020	2035	2010	2020	2035	2010	2020	2035
Coal (% change)#	-2	-5	-24	-4	-17	-38	-9	-27	-51	-20	-47	-90
Gas (% change)#	+1	+3	+19	+1	+10	+14	+1	+18	-9	+0.2	-0.8	-17
Carbon (MT)	398	549	658	386	518	606	377	486	529	362	431	394
SO_2 (MT)	6.22	7.65	6.35	6.09	7.11	5.66	5.87	6.28	4.21	5.48	5.35	3.09
SO_2 elasticity *	1.27	1.20	1.13	0.90	1.22	1.21	1.11	1.46	1.43	1.30	1.36	1.23
MC ($/tC) **	5	14	39	11	21	65	23	41	118	41	83	272

Percentage changes over the reference scenario consumption
* Elasticity of SO_2 reduction with respect to carbon reduction (over the reference case)
** Marginal Cost indicates carbon tax ($/ton carbon)

The Global GHG mitigation regimes would have implications for India's energy system. As power sector has a very large share in the total energy consumption and has almost 50 percent contribution in the total carbon emissions, its energy and technology mix is likely to be altered under carbon mitigation targets. Figure 6 shows the power sector carbon emission trajectories under the mitigation scenarios along with the reference (base) scenario emissions.

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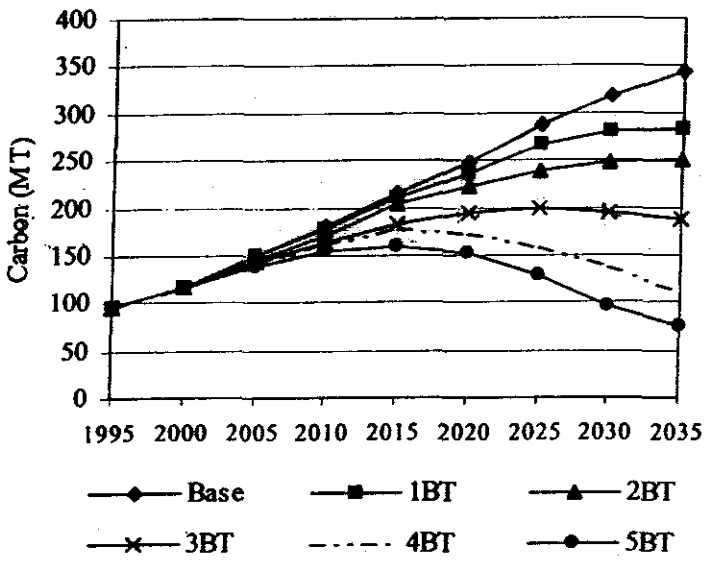
Figure 6: Power sector carbon emissions



3.2 Demand and supply side mitigation dynamics

Analysis of carbon mitigation scenarios provides some useful insights regarding energy supply and demand side contributions to emissions reductions (table 4). In the early periods (2005-2015), the demand sectors show more flexibility than the supply side by contributing more to carbon emission reduction since end-use demand sector technological stock turnover is faster due to their relatively shorter lifetimes[2]. But in later periods, the supply side contribution increases, finally reaching a three-fourth share in the total mitigation in 2035. These, however, include emission reduction due to lower power generation requirements as demand side energy efficiencies improve. The inertia of supply side technology turnover is due to their much longer lifetimes, high investment requirements and longer gestation period for infrastructure development. The supply side mitigation options are primarily associated with fuel switching from coal to natural gas. Long-term options include penetration of carbon-free technologies like nuclear and renewable technologies. Judged from a market perspective, there are large inefficiencies on

[2] The demand side includes all end-use demand technologies that consume electricity like electric arc furnace for steel making and fluorescent lamps for lighting. The supply technologies are the electricity generation technologies.

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the demand side due to capital shortages, risk, high transaction costs and weak financial markets. The supply side is better organized and has lower inefficiencies.

Table 4: Power Sector contribution in Carbon Mitigation

Scenarios	Parameters	2010	2020	2035
Low (1 BT)	Carbon mitigation (MT)	3	11	62
	Share in total mitigation (%)	37	50	77
	Demand side contribution (%)	31	28	14
	Supply side contribution (%)	69	72	86
High (3 BT)	Carbon mitigation (MT)	15	54	156
	Share in total mitigation (%)	52	64	75
	Demand side contribution (%)	45	37	28
	Supply side contribution (%)	55	63	72
Excessive (5 BT)	Carbon mitigation (MT)	25	96	270
	Share in total mitigation (%)	58	68	79
	Demand side contribution (%)	46	32	25
	Supply side contribution (%)	54	68	75

Supply side contribution increases in the medium and long term with retirement of existing capacities and progressively new capacity built up. Table 5 shows the technology shares in electricity generation capacity in the reference and carbon mitigation scenarios.

There are no significant changes in the supply technology mix in the short-term (2010) under low and high carbon mitigation scenarios. The excessive carbon mitigation scenario results in a 20 percent decline in the coal capacity in the short-term with higher shares of natural gas and other renewable technologies.

In the medium term (2020), alterations in the technology mix are caused mainly by capacity increases of gas and other renewable technologies. High carbon mitigation scenario leads to a 30 percent increase in wind power capacity and the renewable capacity doubles over the reference scenario. Moreover, there is a 45 percent increase in large hydro capacity, thereby increasing its share in the generation capacity mix to about 29 percent.

In the long-term (2035), carbon mitigation causes significant alterations in the technology mix. Coal substitution takes place by large increases in the shares of carbon free technologies like large hydro and nuclear, especially in the high and excessive carbon mitigation cases. Cumulative mitigation of 5 BT carbon causes around 90 percent decline

in the coal capacity compared to the reference scenario in 2035. Large hydro capacity increases by about 80 percent over reference, thereby contributing over one-third in the generation capacity mix, while nuclear rises by a staggering 125 percent that brings its share in the capacity mix to 13 percent (table 5).

Table 5: Technology shares in generation capacity (%)

Technology	Scenario	2010	2020	2035
Coal	Reference scenario	57	51	49
	Low mitigation scenario (1 BT)	57	49	39
	High mitigation scenario (3 BT)	54	41	28
	Excessive mitigation scenario (5 BT)	51	32	7
Gas	Reference scenario	13	17	20
	Low mitigation scenario (1 BT)	13	18	24
	High mitigation scenario (3 BT)	13	22	27
	Excessive mitigation scenario (5 BT)	14	23	32
Hydro	Reference scenario	21	21	19
	Low mitigation scenario (1 BT)	21	21	21
	High mitigation scenario (3 BT)	22	23	26
	Excessive mitigation scenario (5 BT)	23	29	32
Nuclear	Reference scenario	3	4	5
	Low mitigation scenario (1 BT)	3	4	7
	High mitigation scenario (3 BT)	3	5	8
	Excessive mitigation scenario (5 BT)	3	5	13
Other Renewable +	Reference scenario	4	5	6
	Low mitigation scenario (1 BT)	4	6	8
	High mitigation scenario (3 BT)	5	7	10
	Excessive mitigation scenario (5 BT)	7	10	15

+It includes small hydro, wind, biomass, cogeneration and solar technologies
Note: The percentage shares in the table do not add up to 100 as the remaining is accounted for by oil based generation

3.3 Energy consumption

Carbon mitigation targets cause substantial changes in the power sector coal and gas consumption (table 6). Coal consumption declines drastically in the long-term for meeting high mitigation targets. Decline in gas consumption in medium and long term in high and excessive carbon mitigation scenarios is due to increasing penetration of carbon free technologies like renewable and nuclear to meet the mitigation targets.

Table 6: Change in energy consumption over reference scenario (%)

Scenario	Fuel	2010	2020	2035
Low mitigation scenario (1 BT)	Coal	-2	-5	-24
	Gas	+1	+3	+19
High mitigation scenario (3 BT)	Coal	-9	-27	-51
	Gas	+1	+18	-9
Excessive mitigation scenario (5 BT)	Coal	-20	-47	-90
	Gas	+0.2	-0.8	-17

3.4 Electricity supply costs

In the reference scenario, there is a 20 percent decline in the average long run marginal cost of electricity supply over the next 35 years. In the reference scenario, the cost declines by about 4 percent in the next decade, increases in the medium term due to rise in energy cost and declines in the long term due to technological advancements. However there are significant changes in the electricity supply costs when carbon emission constraints are imposed on the energy system as power sector energy and technology mix are altered substantially (Table 7).

In the short-term, 5 to 10 percent cumulative carbon mitigation targets over the base scenario lead to less than 5 percent increase in the electricity supply cost due to coal substitution by natural gas. But higher mitigation cases increase the cost quite substantially even in the short-term due to penetration of costly renewable technologies. Cumulative mitigation targets of about 5 to 10 percent over base scenario increase the electricity supply cost by 8 to 10 percent in the medium term. Large increases in the electricity supply cost in the long-term are caused by substantial alterations in the technology mix (table 5). Cumulative carbon emission mitigation requirements of more than 20 percent over base scenario emissions cause substitution of a very large fraction of fossil fuel based generation capacity with high cost carbon free technologies like renewables and nuclear, that causes drastic increases in the electricity supply cost.

Table 7: Electricity supply cost in carbon mitigation scenarios (Rs./kWh)

Scenarios	2010	2020	2035
Low carbon mitigation % change*	2.02 (3.5)	2.18 (7.9)	2.07 (27.2)
Moderate carbon mitigation % change	2.03 (4.4)	2.22 (9.8)	2.18 (34)
High carbon mitigation % change	2.26 (15.8)	2.52 (24.4)	2.38 (46)
Extra high carbon mitigation % change	2.32 (19.2)	2.74 (35.3)	2.57 (58)
Excessive carbon mitigation % change	2.52 (29.6)	2.92 (44)	2.93 (80)

** This refers to the percentage change over the reference scenario cost*

4 Conclusion and Recommendations

This paper outlines the long-term carbon mitigation issues in the Indian power sector and their policy implications. The important conclusions and recommendations are highlighted below.

The Global greenhouse gas agreements that are likely to initiate the setting up of a global carbon market would have implications on India's energy system. India's participation in the global carbon market will depend upon the mitigation costs and the global carbon prices, i.e. participation possibilities arise only when the marginal benefits are greater than the marginal costs. At a global carbon price of 10$/tC, low mitigation trajectory would be optimal and under 20$/tC price, moderate mitigation trajectory would be optimal. The contribution progressively reduces under higher mitigation targets as the revenue falls below the costs, assuming a steady global carbon price of 20$/tC.

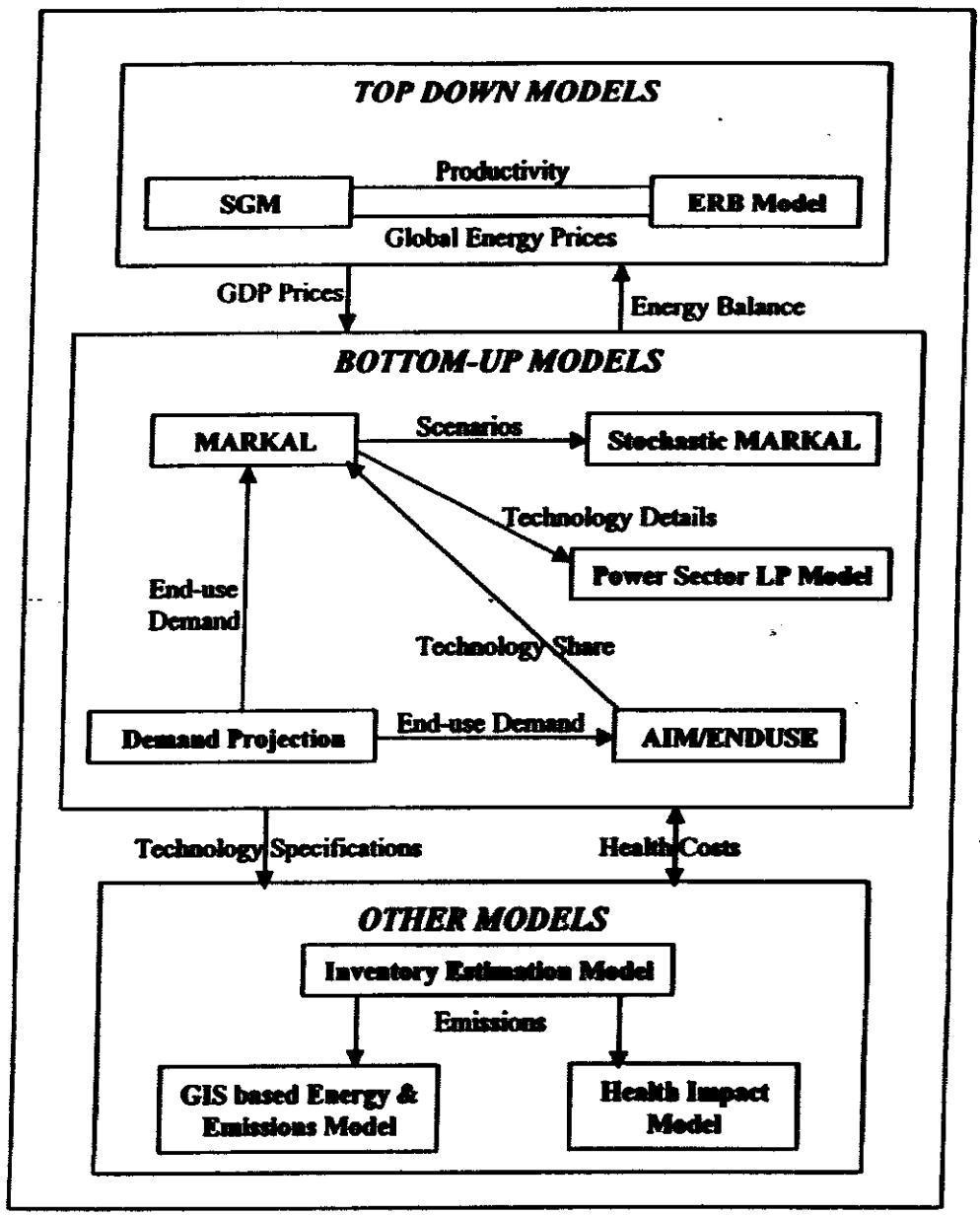
Power sector has a significant contribution in the overall energy sector emission mitigation. Following the long-term optimal carbon mitigation trajectory alters the competitive dynamics of the power sector. In the short-term, end-use demand sectors offer more flexibility for emission reduction than power generation as a result of lower lifetime of the technologies and large scope for technology advancements due to existing large inefficiencies in the demand side. Improvements in efficiencies of electricity consuming demand side technologies in industries, residential, agriculture and commercial sectors

along with transmission and distribution efficiency improvements offer substantial reduction potential by lowering the overall generation requirements. In the medium and long term, electricity generation contribution increases due to substantial shifts in the energy and technology mix. Gas and renewable technologies substitute coal in the medium term, while in the long-term, there is high penetration of carbon-free technologies like large hydro and nuclear. A hedging strategy, therefore, is to keep the energy and technology mix diverse and flexible.

India has gained considerable experience in operation of conventional coal technologies such as Sub-critical Pulverized Coal (PC) technology. However barriers remain in the adoption of some advanced coal technologies like Super-critical PC technology that has high technical and economic potential, but low market deployment potential. It is in wide commercial application in other countries of the world. The deployment and large-scale commercialization of this technology in India will largely depend on institutional and public support with government measures in the initial stages of technology penetration like pricing policies, taxation, incentives, standards and regulations, and information and training programs. Along with these, removal of certain technical barriers, like maintaining high quality fuel supply, needs to be ensured. But for deployment of much advanced technologies like Integrated Gasification Combined Cycle (IGCC) that has high technical potential but low degree of commercial applications in other countries of the world, strong push policies will be necessary in early years along with information exchange programs among countries. The long-term penetration will depend on expectations on realization of the economic and market deployment potential of the technology in integration with its technical feasibility. Some of the barriers in the penetration of renewable energy technologies are lack of existing infrastructure, relative technical and economic immaturity, inadequately demonstrated reliability and maintainability, and a need for economies of scale associated with component manufacture and deployment techniques. Renewable energy technologies can operate in synergy with conventional energy systems. Hybrid systems can enhance overall system robustness and flexibility. The penetration and application of renewable energy sources like Solar PV technology with low economic and market deployment potential will be dependent on international co-operation. Progress is contingent upon successful policy integration and improvements achieved through R&D in order to lower capital costs and enhance system capability.

Carbon emission mitigation leads to rise in electricity costs, especially in the long-term. India's participation in the global carbon mitigation regimes, with a cumulative carbon mitigation target of 2 BT during the period 2005-2035, leads to about 10 percent increase in the supply cost in the medium term and above 35 percent in the long-term. Higher mitigation requirements can result in more than 50 percent increase in the electricity supply cost over the reference scenario in the long run due to penetration of costly carbon-free technologies. Policies targeted at recycling the revenue generated from emission reductions, back to the sectors contributing in emission reduction can assist in lowering of mitigation costs and ensure the sustainability of the regime in the long-term.

Figure 4: Soft-linked Integrated Modeling Framework



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DRAFT RESEARCH PAPER ON MITIGATION IN SELECT SECTORS-BUILDING MATERIALS AND CONSTRUCTION SECTOR

- BY DR. JYOTI PARIKH

SUSTAINABLE PRACTICES FOR CONSTRUTCION SECTOR IN INDIA

1. Introduction

Construction sector is the driving force behind the economy. Building materials are closely linked with the construction sector, whether they are needed for infrastructure, housing, trade or development projects like irrigation, hospitals or schools these sectors represent aspiration of individuals, communities, and societies backed (or hindered) by government policies.

The relative importance of construction in the Indian economy can be assessed by the fact that around 36.5% of gross domestic investment in 1996-97 is accounted for by the construction sector. The share of construction sector in the GDP in India was around 5.6% in 1996-97 and is projected to grow to 7.4% upto 2005-06 (NICMAR, 1998). Construction is an important component of investment in many other sectors. Construction sector is strongly linked with house construction, road construction, port and waterways, airports, railways, construction of canals and irrigation systems and so on. Each of these activities has a very different range of building materials requirements.

Some of the building materials (BM) required for construction are energy intensive. An associated issue with the high-energy intensiveness of building materials is the high volume of emissions that are released due to the burning of fossil fuels in the manufacturing process of these building materials. An economy-wide analysis by Parikh et al (1995) on sectoral CO_2 (carbon dioxide) emissions using an input-output table based modeling approach for India shows that construction is the largest CO_2-emitting sector by final demand with its share of around 17.0% when direct and indirect emissions are considered.

2. Overview of the Construction Sector (CS)

Why do we need to look at this sector in detail in the context of greenhouse gases (GHG) emissions? First, because of its high share in most investment and infrastructure projects. Second, it requires energy intensive materials. Third, it is also highly GHG intensive in terms of overall magnitude. We now see each aspect in detail below.

Table 1 shows how important is the construction component in every sector of the economy in India. Obviously, housing, roads, commercial buildings have 100% component as they are synonymous with CS. The share of CS in irrigation, highways, urban development such as water supply and so on is 70 to 80%. Even service oriented sectors such as tourism, civil aviation, posts and railways have high shares of CS ranging from 40% to 60%.

Table 1 presents the construction component of the investment in various sectors of the economy.

Table 1: Construction component of investment in key sectors

Sector	Construction as % of total
Agriculture	34
Rural development, Poverty alleviation programmes	40
Irrigation and flood control	80
Environment and forests	60
Power (hydro, thermal, nuclear and others)	50
Housing	100
Roads and buildings	100
Highways and waterways	80
Ports, docks and lighthouses	50
Railways	42
Communication, information and broadcasting	40
Industries	30
Mineral and mining	42
Education and culture	25
Social welfare	30
Health	37
Urban development, water supply, sanitation, city level services	70
Civil aviation	42
Tourism, hotels and hospitality industries	60

Sources: NICMAR, 1998 and Our estimates

Table 2 shows energy requirements of building materials in the units of megajoules (MJ) per kg. These are very high for Aluminium, Plastics, copper and steel. The table also gives materials with low energy contents. Moreover, construction sector is a major providers of employment.

Table 2: Energy requirements of building materials

Materials	Primary energy requirement (MJ/Kg)
Very high energy	
Aluminium	200-250
Plastics	50-100
Copper	100+
Stainless steel	100
High energy	
Steel	20-60
Lead, Zinc	25+
Glass	12-25
Cement	5-8
Plaster board	8-10

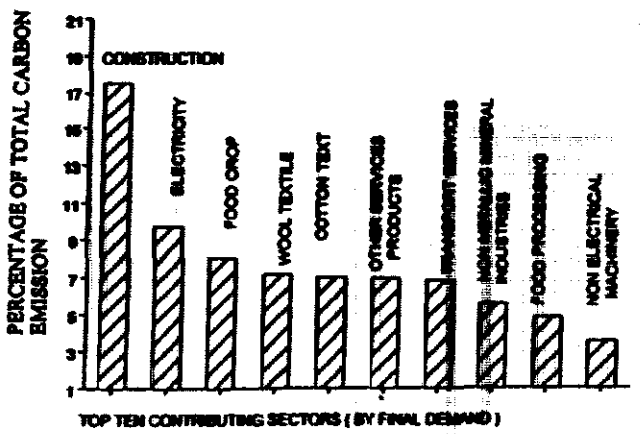
10.

Medium energy	
Lime	3-5
Clay bricks and tiles	2-7
Concrete In situ Blocks Precast	 0.8-1.5 0.8-3.5 1.5-8
Sand lime brick	0.8-1.2
Timber (sawn)	0.1-5
Low energy	
Sand, aggregate	<0.5
Fly ash	<0.5
Soil	<0.5
Mud blocks	<0.2

Source: Building materials in India: 50 Years – A commemorative volume, edited by T. N. Gupta (Building Materials and Technology Promotion Council, New Delhi, India, 1998).

Using input-output table for 1989-90, Parikh et al (1995) showed that when the direct and indirect emissions are considered construction was the most carbon-intensive sector in the economy as it required energy intensive building materials such as aluminium, steel, bricks, glass, cement, plastics and so on. It is for this reason that we undertake a special study on construction sector.

FIGURE 1
DIRECT AND INDIRECT CARBON EMISSIONS : 1989-90
(as a percentage of total carbon emissions)



Source: Parikh J.(1995)

3. Methodology

The objectives of this paper are two fold (I) to estimate the future requirements of building materials (ii) to analyze the possibility of substitution among building materials towards less emission intensive materials.

We have adopted the following procedure:

Step 1: We project the total construction investment based on the data from NICMAR (1998) and India Infrastructure Report (1996).

Step 2: We project key building materials based on their current trends.

Step 3: We estimate the relative shares of key construction components and use them to estimate the share of different construction activities.

Step 4: Using our technical models (Tiwari, Parikh and Parikh 1999 and Tiwari, 2001) we project the building materials requirements for new construction.

Step 5: Finally we estimate the possibilities of reducing emissions by substituting alternative techniques.

As a first step we estimate the value of proposed construction, which is given in Table 3 based on a simple line projection of the data from NICMAR (1998). The table indicates that the construction investment in 2000-01 is Rupees 1669.9 billion and will grow to Rupees 4073.3 billion at current prices.

Table 3: Annual estimated value of proposed construction (Billion Rupees)

Year	Value of construction (Current prices)	*Value of construction (Constant prices 2000-01=100)
2000-01	1669.9	1669.9
2001-02	1842.7	1738.4
2002-03	2035.2	1817.1
2003-04	2250.1	1906.8
2004-05	2490.3	2008.3
2005-06	2759.1	2122.4
*2006-07	3060.4	2250.3
*2007-08	3366.3	2370.6
*2008-09	3703.0	2502.0
*2009-10	4073.3	2638.1

Source: India infrastructure report, 1996
NICMAR, 1998
*Based on our estimates.

Table 4 presents the share of different construction activities in total investment for 1995-96. We have assumed that the share of different activities would remain same till 2009-10.

Table 4: Share of various construction activities in total construction investment in 1995-96

Sectors	
Housing	50%
Urban services, Electricity, Gas and Water supply	24%
Industries	10%
Highways	6%
Railways	4%
Ports	1%
Telecommunication	4%
Others	1%

Source: Our estimates

Table 5 presents the total investment in different construction activities based on the shares of table 4.

Table 5: Projected construction investment in various sectors
(Billion Rupees, at 2000-01 Constant prices)

	Housing	Urban services	Industries	Highways	Railways	Ports	Telecom	Others
2000-01	835	401	167	100	67	17	67	17
2001-02	870	417	174	105	70	17	70	17
2002-03	909	436	182	109	72	18	72	18
2003-04	953	458	191	114	76	19	76	19
2004-05	1004	482	201	120	78	20	78	20
2005-06	1062	509	212	128	85	22	85	22
2006-07	1125	540	225	135	90	23	90	23
2007-08	1185	569	237	142	95	24	95	24
2008-09	1251	601	250	150	100	25	100	25
2009-10	1323	635	264	158	106	27	106	27

Source: Authors estimates

To project the building materials requirements we use the projected value of construction as given in Table 5 as the upper limit of construction investment in that sector. We translate this investment into the construction activity that can be carried out and finally estimate the requirements of building materials under the Business-As-Usual (BAU) scenario. We will focus on the housing, highways and industries, which together constitute 66% of the construction activity in India. We overview the existing sectoral features and Government policies and try to match up the policies (projected construction targets) with the projected investment of table 5, with table 4 as the upper bound. The results of the BAU scenario are presented in the section 2.

4 BUILDING MATERIALS REQUIREMENTS UNDER BUSINESS-AS-USUAL

4.1 HOUSING

4.1.1 HOUSING SECTOR IN INDIA

The aggregate picture of the housing situation in India can be judged from the relative *quantitative and qualitative* improvement in the total residential houses, vis-a-vis the household growth rate during 1981-91[1]. From the data presented in Table 1 it is seen that the growth during 1981-91, in the total residential houses, has been higher than the household growth overall and separately for rural and urban areas. Qualitatively also the dwelling units have exhibited significant improvements. The proportion of *pucca*[2] houses has gone up significantly both in rural and urban areas *almost by 8 per cent during 1981-91*.

Despite the quantitative and qualitative improvements in housing stock in India, the housing shortage persists. The Planning Commission (1992) estimates the housing shortage in 1991 at 18.5 million units (Table 6). The growth in housing supply has always lagged behind the demand as shown in Table 7. During last census decade (1981-91), there have been slight improvements in the growth rate of housing supply, but there already exists a huge unmet demand.

Table 6: Quantitative and qualitative aspects of houses during 1981-91

	Total Residential houses(Mn.)		Percentage decadal growth		Average household size	
	1981	1991	Resi. Houses	Households	1981	1991
Total	148.63	155.43	31.02	25.2	5.6	5.53
Rural	89.59	112.87	25.99	21.22	5.63	5.56
Urban	29.04	42.56	46.55	37.73	5.52	5.45

Proportion of households with house quality type					
Pucca		Katcha		*Semi-pucca*	
1981	1991	1981	1991	1981	1991

[1] We have based our discussion on the 1991 Indian Census data. The data collected during the 2001 Census is not yet available.

[2] Pucca houses: Houses with wall and roof made of permanent materials. Material of wall can be burnt brick or other metal sheets, stone, or cement concrete. Roofs can be made of tiles, slate, shingle, iron, zinc or other metal sheets, bricks, lime and stone, stone and reinforced concrete.
Kutcha: Houses with wall and roof made of temporary materials. Wall may be made of grass, leaves, bamboo, mud, unburnt bricks or wood. Roofs may be made from grass, leaves, bamboo, thatch, burnt brick or wood.

Total	32.67	41.61	34.04	27.44	33.29	30.95
Rural	22.53	30.59	40.55	33.76	36.93	35.65
Urban	64.7	72.75	13.50	9.56	21.8	17.69

Housing Shortage (Million Units)	Total	Rural	Urban
1991 housing census	18.5	13.7	4.8

Source: Planning Commission (1992)

TABLE 7: HOUSING NEEDS *VIS-A-VIS* HOUSING SUPPLY

	Additional Houses Needed (millions)	Additional Housing Stock Added(millions)
1971-81	44.8	23.7
1981-91	49.9	31.4

Source: Planning Commission (1992)

4.2.2 BUILDING MATERIAL REQUIREMENTS IN HOUSING

The demand for building materials in housing emanates from two facts: (I) construction of new houses, and (ii) maintenance, extension, repairs of existing houses. It is possible to have an idea about the planned construction of new houses through Government policy documents but estimating the construction activity for maintenance, extension or repairs is not possible. To project building materials in house construction, we adopt following procedure.

1. We estimate building materials requirement for the new house construction activity.
2. We guesstimate the amount of maintenance, repairs, extension from the total investment in housing construction minus the investment required for new house construction,
3. We use material required per billion Rupees of investment in new housing as a norm and apply this norm to estimate building materials required for maintenance, repairs etc.

4.2.2.1 BUILDING MATERIALS FOR NEW HOUSING CONSTRUCTION

The Indian Government, through its 'National Agenda' has set a target of constructing two million houses every year (Ministry of Urban Affairs, 1998). For the purpose of this paper, we will focus on the target of two million houses ever year and would analyze the building materials required to meet this target under the Business-as-usual scenario. Table 8 presents the distribution of households according to he number of rooms. The proportion of each type of house that would be constructed is assumed according to Table 8.

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Table 8: Distribution of households according to rooms in 1991

Number of Rooms	Percentage of households
1	41.41
2	30.58
3	13.85
4	7.14
5 or more	7.02

Source: Census of India 1991 Housing and Amenities, Paper 2 of 1993

Based on the technical model (Tiwari, Parikh and Parikh, 1999; see appendix I) we estimate the materials requirements for the construction of two million new houses every year. Since the number of houses to be constructed is two million each year during the period under consideration (2000-10), we have quoted below the cost, carbon dioxide emissions and building materials requirements for 2000-01.

Table 9: Cost of various inputs

	Value (Billion Rupees)	Carbon dioxide emissions (Million tonnes)
2000-01	275	38900

The requirements for building materials are given in Table 2.5.

Table 10: Building materials requirements in each year (BAU case)

Building materials	Quantities
Cement (Mt)	13.99
Bricks(billion)	36.1
Coarse sand (Million m^3)	34.7
Fine sand (Million m^3)	8.13
Stone aggregate (Million m^3)	30.4
Steel (thousand tonne)	529.2

4.2.2.2 BUILDING MATERIAL REQUIREMENTS FOR MAINTENANCE, REPAIR, EXTENSION ETC. OF EXISTING HOUSES

To estimate the total building materials required for maintenance, repair and extension, etc., we use materials intensity per billion Rupees in investment in housing as a norm and we apply the same materials intensity to the available investment for this purpose. Table 11 presents the material intensity for the housing sector.

Table 11: Material intensity for building construction in the housing sector

	Material intensity of the housing sector (Material per Billion Rupees in investment)
Cement (Mt)	0.051
Bricks(billion)	0.13
Coarse sand (Million m^3)	0.13
Fine sand (Million m^3)	0.03
Stone aggregate (Million m^3)	0.12
Steel (thousand tonne)	1.91

Using the material intensity of Table 11, we have projected the materials required for maintenance, repair and extension every year. Table 12 presents the building materials requirement for this activity.

Table 12: Material requirements for the repair, maintenance and extension in housing sector (CP-BAU case)

	Cement	Bricks	Coarse sand	Fine sand	Stone aggregate	Steel	Carbon dioxide emissions
Units	Million tonnes	Billion	Million m^3	Million m^3	Million m^3	Thousand tonne	Billion tonnes
2000-01	28.56	72.8	72.8	16.8	67.2	1069.6	78.96
2001-02	30.345	77.35	77.35	17.85	71.4	1136.45	83.895
2002-03	32.334	82.42	82.42	19.02	76.08	1210.94	89.394
2003-04	34.578	88.14	88.14	20.34	81.36	1294.98	95.598
2004-05	37.179	94.77	94.77	21.87	87.48	1392.39	102.789
2005-06	40.137	102.31	102.31	23.61	94.44	1503.17	110.967
2006-07	43.35	110.5	110.5	25.5	102	1623.5	119.85
2007-08	46.41	118.3	118.3	27.3	109.2	1738.1	128.31
2008-09	49.776	126.88	126.88	29.28	117.12	1864.16	137.616
2009-10	53.448	136.24	136.24	31.44	125.76	2001.68	147.768

4.2 INDUSTRIES

The share of industries in total construction investment is 10% in 1995-96. We assume this yearly share would remain same up to 2009-10. The construction activities of industries require the building of industrial premises. It is not easy to generalize the nature of industrial buildings because the type of building would depend on the type of load that industry is envisaged to expect. However, as a guiding principle, we assume that the basic unit of construction of industrial buildings is similar to housing. This may at most be considered as the lower bound for the materials requirements.

Using the material intensity of Table 11, we project the materials requirement in the industrial sector. Table 13 presents the materials requirements in the industrial sector.

Table 13: Material requirements in the industrial sector (CP-BAU case)

	Cement	Bricks	Coarse sand	Fine sand	Stone aggregate	Steel	Carbon dioxide emissions
Units	Million tonnes	Billion	Million m^3	Million m^3	Million m^3	Thousand tonne	Billion tonnes
2000-01	8.4	21.54	21.03	5.01	20.04	315.6	23.34
2001-02	8.76	22.44	21.93	5.22	20.88	328.8	24.33
2002-03	9.18	23.49	22.92	5.46	21.84	344.1	25.44
2003-04	9.63	24.63	24.06	5.73	22.92	360.9	26.7
2004-05	10.14	25.92	25.32	6.03	24.12	379.8	28.08
2005-06	10.68	27.36	26.7	6.36	25.44	400.8	29.61
2006-07	11.34	29.04	28.35	6.75	27	425.4	31.44
2007-08	11.94	30.6	29.85	7.11	28.44	447.9	33.12
2008-09	12.6	32.4	31.5	7.5	30	472.5	34.92
2009-10	13.32	34.2	33.3	7.92	31.8	498.9	36.9

4.3 HIGHWAYS

As a share of total construction investment, highways constitute around only 4%. However, the nature of highway construction activity is highly polluting. There are two primary methods of highway construction. These methods depend on the type of construction material used. The cement-concrete roads use concrete slabs as the road surface, while bitumen road use bitumenous wearing coat. There are life cycle differences in the maintenance cost of these two types of roads. The yearly maintenance cost of concrete road is Rupees 2000 per Km. As against Rupees 50,000 per Km for bitumen road. However, in India, almost all of the road construction activity uses bitumen based. Table 14 presents the cost comparison of concrete and bitumen roads for one Km. Stretch.

Table 14: Cost Comparison -Concrete road versus Bitumen Road
(For one kilometer stretch)

Parameter	Concrete road	Bitumen road
Width (single lane)	3.5 Mtr	3.5 Mtr
Base course thickness	150 mm	300 mm
WBM thickness	Not required	225 mm
Wearing coat thickness	Not required	20 mm
Concrete slab thickness	200mm	Not required
Total pavement thickness	350 mm	545 mm
Average initial cost per Km	Rs. 2.6 Million	Rs. 2.3 Million

Source: Our estimates

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As a base case, we will designate the bitumen road as the base case, because this is the type of road typically constructed in India. Road construction involves many associated activities like bridges, culverts, underpass and overpass etc. To account for all these would require very detailed information, which is very difficult to obtain for future periods. We estimate the building materials requirements with the assumption that highways do not have bridges etc. This would bias our estimate downwards. The material requirements may at best be considered as lower bound. We use the total investment in the highways construction sector as the bound and estimate the material requirement for the construction of road for the investment available. The materials requirement for different years is presented in Table 15.

Table 15: Requirement of construction materials for bitumen road construction

Year	Coarse sand (Million cubic meter)	Bitumen (Million tons)	Diesel (Million litre)	Soling stone (Million cubic meter)	Coal (Million tonnes)	Carbon dioxide emission (Million tonnes)
2000-01	79.7	10.2	118.3	12.3	2.04	316000
2001-02	83.7	10.7	124.2	12.9	2.14	331800
2002-03	86.9	11.1	128.9	13.4	2.22	344440
2003-04	90.9	11.6	134.8	14.0	2.33	360240
2004-05	95.6	12.2	141.9	14.7	2.45	379200
2005-06	102.01	13.1	151.4	15.7	2.61	404480
2006-07	107.6	13.8	159.6	16.6	2.75	426600
2007-08	113.2	14.5	167.9	17.4	2.90	448720
2008-09	119.6	15.3	177.4	18.4	3.06	474000
2009-10	125.9	16.1	186.8	19.4	3.22	499280

5. ALTERNATIVE TECHNOLOGIES TO MITIGATE EMISSIONS AND MATERIAL REQUIREMENTS

5.1 HOUSING

As we have discussed earlier that housing activity involves two types of construction activities: (I) construction of new houses and (ii) repairs, maintenance and extension of existing houses. It is possible to use alternative energy efficient technologies for both these activities but the technological possibilities are rather limited for existing houses. For example, for an existing house, it would not be possible to replace an existing brick wall with mud blocks wall. In this section, we have therefore restricted ourselves only to the new construction houses.

In the Business-As-Usual scenario, we assumed that the houses are constructed as usual with bricks and cement, the commonly used building materials in India. Using our

technical model (Tiwari, Parikh and Parikh, 1999), we introduce various alternative construction technologies and the model is solved with an objective to minimize cost and Carbon dioxide emissions. Some technical definitions are required before presenting the scenarios.

Common practices: We define common practices as the case where the construction materials like bricks, stone, cement and concrete is used for construction. The technical alternatives in this type of construction presents a choice between brick masonry or stone masonry.

Low cost techniques(Doat et.al.,1991; Balkrishnan; Eashwaran; Niazi; Radhika et.al.,1993; Sharma, Sreedevi; Sriraman,1993a; Sriraman,1993b; Valmeekinathan)

A number of construction technologies using cost effective, low energy building materials are available. We have compiled these building materials and technologies and they have been incorporated into our technical model. The techniques considered are briefly and broadly discussed below.

Hollow Concrete Blocks (Jain,1992)
These are generally made of 1:5:10 cement, sand, stone aggregate on a gospel machine which has a vibrator and a ram. The blocks are of size 40x20x10 cm^3 and are around four times the size of ordinary bricks. They are used in wall construction.

Hollow Concrete Blocks with Flyash(Jain,1992)
These are similar to the hollow concrete blocks with a difference that 25% of cement is substituted with flyash. Their application is in wall construction.

Balram techniques(Nathan and Revi, Singh)
These techniques of compressed mud blocks have been developed by Development Alternatives for their use in wall construction. The size of the blocks is 20x10x10 cm^3. The average strength of these blocks is around 14-16 Kg/cm^2. Though this is less than the compressive strength of fired clay bricks of 35 Kg/cm^2, but is sufficient to take loads upto three floors provided the minimum thickness of wall is one block thick. The total number of operators required for 1500 blocks is around five. Sometimes, these blocks have to be stabilised using stabilisers such as cement, lime, flyash etc. if the quality of soil is not good or the construction is in the zone which has high rainfall. The alternative components of these mud blocks are following. These have been named as Balram with suffices one to ten.
Balram 1: Good local soil
Balram 2: Local soil + maximum 50% outside soil
Balram 3: Local soil + 5% cement stabilised
Balram 4: Local soil + 5% cement stabilised + 50% outside soil
Balram 5: Local soil + 8% lime stabilised
Balram 6: Local soil + 8% lime stabilised + 50% outside soil
Balram 7: Local soil + 4% asphalt, bitumen or cutback stabilised
Balram 8: Local soil + 4% lime + 8% flyash stabilised
Balram 9: Mud block is dipped in a mix of one part sodium silicate and three parts water.

Balram10: Local soil + 5% molasses as stabilizers

Filler slab with 2 M.P. tiles (Parikh,1974)
These have been developed by Central Building Research Institute, Roorkee. These are flat slabs and can be used for floors as well as roofs. The basic idea is to substitute substantial portions of concrete below the neutral axis which does not contribute anything to the strength of slab by M.P. tiles. This not only saves the concrete but also makes the structure light.

Filler slab with Manglore tiles (Parikh,1974)
In this method the redundant concrete is substituted by Manglore tiles.

Precast beam and Hourdis (K. Parikh,1974)
In this method precast reinforced concrete beams are used to carry hourdis as a roofing and flooring systems.

Jack Arch Roofing (Sriraman, Jain,1992)
This is basically a flat roofing system, formed of shallow segmented arches over precast R.C. beams. This is used for roofing.

Funicular Shell (Jain,1992)
These are doubly curved thin membranes which use very little materials and yet very strong.

Mortars (Sriraman)
The cost of mortars can be reduced by substituting the cement/lime by flyash.

Plasters (Niazi, Scott and Revi)
The various types of low cost, low energy plasters which may be used without compromising the longevity and performance of earth walls.
Using the above materials and technological possibilities, we have constructed three carbon dioxide reduction scenarios for common practices and two carbon dioxide reduction scenarios for low cost technologies.

The nomenclature for various scenarios is given below:

Common Practices(CP)

CP-BAU: There is no carbon dioxide reduction constraint and this replicates the current construction technological scenario.
CP-5: In this scenario we impose a constraint that the construction would have to choose those technologies that reduce carbon dioxide emissions by 5% from the base case level.
CP-10: This scenario imposes a constraint that the construction would have to choose those technologies that reduce carbon dioxide emissions by 10% from the base case level.
CP-20: This is similar to above two scenarios except that the level of carbon dioxide emissions reduction is by 20% from the base case level.

Cost effective, energy efficient technologies (EE)

For the low cost technologies we construct three scenarios:

EE-BASE: There is no carbon dioxide reduction constraint in this scenario.

EE-5: There is a constraint to reduce Carbon dioxide emissions by 5% from the EE-Base level.

EE-10: There is a constraint to reduce Carbon dioxide emissions by 10% from the EE-Base level..

We could not construct 20% reduction scenario for the low cost technologies because the model became infeasible with the present set of low cost technologies.

The above model is solved using the optimization module of GAMS software (Brooke et al 1995).

5.2 Cost

Table 16 presents the changes in various cost parameters for CP and EE techniques for the construction of 2 million houses in 2000-01. With a shift among these techniques there is substantial change in the cost and carbon dioxide emission level. With carbon dioxide constraint being imposed, the cost of construction rises by 1.2% for a corresponding 5% reduction in Carbon dioxide emissions from the CP-BAU levels. The cost increases non-linearly with further reduction in Carbon dioxide emissions. A reduction of 10% in Carbon dioxide emissions increases the cost by 2.6% and the reduction by 20% in carbon dioxide emissions increases the cost by 10.7%.

The second group of techniques evaluated are, low cost techniques. These techniques, besides being cost effective are associated with less carbon dioxide emissions. The cost of construction of 2 million houses in 2000-01 by using EE-Base is 78% of the cost of construction by using CP-BAU case and Carbon dioxide emissions for the EE-Base are only 35% of the common practices.

Table 16: Cost of various inputs

	CP-BAU	CP-5	CP-10	CP-20	EE-BASE	EE-5	EE-10
Cost (Billion Ruppes) in 2000-01	275	282	285	307	160	166	174
Carbon dioxide emissions (Million tonnes)	38900	36955	35010	31120	13598	12918	12238

The annual emissions due to construction of houses would remain same during our period of consideration.

5.1.3 Material Requirements

The requirement for building materials under various scenarios is presented in Table 17. The table indicates that by the imposition of carbon dioxide constraint, the consumption of cement, bricks and steel reduces which causes reduction in emissions. Table 17 indicates the quantity of building materials that would be required each year.

Table 17: Final input requirements

	CP-BAU	CP-5	CP-10	CP-20	EE-Base	EE-5	EE-10
Cement (Mt)	13.99	14.82	15.33	11.05	6.64	5.9	6.1
Bricks(billion)	36.1	27.61	20.93	20.93	6.39	6.13	3.2
Coarse sand (Million m^3)	34.7	38.06	41.13	26.23	26.62	24.3	24.3
Fine sand (Million m^3)	8.13	8.13	8.13	11.61		0.11	1.25
Stone aggregate (Million m^3)	30.4	30.47	31.36	33.1	19.4	19.5	20.91
Unslaked lime (Mt)				48.14		9.87	12.74
Steel (thousand tonne)	529.2	529.2	487.06	398.4	43.81	43.8	43.8
Flyash (Million m^3)					6.41	6.41	6.41
Mud blocks (Billion)					29.35	29.35	29.35
Manglore tiles (Million Square meter)					0.35	0.35	0.35
Stone at quarry(Million m^3)		28.13	50.33	30.25		0.67	8.78
Through stones (Million Number)		158.2	282.9	282.9		4.72	57.5
Surkhi(Million m^3)				8.71		1.57	2.02

5.2 INDUSTRIAL SECTOR

To analyze the opportunities for reducing carbon dioxide emissions in the industrial sector, we have restricted ourselves to only common practice technologies. The analysis of the use of energy efficient, cost effective technologies (which were analyzed for the house construction activity) in the industrial sector has not been attempted in this paper. The reason for not attempting the possibility of use of low energy intensive, cost effective

technologies is that we are not sure about the load coming on the structure and how these materials would react to the industrial load. Most of the research on the applicability of energy efficient, cost effective materials has been in the housing sector. A further research would be needed to see the possibility of these materials being used in the industrial sector. Table 18 presents the material requirements under various emission reducing scenarios, with in the common practices group of technologies.

Table 18: Building materials requirements in the industrial sector

	2001-02			2002-03			2003-04			2004-05			2005-06			2006-07			2007-08			2008-09			2009-10		
	CP-5	CP-10	CP-20	CP-5	CP-10	CP20	CP-5	CP-10	CP-20	CP-5	CP-10	CP-20	CP-5	CP-10	CP-20	CP-5	CP-10	CP-20	CP-5	CP-10	CP-20	CP-5	CP-10	CP-20	CP-5	CP-10	C
CE	9.07	9.37	6.75	9.49	9.81	7.08	9.96	10.31	7.43	10.48	10.84	7.81	11.04	11.4	8.25	11.72	12.13	8.75	12.36	12.78	9.22	13.04	13.48	9.72	13.77	14.24	10
BR	16.89	12.80	12.80	17.68	13.39	13.39	18.56	14.07	14.07	19.53	14.80	14.80	20.59	15.6	15.59	21.85	16.56	16.56	23.02	17.44	17.44	24.29	18.41	18.41	25.64	19.44	19.
CS	23.29	25.17	16.06	24.38	26.31	16.80	25.58	27.64	17.62	26.90	29.07	18.53	28.37	30.5	19.56	30.25	32.60	20.76	31.72	34.27	21.85	33.48	36.15	23.05	35.33	38.18	24.
FS	4.96	4.96	7.11	5.20	5.20	7.43	5.46	5.46	7.81	5.76	5.76	8.19	6.05	6.17	8.66	6.43	6.43	9.19	6.78	6.78	9.69	7.14	7.14	10.22	7.55	7.55	10.
STA	18.65	19.18	20.26	19.50	20.09	21.17	20.47	21.06	22.23	21.53	22.17	23.41	22.73	23.5	24.67	24.11	24.82	26.20	25.40	26.14	27.58	26.78	27.58	29.10	28.28	29.13	30.
UL	0.00	0.00	29.46	0.00	0.00	30.81	0.00	0.00	32.33	0.00	0.00	34.04	0.00	0.00	35.83	0.00	0.00	38.09	0.00	0.00	40.12	0.00	0.00	42.32	0.00	0.00	44
St	323.9	298.09	243.81	338.91	311.89	255.03	355.65	327.2	267.63	374.15	344.19	281.64	394.71	364	297.2	418.79	384.7	315.41	441.11	405.87	332.15	465.19	428.19	350.36	491.33	452.27	370.
STQ	17.21	30.81	18.50	18.00	32.22	19.35	18.88	33.80	20.32	19.88	35.59	21.38	20.97	37.6	22.55	22.26	39.82	23.93	23.44	41.97	25.23	24.73	44.26	26.61	26.11	46.72	28.
TH	96.83	173.12	173.12	101.26	181.08	181.08	106.28	190.0	190.04	111.83	200.00	200.00	117.97	211	210.9	125.20	223.9	223.87	131.86	235.83	235.83	139.12	248.75	248.75	146.90	262.67	262.
SUR	0.00	0.00	5.34	0.00	0.00	5.58	0.00	0.00	5.84	0.00	0.00	6.17	0.00	0.00	6.49	0.00	0.00	6.90	0.00	0.00	7.25	0.00	0.00	7.67	0.00	0.00	8.
CO2	22.29	20.88	17.21	23.35	21.85	18.00	24.49	22.94	18.88	25.79	24.14	19.88	27.19	25.5	20.97	28.87	27.02	22.23	30.40	28.46	23.44	32.07	30.01	24.70	33.86	31.69	26.

CE: Cement (Million tonnes)
BR: Bricks (Billion numbers)
CS: Coarse sand (Million cubic meter)
FS: Fine sand (Million cubic meter)
STA: Stone aggregate (Million cubic meter)
UL: Unslaked lime (Million tonnes)
St: Steel (Thousand tonnes)
STQ: Stone at quarry (Million cubic meter)
TH: Through stone (Million number)
SUR: Surkhi (Million cubic meter
CO2: Carbon dioxide emissions (Billion tonnes)

5.3 HIGHWAYS

The only available alternative for the highway construction against the bitumen road is the concrete road. A cost comparison of bitumen roads and cement concrete road in Table 2.8 indicates that cement concrete roads are slightly expensive than the bitumen roads.

Table 19: Material requirement for cement concrete road construction

Year	Cement (Mt)	Coarse sand (Mill. cum)	Fine sand (Mill. Cum)	Stone aggregate (Mill. cum)	Unslaked lime (Mill. tonnes)	Surkhi (Mill. cum)	Diesel (Mill. liter)	Carbon dioxide (Mill. Tonnes)
2000-01	8.64	15.03	2.02	38.7	1.28	4.09	2.33	19400
2001-02	9.08	15.8	2.13	40.7	1.35	4.3	2.45	20370
2002-03	9.43	16.4	2.21	42.23	1.40	4.46	2.54	21146
2003-04	9.86	17.14	2.31	44.17	1.46	4.66	2.66	22116
2004-05	10.38	18.04	2.43	46.5	1.54	4.91	2.80	23280
2005-06	11.07	19.24	2.59	49.6	1.64	5.23	2.98	24832
2006-07	11.7	20.3	2.73	52.3	1.73	5.52	3.15	26190
2007-08	12.28	21.35	2.88	55.01	1.82	5.81	3.31	27548
2008-09	12.97	22.55	3.04	58.11	1.93	6.13	3.50	29100
2009-10	13.66	23.75	3.20	61.21	2.03	6.46	3.69	30652

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6. IMPLEMENTATION AND BARRIERS

7. RECOMMENDATIONS

References

Balkrishnan,A. "Mud Technology: For Housing of Common People", in. Nirmithi Compendium, Kerala State Nirmithi Kendra, India

Brooke, A., Kendrick, D. and Meeraus, A. (1995) "*GAMS: A User's Guide*". Boyd and Fraser Publishing Company, Massachsetts.

Census of India. "Housing and Amenities," Paper 2 of 1993.

Development Alternatives (1995), "Energy Use and Structural Change". mimeo, New Delhi.

Doat,P.,Hays,A.,Houben,H.,Matuk,S. and Vitoux,F., "Building with earth", India,The mud village society publication,1991.

Easwaran,V. "Precast Products for mass housing",in. Nirmithi Compendium, Kerala State Nirmithi Kendra,India

Jain,A.K., "Building systems for low cost housing, Management Publishing company, Dehradun, India, 1992.

Khanna,P.N., "Indian practising civil engineers handbook",1993.

Ministry of Finance (2000), Economic Survey, Ministry of Finance, New Delhi.

Ministry of Urban Affairs, Draft Housing Policy, Ministry of UrbanAffairs, Government of India, 1998.

GOI (1998), India Infrastructure Report, Report of the expert committee on infrastructure chaired by Dr. Rakesh Mohan, New Delhi.

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NICMAR (1998), India Construction Statistics, National Institute of Construction Management and Research, Mumbai.

Niazi,Z.,"Soil based plasters-Low cost options for protection of earth walls", Development Alternatives mimeo

Parikh,J. and Gokarn,S. (1993), " Climate change and India's energy policy options in India", Global environment change, Global Environmental Change, Butterworth UK, September,1993.

Parikh,K.S.,"Performance approach to cost reduction in building construction", Report of the expert committee, Government of Kerala, India, 1974

Planning Commission, "Eighth five year plan of India",1992

Radhika,B.V., Manoj,R., Santhosh,B.,Pradeep,D.,Jayaprabhan,R. and Unnikrishnan,S. "Project Report on Performance Evaluation of Cost Effective Buildings", Department of Civil Engineering, College of Engineering, Trivandrum, Kerala, 1993.

Scott, C.A. and Revi,A., "Cover the earth-Plaster for soil block buildings", Development Alternatives mimeo.

Sharma,S.K., "Back to Mud: A Step Forward" in. Nirmithi Compendium, Kerala State Nirmithi Kendra, India

Shukla, P.R. (1997) Energy and greenhouse gas emissions from India: an overview and a perspective on policy modeling, in *Energy Strategies and Greenhouse Gas Mitigation* (ed. P.R. Shukla), Allied Publishers Limited, India.

Sreedevi,B.G., "Soil-The modest building material", in. Nirmithi Compendium, Kerala State Nirmithi Kendra, India

Sriraman,V., "Industrial wastes and building technology - The uses of flyash and pressmud", Development Alternatives, 1993a, Vol.3 No.6

Sriraman,V.,"Rural housing-Cost reduction technology and cost effective alternatives", Development Alternatives, 1993b, Vol.3, No.1.

Tata Economic Services. "Statistical Outline of India", Tata Press, Mumbai 1997.

Tiwari, P., Parikh, J. and Sharma, V.(1996). "Performance evaluation of cost effective buildings -a cost, emissions and employment point of view." *Building and Environment,* 31(1), 75-90.

Tiwari, P., Parikh, K. and Parikh, J.(1999). "Structural design considerations in house builders construction model: A multiobjective optimisation technique." J. *of Infrastructure Systems,* ASCE, 5(3), 75-90.

UNCHS., "Energy Efficiency in Housing Construction and Domestic Use in Developing Countries", Nairobi, Kenya, 1991.

UNCHS (1997) *Shelter for All: The potential of Housing Policy in the Implementation of the Habitat Agenda*, HS/488/97E, UNCHS, Nairobi, Kenya.

Valmeekinathan,S. and Revi,A." Designing the Valram", Development Alternatives mimeo.

Zeleny, M. "Multiple Criterion Decision Making" McGraw-Hill book company, 1982.

Appendix I: Technical notes

The house considered for analysis, is measured in units of a room of hypothetical size (3.5x3.5x3.14 m^3). A house may be assumed to be a combination of such rooms, which can exist anywhere in the building up to three floors. Up to three floors, the minimum wall thickness is one brick and beyond this, the minimum wall thickness increases (Khanna 1992). However, in normal construction practices, the walls beyond the third floor are rarely load bearing. Generally, a framework of columns and beams is constructed which is load bearing and the space in between is filled with non-load-bearing brick walls. The energy estimates for buildings above three floors will be slight underestimate since emissions due to columns are not accounted for.

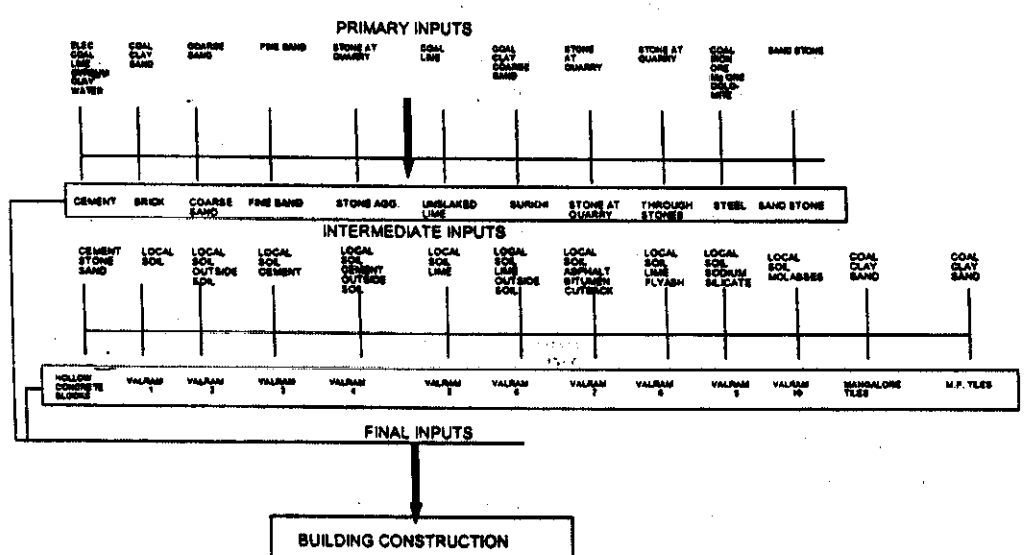
A model has been developed in this paper, which is an extension of earlier works by Tiwari et al. (1999). A building can be constructed using a number of technologies. A builder will optimize his choice of technology based on the cost, carbon dioxide emissions and the available technology. The choice of technology requires a combination of materials and labour, which are constrained by their availability. The construction of a building consists of following ten stages: stage 1 - foundation bed under load bearing wall; stage 2 - foundation bed under partition wall; stage 3 - foundation for load bearing wall; stage 4 - foundation for partition wall; stage 5 - wall construction; stage 6 - partition wall construction; stage 7 - roof construction; stage 8 - flooring; stage 9 - external plastering; stage 10 - internal plastering.

The model identifies technologies at different stages of construction (viz., foundation, wall, etc., as defined below) to meet output levels for various activities required at each stage to construct the room. Besides resource availability, there are structural design constraints (discussed later in more details) which also restrict the combination of technologies at different stages. The process of building construction has three types of activities, as shown in figure A.1: activities related to primary resources required to produce the intermediate and final inputs to be used for construction of the structure and activities related to various technological alternatives of construction of each stage of the building. Primary resources include fuel (electricity, coal), limestone, gypsum, etc. which are required in the production of cement, bricks, lime, steel, etc. which can be either directly used in construction (final inputs) or can be used in manufacturing of final inputs such as concrete blocks, which are used in building construction. The detailed list of inputs is given in Appendix II. Input prices are calibrated at 2000-01 prices. If the resources are used to manufacture inputs, which are used in construction and are not used directly in building construction, they are referred as intermediate inputs.

In this model, different technical specifications that provide the same outputs (a house with a combination of functional room of the size defined earlier) are considered. The levels of resources and production activities are determined so that the overall cost of construction of the specified house is the minimum. The notations for different sets appearing in this model are: 'p' is the set of

primary inputs; 'i' is the set of intermediate inputs; 'j' is the set of production-activity levels; 'q' is the set of different wage classes; and 'g' is a set of different stages in construction. The optimization process will choose those techniques, which minimize overall cost of construction.

Two groups of techniques[3] are considered for analysis; common practices and low cost techniques. The list of techniques, which are evaluated in this paper, is presented in Appendix III. There are three technologies, for the foundation bed construction under load bearing and partition wall, sixteen technologies for foundation construction, 136 technologies for load bearing wall construction, 64 technologies for partition wall construction, 13 technologies for roof construction, 14 technologies for floor construction, and 12 technologies for external and internal plastering, that have been evaluated in this paper. These techniques are suitable for India and we design the room according to Indian building code IS 456.



[3] Three groups of technologies are defined in this model. Common practices are those technologies, which are commonly used in India. These technologies primarily use materials like cement, bricks, concrete, steel etc. Low cost technologies are those, which include building materials such as stabilized mud blocks, jack arch roofing, tile roofing and technologies like rat trap brick bond for walls. There are many low cost technologies available in building construction.

Figure A.1: Direct and indirect inputs in building construction

Model equations are given below:

Objective Function

The objective function to minimize

$$cost = \sum_i \sum_j c_i a_{ij} x_j + \sum_q \sum_j w_q d_{qj} x_j ,$$

Intermediate + *Direct*

Inputs *Labour* ,

where c_i is the cost coefficient for the it intermediate input corresponding to th ith activity and w_q is the wage rate for th qth class of labour. The requirement fc the ith intermediate input to produce un output of the jth activity is given b element a_{ij}. For each stage we have matrix of intermediate input coefficient a_{ij}, which are fixed for a set c technologies and each column of this matrix refers to one technology. x_j is the level of the production techniques. d_{qj} is the qth type c labour employed directly for unit production level of activity j. d_{qj} is also fixed coefficient matrix, with each column referring to or technology. The matrices, a_{ij}, and d_{qj} have been compiled based on technologies from Tiwari et al. (1996).

Resource Constraint

If N_g is the number of alternative techniques available at stage of construction g, the total number of techniques available is

$$N = \sum_{g} N_g$$

2 All levels of activities from G stages taken together are represented as

$$(x_1, x_2, \ldots x_j, \ldots x_n) = X'.$$

For detailed list of x_j refer to table 4.

3 a_{ij} is the requirement of final inputs to produce unit output of jth activity, i.e.

Final inputs

$$\sum_j a_{ij} x_j \leq r_i.$$

requirements Primary inputs availability.

The element r_i is the total amount of the ith final input required to run the production activity at a level X. The element b_{pi} gives the requirement of

4 the pth primary input to produce unit output of the ith final input, i.e.

$$\sum_i b_{pi} r_i \leq t_p.$$

Primary inputs

requirements $\leq$ *availability.*

where t_p (p=1,P) is the total amount of the pth primary inputs required to produce the intermediate inputs r_i. Combining Eqs.(7) and (8) yields

5 The model faces two resource constraints (i) final inputs (Eq.7) and (ii) primary input constraints (Eq.9).

$$t_p \geq \sum_i \sum_j b_{pi} \cdot a_{ij} \cdot x_j.$$

6

availability $\geq$ *requirement.*

Direct and Indirect Employment

d_{qj} is the qth type of direct labour required for the jth activity. This is the labour that is required at the construction site and is constrained by the availability of construction workers Dlq. s_{qi} are the indirect labour requirements of the qth earning class to produce the ith intermediate input. The direct and indirect labour requirement for each wage class is

Direct labour

$$\sum_j \sum_i d_{qj} a_{ij} x_j \leq Dl_q \quad (10)$$

requirement ≤ *availability*,

Indirect labour

$$\sum_j \sum_i s_{qi} a_{ij} x_j \leq Il_q \quad (11)$$

requirement ≤ *availability*,

where l_{qi} is the qth type of labour required to produce the ith intermediate input. The total supply of indirect labour is Ilq.

Output Constraint

The task level for every stage of building a house varies with the choice of the technique of construction. For example, to support the same load, the thickness of a stone wall should be more than that of a brick wall. The type and quantity of materials required change according to principles of structural engineering. The material requirement at every stage is a polynomial function of the area and height of the building (Tiwari et. al., 1999).
The output constraint is

$$\sum_j z_{jg} x_j \leq y_g. \quad (12)$$

Output ≤ Task level.

The element z_{jg} represents the output coefficient of the jth activity at stage g. y_g is the task level for each stage.

Engineering Constraints

In building construction, the choice of techniques for one stage is not entirely independent of the choice of techniques for other stages These interdependencies and internal balances in production have to be taken care of.
These engineering constraints are written as

$$u_{ij}\ x_{ij} \geq 0. \qquad 13$$

To understand this constraint, it is necessary to explain how the u_{ij}'s are derived. Consider two activities x_1 and x_2 corresponding to stages 1 and 2, respectively. Let 1 correspond to the foundation and 2 to the superstructure wall. Now, if the wall is constructed by using technique x_{2j}, it is required that the foundation is to be built only by using x_{1j}. This constraint is introduced as follows. Let x_2 = superstructure wall work in m^3 built by using technique x_{2j}, and x_1 = foundation work in m^3 built by using technique x_{1j}. As the dimensional details of both wall and foundation are known from engineering calculations, the lengths for which x_1 and x_2 are built are calculated by multiplying their levels by proper constants.

If k_1x_1 is the length for which the foundation is built by using x_{1j} and k_2x_2 the length for which the wall is built by technique x_{2j}, then x_2 depends only on x_1, so that k_1x_1 should be at least equal to k_2x_2, i.e.

$$k_1x_1 - k_2x_2 \geq 0 \quad \text{or} \quad x_1 - (k_2/k_1)x_2 \geq 0. \qquad 14$$

The coefficients of x_i and x_j become the u_{ij}.

Environmental Constraint

In this model, the environmental constraints appear as

$$\sum_p t_p\ E_p \leq TC. \qquad 15$$

$$CO_2\ emissions \leq Upper\ limit\ on\ CO_2.$$

Only indirect CO_2 emissions due to production of primary inputs are considered. E_p is a vector of the CO_2 emission-coefficients for p primary inputs. The total requirements of p primary inputs to meet the levels of intermediate-input requirements are calculated. When multiplied by emission coefficients associated with each of the p primary inputs and aggregated over p, we find the total CO_2 emissions related to construction. TC is the upper limit on CO_2 emissions.

We run above model for various alternative scenarios of emissions (CP-BAU, CP-5, CP-10, CP-20, EE-Base, EE-5 and EE10). The imposed constraints lead to changes in technologies, at various stages. We have not presented the changes in technologies in the main text to avoid technical details. However, we present them here and table A.2 reports the changes in technologies.

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Table A.2: Alternative technology choices

	CP-BAU	CP-5	CP-10	CP-20	EE-BASE	EE-5	EE-10
Foundation under load bearing wall	1:4:8 Cement concrete						
Foundation under partition wall	1:4:8 Cement concrete						
Foundation under load bearing wall	1:6 Cement coarse sand brickwork			1:1:1lime surkhi sand brickwork 1:1:1 lime surkhi sand random stonework	1:6 Cement coarse sand brickwork	1:1:1 lime surkhi sand brickwork 1:1:1 lime surkhi sand random stonework	1:1:1 lime surkhi sand random stonework
Foundation under partition wall	1:6 Cement coarse sand brickwork			1:1:1 lime surkhi sand brickwork	1:6 Cement coarse sand brickwork	1:1:1 lime surkhi sand brickwork	
Load bearing wall	1:6 Cement coarse sand brickwork	1:6 cement sand random stone work 1:6 cement coarse sand brickwork	1:6 cement sand random stonework	1:6 cement sand random stonework 1:1:8 Cement lime sand random stonework	1:4:8 cement flyash sand Valram 1		
Partition wall	1:6 Cement coarse sand brickwork		1:2 lime surkhi brickwork	1:1:1 lime surkhi sand barickwork	1:4:8 cement flyash sand Valram 1		
Roof	1:2:4 RCC balanced		1:2:4 RCC balanced 1:3:6 RCC balanced	1:3:6 RCC balanced	Filler slab with mangalore tiles		
Floor	40mm thick 1:2:4 cement concrete flooring				Filler slab with mangalore tiles		
Internal plastering	12mm thick 1:6 cement			12mm 1:1:1 lime surkhi sand mortar	12mm thick 1:6 cement plastering		

	plastering						
External plastering	12mm thick 1:6 cement plastering				12mm thick 1:6 cement plastering		

Note: The blanks mean that there is no change with respect to previous column.

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Appendix II: List of Inputs

Primary Inputs	Intermediate Inputs	Final Inputs	Labour Wages(sm)1-6
Coarse sand	Cement	Cement	Rs. 0-40
Fine sand	Bricks	Bricks	Rs.41-50
Quarry stone	Coarse sand	Coarse sand	Rs.51-60
Coal	Fine sand	Fine sand	Rs.61-70
Electricity	Stone aggregate	Stone aggregate	Rs.70-80
Limestone	Unslaked lime	Unslaked lime	Rs.>80
Gypsum	Surkhi	Surkhi	
Clay	Stone at quarry	Stone at quarry	
Water	Through stone	Through stone	
Ironore	Sand stone	Sand stone	
Dolomite	Steel	Steel	
Sand stone	Manglore tiles	Bairam 1-10	
Mangnese ore	M.P. tiles		
	Hourdis		
	Bitumen		
	Flyash		
	Asphalt		
	Sodium silicate solution		

Appendix III: Techniques evaluated for construction of a house

Techniques	Proportion
FOUNDATION BED UNDER LOAD BEARING WALL / FOUNDATION BED UNDER PARTITION WALL	
Cement concrete	1:4:8,1:3:6,1:2:4
FOUNDATION AND BASEMENT/ FOUNDATION FOR PARTITION WALL/ PARTITION WALL	
Brickwork	
Cement:coarse sand	1:3,1:2,1:4,1:6
Cement:lime:sand	1:1:6,1:2:9,1:1:8, 1:1:3
Lime:surkhi:sand	1:1:1
FOUNDATION AND BASEMENT / LOAD BEARING WALL/ PARTITION WALL	
Stonework:coursed;random	
Cement:sand	1:4,1:6
Lime:surkhi:sand	1:1:1
Cement:lime:sand	1:1:8
FOUNDATION AND BASEMENT / FOUNDATION FOR PARTITION WALL	
Lime:surkhi	1:2
Block work/block masonry	
Precast	

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LOAD BEARING WALL/PARTITION WALL	
Pressed soil blocks	
Cement:coarse sand	1:3,1:2,1:4,1:6
Cement:lime:sand	1:1:6,1:2:9,1:1:8, 1:1:3
Lime:surkhi:sand	1:1:1
Cement:flyash:sand	1:3:6,1:4:8
Concrete blocks with flyash	
Cement:coarsesand	1:3,1:2,1:4,1:6
Cement:lime:sand	1:1:6,1:2:9,1:1:8, 1:1:3
Lime:surkhi:sand	1:1:1
Cement:flyash:sand	1:3:6,1:4:8
Balram 1;2;3;4;5;6;7;8;9;10	
Cement:coarsesand	1:3,1:2,1:4,1:6
Cement:lime:sand	1:1:6,1:2:9,1:1:8, 1:1:3
Lime:surkhi:sand	1:1:1
Cement:flyash:sand	1:3:6,1:4:8
PARTITION WALL	
Soil cement blocks	
Cement:coarsesand	1:3,1:2,1:4,1:6
Cement:lime:sand	1:1:6,1:2:9,1:1:8, 1:1:1
Lime:surkhi:sand	1:1:1
Cement:flyash:sand	1:3:6,1:4:8
Mud bricks	
Cement:coarsesand	1:3,1:2,1:4,1:6
Cement:lime:sand	1:1:6,1:2:9,1:1:8, 1:1:3
Lime:surkhi:sand	1:1:1
Cement:flyash:sand	1:3:6,1:4:8
Hollow concrete blocks	
Cement:coarsesand	1:3,1:2,1:4,1:6
Cement:lime:sand	1:1:6,1:2:9,1:1:8, 1:1:3
Lime:surkhi:sand	1:1:1
Cement:flyash:sand	1:3:6,1:4:8

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Earth Blocks	
Cement:coarsesand	1:3,1:2,1:4,1:6
Cement:lime:sand	1:1:6,1:2:9,1:1:8, 1:1:3
Lime:surkhi:sand	1:1:1
Cement:flyash:sand	1:3:6,1:4:8
Rat trap bonding brickwork	
Cement:coarsesand	1:3,1:2,1:4,1:6
Cement:lime:sand	1:1:6,1:2:9,1:1:8, 1:1:3
Lime:surkhi:sand	1:1:1
Cement:flyash:sand	1:3:6
Compressed earth blocks	
Cement:coarsesand	1:3
Cement:lime:sand	1:1:6,1:2:9,1:1:8, 1:1:3
Lime:surkhi:sand	1:1:1
Cement:flyash:sand	1:3:6,1:4:8
Brickwork	
Cement:flyash:sand	1:3:6,1:4:8
ROOF/FLOOR	
Flat R.C.C balanced	1:2:4,1:1.5:3,1:1:2, 1:3:6
Flat R.C.C over reinforced	1:2:4
Flat R.C.C under reinforced	1:2:4
Filler slab with 2 M.P. tiles	
Precast beam with hourdis	
Filler slab with Manglore tiles	
Jackarch	
Funicular shell	
ROOF	
Raniganj tile	
Manglore tile	
FLOOR	
40mm thick cement concrete	
Brick flooring	

Cement mortar	1:4,1:6
Sanstone:rough chiselled / fine chiselled	
Cement mortar	1:5
INTERNAL PLASTERING / EXTERNAL PLASTERING (12mm thick)	
Cement:sand	1:6,1:3,1:4
Cement:lime:sand	1:1:7,1:2:9
Lime:surkhi	1:2,1:4,1:6
Lime:surkhi:sand	1:1:1
Lime:coarsesand	1:3,1:4
Lime:cement:coarsesand	1:1:8

DRAFT RESEARCH PAPER ON MACRO ECONOMIC ISSUES - ECONOMIC GROWTH, POVERTY AND CO2 EMISSIONS

- BY DR. MANOJ PANDA

Economic Growth, Poverty and CO_2 Emission in India

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Executive Summary

The recent worldwide concern about global warming calls for measures to reduce carbon dioxide (CO_2) emissions from burning of fossil fuel, the largest source of anthropogenic green house gases. The signatory nations to the United Nations Framework Convention on Climate Change (UNFCC) in 1992 agreed to prevent 'dangerous anthropogenic interference with the climate system'. The convention recognised the concept of 'common but differentiated responsibilities' for developed and developing countries. The Kyoto Protocol signed in 1997 required industrialised 'Annex I' countries to reduce their total emission of CO_2 and other GHGs to 5% below the 1990 level by 2008-12. The developing countries have been only minor contributors to the global warming problem in the past and have been excluded from any fixed commitment to reduce CO_2 emissions in view of the urgent need to improve their low level of living.

Yet, it is felt that attention must be given in future to emissions taking place in some of the large developing countries like China and India. The per capita CO_2 emission was 0.9 tonnes for India in 1997 compared to world average of 4.0 tonnes and OECD average of 11.1 tonnes. India accounts for about 4 per cent of total CO_2 emissions in the world and its total emissions are likely to increase substantially in the coming decades. There is a need for India to develop a long-term strategy for CO_2 emission reduction without compromising its development objective.

Economic growth usually involves CO_2 emission whose reduction would mean additional constraint on growth. Such a constraint might imply a lower economic growth and/or adoption of better techniques of production. A policy maker would like to know the strategic tradeoffs between development and environment: how much of growth would be affected or how much additional investment would be needed to adopt better technology. In the context of a country like India where mass poverty prevails, we also need to examine the effects of environmental constraints on the incidence of poverty.

This paper examines the quantitative impact of CO_2 emission reduction on economic growth and poverty using an economy-wide model for India. The model used here integrates both the top-down and the bottom-up approaches. It provides macroeconomic consistency and incorporates specific technological options. Using this model, we specifically examine the likely effects on national income and incidence of poverty due to annual or cumulative restrictions on CO_2 emissions over a business as usual (BAU) scenario.

The results from the scenarios suggest that *annual* emission reductions, imposes unnecessary costs in terms of reduced GDP and higher poverty, both in the short and the long run through distortions in choice of techniques in electricity generation as well as in energy use in industry. The quantitative dimension of GDP fall could vary from about 0.5 - 0.7% in case of 10% reduction in emission to as high as 12% in case of 30% annual emission reduction. *Cumulative* emission reduction targets over a few decades are preferable to annual reduction targets and that a dynamically optimum strategy can help reduce the burden of emission reductions. Even cumulative reduction targets increase poverty by a larger percentage in the range of 2-17% as compared to GDP reduction of 0.5 - 4% in the 30th year for CO_2 reduction

of the order of 10-30% over a BAU scenario. GDP loss of this extent is not negligible in the long run.

Overall, emission reduction imposes costs in terms of lower GDP and higher poverty. If India were to reduce its carbon emissions for the sake of the global good, it should have sufficient built in compensation or incentives for such an action.

Economic Growth, Poverty and CO_2 Emission in India

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1. Introduction

In recent years, there has been a worldwide concern about global warming due to concentration of green house gases (GHGs) that block radiation of sunlight. It is believed that emission of GHGs caused by anthropogenic factors associated with human activities has mainly been responsible for the global warming problem that faces mankind. Attention has been directed particularly to carbon dioxide (CO_2) emissions from burning of fossil fuel, the largest source of anthropogenic GHGs. While the scientific community continues to debate about global warming and risks involved in it, there has been a broad consensus among the community of nations for exploration of possible measures to reduce carbon dioxide (CO_2) emissions. This is reflected in the United Nations Framework Convention on Climate Change (UNFCC) in 1992 where signatory nations agreed to prevent 'dangerous anthropogenic interference with the climate system'. The convention required all nations, developed and developing, to maintain accounting and reporting of emission and encourage environment friendly activities. At the same time, it recognised the concept of 'common but differentiated responsibilities' depending on development levels of the nations. The Kyoto Protocol signed in 1997 took this concept further and required industrialised 'Annex I' countries to reduce their total emission of CO_2 and other GHGs to 5% below the 1990 level by 2008-12. It excluded developing countries from any binding commitment to reduce GHGs emissions.

CO_2 emission takes place when we use fossil fuel like coal, oil and gas which are needed as essential and critical raw materials for several production process. Hence, economic growth usually involves CO_2 emission whose reduction would mean additional constraint on growth. Such a constraint might imply a lower economic growth and/or adoption of better techniques of production. Before deciding upon appropriate policy for dealing with CO_2 emissions, a policy maker would like to know, if a particular policy were followed, how much of growth would be affected or how much additional investment would be needed to adopt better technology. In the context of developing countries, prevalence of mass poverty is a basic issue that figures high on their agenda, and we need to examine the effects of environmental constraints on the incidence of poverty. On the whole, we need to know the strategic tradeoffs between development and environment.

Table 1 shows some basic economic and social indicators for India in relation to the world as well as developed countries. India's per capita income at about $450 is less than one-tenth of the world average and one-fiftieth of that of high income countries. Given such low income level, poverty persists at a high level. India has about 40% of people living below the poverty line defined as an income level of $ 1 per capita per day. Large differences could be observed between India and developed countries in the performance indicators of social sectors like health and education too. India has a long way to go in reducing infant mortality and illiteracy. It must continue to have high economic growth to take care of poverty and to provide better health and other social services to their people.

The developing countries have not contributed in a large scale to the global warming problem. In fact, about a quarter of the world population living in the developed countries have been

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responsible for about three-quarters of the accumulated CO_2 emissions. While developing countries need not have a fixed commitment to reduce CO_2 emissions, as recognised in the Kyoto Protocol, it is also felt that attention must be given to emissions taking place in some of the large developing countries. The obvious examples that come up in this context are China and India which respectively account for about 14 per cent and 4 per cent of total CO_2 emissions in the world. The emission data in Table 2 shows that total emission in the world increased by about 4300 million tonnes during 1980-97. Of this total incremental emission, China accounted for about 38% and India another 13%. In per capita terms, however, CO_2 emission during 1997 was 0.9 and 2.5 tonnes for India and China respectively as against world average of 4.0 tonnes and OECD average of 11.1 tonnes (see, Table 3). Thus, per capita emission levels are substantially below the world average. Yet, it is evident that total emissions of China and India are likely to increase substantially in the coming decades. There is thus a need to develop a long term strategy for CO_2 emission reduction without sacrificing the development objective.

It is against this background that this paper examines the impact of CO_2 emission reduction on economic growth and poverty using an economy-wide model for India. Specifically, we examine the likely loss in national income growth and increase in the incidence of poverty due to annual or cumulative restrictions on CO_2 emissions. In section 2, we make a brief review of the literature and set out the model structure. In section 3, we discuss the design of the scenarios. The results are reported in section 4 and section 5 makes the concluding observations.

2. Model structure

There are several models in the literature that deal with economic impact of GHG emission reduction. These models[1] might be classified into three categories: bottom-up, top-down and integrated. The first category of bottom-up models typically focus on production process and emission details of one or two sectors of interest and then find out implications of the sectoral effects on the whole economy in a rudimentary form without adequate consistency. While such models bring technological knowledge and specificity, they often have incomplete technoeconomic evaluation and turn out to be overtly optimistic in that policy and institutional obstacles are not fully accounted for. The second category of top-down models focus on macroeconomic consistency. Among them are macro econometric models which use reduced form equations without structural details and the implied policies behind them remain unclear. Another approach of top-down modeling is the computable general equilibrium (CGE) approach where equilibrium prices and quantities are computed for one period and repeated sequentially for several periods. The main choice of the economic agents is essentially of static nature confined to events occurring in a single period with a few linking equations for capital or labour stock from one period to another. Both econometric and CGE models often assume a high substitution elasticity which makes it easy and relatively cost less to adjust to CO_2 constraints. The problem is thus assumed away. An activity analysis approach involves simultaneous choice of economic variables for several periods in a dynamic setting. It provides macroeconomic consistency and incorporates specific technological options with limited substitution possibilities. This method can be viewed as one that integrates both the top-down and the bottom-up approaches.

In this paper, we use an activity analysis framework to examine effects of CO_2 emission reduction on the national economy. This model reported in Murthy, Panda and Parikh

[1] For example, see Manne and Richels (1992), Blitzer et al (1992), Nordhouse (1994), Shukla (1996), Fisher-Vander et. al (1997) and Gupta and Hall (1997) for a sample of such models.

(2000) permits exploration of alternative technologies to meet CO_2 constraint from a long term dynamic perspective. With alternative activities representing different technologies, one can permit substitution of various kinds and incorporate non-linearities in such models. The model maximizes a social welfare function given as the present discounted value of utility streams corresponding to the per capita consumption of an average consumer, given the resources available to it and the various technological possibilities for using them. In principle, the time horizon of the model must extend to infinity. Empirical models, however, work with a finite time horizon of length, say, T time periods only (taken to be 35 years in our case) as it is computationally impossible to work with an infinite number of time periods. Instead, they account for the post-horizon periods in other ways.

We represent the whole economy with seven commodities/goods, some of which can be produced in more than one way. In particular, electricity can be produced by coal, oil, gas (combined cycle gas turbine, CCGT) and others (hydro and nuclear). We focus on specific options on the power side as large part of India's CO_2 emissions occur in this sector and policy options here need to be clearly understood. Industrial output can be produced by two alternative activities that use coal-boiler and oil-boiler. Technical progress and energy efficiency gains over time are prescribed exogenously. These remain the same across all scenarios.

Income distribution is endogenous and depends on the total consumption, exogenously projected total population and specified Lorenz ratio. Thus population belonging to each consumption expenditure class is determined in the model. Thus the composition of aggregate consumption changes nonlinearly as the economy grows and people move from one income class to another. Fifteen alternative consumption bundles are provided for each class to represent approximately the indifference curve of the class. This permits substitution across commodities as relative prices change. The bottom class corresponds to those below the poverty line so that we also get an indication of the number of poor in each period.

Ideally income distribution should be linked to production structure and techniques. Unfortunately, adequate data on income generated by activities and how they are distributed to different income classes are not available. However, empirically income distribution as reflected in consumption expenditure has remained very stable with slow and miniscule changes in the Lorenz ratio. National Sample Survey (NSS) data show that it varied with minor fluctuations between 0.3417 in 1956-57 and 0.3202 in 1992 [see, Panda (1999)]. Thus an assumption of a constant Lorenz ratio over a long period of time is justified for India.

The constraints in the model include the following:

a) Commodity balance to ensure that demand does not exceed availability;
b) Production requires fixed capital which once allocated to an activity can not be shifted. Capacity constraints ensure that production does not exceed capacity created by investment in each activity;
c) Capital accumulation constraints that restrict capital stock in each activity to increase by net investment in each activity;
d) Domestic production of oil is restricted to reflect the small oil reserves in India.

On the trade side, we impose a balance of payment constraint. There is also a wedge between export price and import price to reflect international trade and transport margins. Some restrictions are imposed on exports and import growth rates by sectors to keep the model realistic. Thus, import of agriculture is restricted to reflect a self-sufficiency requirement for a large country which is considered necessary for food security. We also restrict import of

services as not all services can be imported. Generous export bounds are introduced to account for crudely, fall in export price and profitability consequent to large exports by India. The values of the bounds are given in the Appendix Table.

A savings constraint is imposed to restrict marginal savings rate to 30 percent. Programming models often give high investments and implied savings rate. Such rates are not realistic as governments in a democratic developing poor country are not able to force savings rate beyond a limit. Finally, though the model is run for a period of 35 years, the post-terminal future has to be taken care of. This is done by assuming that a stationary state would prevail in the future with the composition of output, consumption, investment etc. fixed and growing at a prescribed rate. This translates into a larger weight for the terminal year consumption in the objective function.

Emissions Inventory

CO_2 is emitted when fossil fuels such as coal and oil are burnt in production and household activities. For a given fuel, the amount of emission is directly proportional to its quantity burnt. The CO_2 emission coefficient of a fuel depends upon its carbon content. We account for these emissions in two different ways: flows and stocks. The emissions from the production sectors are computed by considering the scalar product of the activity vector and the emission coefficient vector that indicates the amount of emissions per unit level of activity. The emission coefficient for an activity is derived by considering the fuel specific emission coefficient and the fuel input coefficient. Apart from the production activities, emissions are also caused by the private and public consumption of fuels like kerosene, LPG and motor gasoline. We account for these by considering emission coefficients attached to each consumption activity.

The cumulative emission of CO_2 at the end of any period is computed by adding the emission flows during the current period to the cumulative emissions carried over from the previous period. CO_2 emissions are known to accumulate and reside for long duration in the atmosphere leading to increase in CO_2 concentrations.

Carbon Reduction Options

In the model CO_2 emissions can be reduced in a number of ways. First, it can be reduced by reducing the levels of different activities. This has the direct effect of reducing income and consumption and hence a loss in the social welfare. The second method is to change the composition of production in the economy in favour of less CO_2-intensive activities. This can be done either by changing the structure of trade so that the more CO_2-intensive products are imported or the structure of consumption and other final demand may be changed by reducing the budget share of CO_2-intensive goods in total final demand. This leads to an indirect loss of current welfare as the investor and consumer choices get distorted.

In addition, technological options are also available for reducing the CO_2 intensity of activity levels. These have the virtue of reducing emissions without any significant loss of output. There are essentially two types of such options: (a) Reduce the amount of CO_2 emitting energy inputs required by different activities; additional investment may be required to install equipment that can operate these processes at higher energy efficiency. (b) Switch to less carbon intensive fuels. For example, instead of a coal based power plant, we may install a CCGT power plant, or instead of running industrial boilers on coal, we may use oil. The CO_2 emission coefficient varies across the fuels, being highest for coal (26 tC/GJ), followed by oil

(21 tC/GJ) and the lowest for natural gas (14.7 tC/GJ). Thus, oil or natural gas can substitute coal and lower CO_2 emissions.

To sum up, the model used here belongs to dynamic optimization category in a multisectoral and intertemporal framework with particular options for technology. It maximizes an objective function which is the discounted sum of utilities from consumption. The dynamic framework permits examination of optimal intertemporal choices. There are some specific features we might to highlight in this model for the Indian economy. First, the model incorporates specific technological options with choice of alternative activities (or a combination of them) for producing a commodity. Secondly, it traces welfare effects for the low-income groups by examining the incidence of absolute poverty in the population. Thirdly, there are large differences in consumption patterns among different income classes in a developing country, which are represented in our model. In this context, we also specify several alternative consumption bundles for each income class from which the respective representative consumers can choose. Thus, we permit consumer purchases to be sensitive to the relative shadow prices of commodities in our programming model. Endogenous income distribution is important because it will have considerable impact on the structure of consumption demand in the economy, as population in a lower income class today will move to a higher income class in the future as income growth takes place. Finally, we impose terminal conditions on stock variables in our model. With the inclusion of natural resources among the stock variables, the terminal conditions can be interpreted as sustainability constraints.

Data

We have empirically implemented the model by using recent data for India to estimate the various parameters and initial values of different variables included in the model structure discussed in the previous section. Input-output coefficients and capital-output ratios for various activities form the core of the model. This data is available from published sources for most sectors.[2] In some cases, like the capital-output ratios for the generation of electricity using alternative technologies, we have based our estimates on statistics published by the Centre for Monitoring Indian Economy (1995) on the ongoing and proposed power projects in India. Future projections of government consumption levels and of the upper and lower bounds for exports and imports (where relevant) are specified in terms of growth rates. The database for operating the model is listed in the Appendix Tables. The model is solved using GAMS programming tool developed by Brooke et. al (1988). For endogenous income distribution consistency, we iterate over optimal solutions changing distribution parameters between iterations till they converge.

3. Scenarios

We use the model described in the earlier section to evaluate the impact on economic growth and other related variables corresponding to several alternative CO_2 reduction scenarios over a reference scenario during a period of 35 years from 1990 to 2025.

Reference scenario: The reference scenario is a 'business-as-usual' (BAU) scenario in which the pattern of growth of various variables is determined by the model *in the absence of any emission constraints.*

Emission Reduction Scenarios: We then develop scenarios in which there are restrictions on the amount of CO_2 emissions. These restrictions are applied in two different forms:

[2] Details are available in Parikh et al. (1995)

(a) reduction of 10%, 20% and 30% in *cumulative* CO_2 emissions (CEM_T) over 35 years (these three scenarios are labeled **C10, C20** and **C30** respectively);
(b) annual reduction of 10%, 20% and 30% in CO_2 emissions (EM_t) in *each year* of the 35-year time horizon (these three scenarios are labeled **A10, A20** and **A30** respectively).

Thus, we have six different scenarios of emission restrictions for comparison with the BAU scenario.

4. Impact of Carbon Dioxide Emission Reduction

We now discuss the results of our experiments as designed above. Tables 4-6 shows the values of some important macroeconomic variables and alternative activity levels for selected years for BAU scenario as well as various scenarios involving cumulative and annual emission reduction. Some characteristics of the BAU scenario may be noted. Under it, the economy grows at an average annual rate of 6.3% over 35 years. The carbon emissions grow from 157 mtc in 1990 to 1421 mtc in 2025. Of these emissions, 61 mtc are from electricity generation and 53 mtc from industrial production in 1990 and 659 mtc and 397 mtc respectively in 2025. The annual emissions are plotted in Figure 2. The cumulative emissions over the 35-year period amount to 20353 mtc.

Table 4 gives the effects of CO_2 reduction on aggregate GDP and per capita consumption. Enforcing a 10% (or even a 20%) cut on cumulative CO_2 emissions has virtually no impact in the short run (3rd or 5th year) or medium run (10th year); see column C10 or C20 of Table 4. The GDP and consumption levels fall only marginally. In the long run (30th year), however, the effects of emission restriction are more visible. In the 30th year under the C20 scenario, for example, GDP and consumption per capita fall by 1.36% and 1.85% respectively compared to the BAU scenario. As a result, number of people below the poverty line increases by 5.94% (Table 5).

As the emission restriction level is tightened from 10% to 20% and further to 30%, the effects on long run GDP and welfare become increasingly adverse. Thus, GDP falls by 0.53%, 1.36% and 4.06% and the number of poor increases by 2.1%, 5.9% and 17.5%, in the 30th year for 10%, 20% and 30% cumulative carbon emission restrictions respectively (Tables 4 and 5). The flexibility of the economic system gets reduced, as emission restriction becomes tighter. Also, note that the loss in GDP and consumption is nonlinear i.e., loss rises at an increasingly faster rate than emission restriction. For the case of a 30% restriction, even the short run effects (up to 5 years) are noticeable: GDP and per capita consumption loss is about 0.2% and incidence of poverty is higher by 0.3% compared to the BAU scenario. Furthermore, the losses are more severe towards the end of the target period (30th year) than near the beginning of the restriction period. The model tries to postpone the economic losses due to two reasons: it discounts the future consumption flows and it also enjoys the facility of attaining emissions reduction target over a 35-year period rather than in just one or two years.

Next, we consider the impacts of imposing annual reduction targets for CO_2 emissions. A 10% annual reduction target over each of the 35-year period (scenario A10) achieves the same reduction over the period as the 10% cumulative reduction scenario (C10). But the economic losses are larger under annual reduction scenario than cumulative reduction of the same order. For example, in the 20% restriction case, annual constraints lead to a GDP fall of 3.66% in 30th year as compared to 1.36% for cumulative constraint and for 30% reduction, GDP is lower by a whopping 10.7% (Table 4). Annual constraints are more restrictive than cumulative constraints because they deprive the economic system of its freedom to choose an adjustment path over time, though the terminal period carbon stock level is the same under both types of

constraints. It can be seen in Figure 2 that under the C30 scenario, emission reductions are postponed towards the later part of the time horizon.

The short-run effects are also large for the case of annual constraints. GDP losses in 3rd year vary from 0.47% in the case of 10% annual emission restriction to 11.86% for 30% restriction. The increase in number of poor is a large 20.67 percent increase even in the short run, and in the 30th year the number of poor increase by nearly 50 percent for a 30% annual reduction which indicates a significant short run burden on the lower income segment of the population (Table 5).

The model results for alternative activity levels for 5th and 30th years are presented in Table 6. These results clearly illustrate that, when a CO_2 emission constraint would be active, India would shift away from coal based electricity to oil and gas based electricity and from coal-boiler based manufacturing to oil-boiler based manufacturing. There is, however, no change over to a new technology in the short run when cumulative restriction of 20% or less is affected.

5. Conclusions

The global warming problem due to carbon dioxide emission from anthropogenic sources in the industrial age has attracted attention of nations. Even as the world community is moving towards reduction of such emission on an urgent basis, it also understands the need for the low income developing countries to attain a decent level of living. Hence, it is recognized, as in the Kyoto Protocol, that global CO_2 emission reduction strategy must safeguard the developmental objectives of the developing countries. It is for this reason that India has rightly been excluded from undertaking any binding commitment for CO_2 emission reduction.

Yet, the two largest countries China and India might contribute significantly to incremental carbon emission in the coming decades. They need to explore whatever possible emission reduction measures they could take without compromising their income growth and poverty reduction objectives. In this paper, we have attempted to examine the impact of alternative levels of carbon dioxide reduction measures from a 'business as usual' scenario on growth and poverty in India.

The results from the scenarios suggest that annual emission reductions, imposes unnecessary costs in terms of reduced GDP and higher poverty, both in the short and the long run through distortions in choice of techniques in electricity generation as well as in energy use in industry. The quantitative dimension of GDP fall could vary from about 0.5 - 0.7% in case of 10% reduction in emission to as high as 12% in case of 30% annual emission reduction. Cumulative emission reduction targets are preferable to annual reduction targets and that a dynamically optimum strategy can help reduce the burden of emission reductions. Even cumulative reduction targets increase poverty by a larger percentage in the range of 2.1-17.5% as compared to GDP reduction of 0.5 - 4.1% in the 30th year. GDP loss of this order is not negligible in the long run.

Thus, emission reduction imposes costs in terms of lower GDP and higher poverty. India cannot have any obligation to reduce its carbon emissions for quite some time without sacrificing its basic development objectives of GDP growth and poverty removal. If India were to reduce its carbon emissions for the sake of the global good, it should have sufficient built in compensation or incentives for such an action.

Table 1: Basic Statistics: India, World and High Income Countries				
	Year	India	World	High Income Countries
1.Gross National Product (Billion $)	2000	471	31171	24828
2.Population (Million)	2000	1016	6054	903
3.GNP Per Capita ($)	2000	460	5150	27510
4.Life Expectancy at Birth				
Male	1998	62	65	75
Female	1998	64	69	81
5.Infant Mortality Rate (Per 1000 live birth)	1998	70	54	6
6.Net enrollment ratio (% of relevant age group)				
Primary	1997	77	90	100
Secondary	1997	60	68	96
7. % of Population below Poverty Line				
Below $1 a day	1997	44.2		
Below $2 a day	1997	86.2		

Source: World Bank: "World Development Report" for 2000/2001 and 2002.

Table 2: CO_2 Emissions in India, China and World					
	CO_2 emission (mt)			India/World	China/World
Year	India	China	World		
1980	305.97	1491.34	18658.1	0.0164	0.0799
1981	338.22	1474.86	18337.2	0.0184	0.0804
1982	349.88	1537.74	18202.8	0.0192	0.0845
1983	374.01	1618.53	18334.6	0.0204	0.0883
1984	386.63	1757.34	18891.4	0.0205	0.0930
1985	424.75	1888.28	19391.8	0.0219	0.0974
1986	460.75	2003.98	19761.8	0.0233	0.1014
1987	494.42	2136.52	20443.0	0.0242	0.1045
1988	533.28	2274.54	21095.9	0.0253	0.1078
1989	568.62	2364.21	21426.4	0.0265	0.1103
1990	599.78	2398.29	21245.9	0.0282	0.1129
1991	635.28	2485.86	21446.9	0.0296	0.1159
1992	672.57	2552.70	21391.7	0.0314	0.1193
1993	705.22	2699.37	21534.2	0.0327	0.1254
1994	750.05	2844.21	21607.2	0.0347	0.1316
1995	817.32	3035.00	22073.4	0.0370	0.1375
1996	863.19	3179.72	22784.4	0.0379	0.1396
1997	880.71	3161.95	22981.1	0.0383	0.1376

Source: International Energy Agency (1999): "CO_2 Emissions from Fuel Combustion"

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Table 3: Per Capita CO_2 Emissions

(Tonnes CO_2)

Year	India	China	World	OECD
1980	0.45	1.51	4.23	11.42
1981	0.48	1.48	4.09	10.94
1982	0.49	1.52	3.99	10.51
1983	0.51	1.57	3.95	10.36
1984	0.52	1.69	4	10.57
1985	0.56	1.79	4.04	10.65
1986	0.59	1.87	4.05	10.57
1987	0.62	1.96	4.12	10.76
1988	0.65	2.05	4.17	10.93
1989	0.68	2.1	4.17	11.02
1990	0.71	2.1	4.07	10.77
1991	0.73	2.15	4.04	10.71
1992	0.76	2.18	3.97	10.68
1993	0.79	2.28	3.94	10.75
1994	0.82	2.38	3.89	10.8
1995	0.88	2.51	3.92	10.85
1996	0.91	2.6	3.99	11.14
1997	0.92	2.56	3.97	11.18

Source: International Energy Agency (1999): "CO_2 Emissions from Fuel Combustion"

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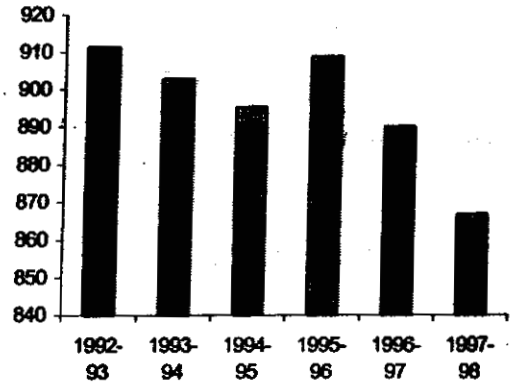

CO2 emission / GDP (tC per rupee crore at 1993-94 prices)

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Table 4: Income and Consumption Effects of Carbon Emission Reduction in India							
	BAU	C10	C20	C30	A10	A20	
		Percentage Change from BAU					
Gross Domestic Product (Rs. Billion)							
Year 3	4850	-0.02	-0.02	-0.19	-0.47	-3.79	-11
Year 5	5301	-0.02	-0.02	-0.17	-0.47	-2.83	-10
Year 10	6801	-0.03	-0.03	-0.62	-0.59	-2.93	-9
Tear 20	12307	-0.02	-0.30	-1.45	-0.59	-3.30	-10
Year 30	24595	-0.53	-1.36	-4.06	-0.69	-3.66	-10
Per Capita Consumption (Rs.)							
Year 3	3758	0.00	0.00	-0.21	-0.48	-4.18	-12
Year 5	3902	0.00	0.00	-0.21	-0.44	-3.13	-11
Year 10	4431	-0.02	-0.02	-0.74	-0.59	-3.14	-9
Tear 20	6520	-0.02	-0.41	-2.42	-0.71	-3.74	-11
Year 30	10688	-0.63	-1.85	-4.95	-0.81	-4.14	-12
Cumulative Emissions (mtc)	20353	-10.00	-20.00	-30.00	-10.00	-20.00	-30
BAU: Business as usual							
A10,A20,A30: Annual reduction of CO2 emission by 10%, 20%, 30% over BAU							
C10,C20,C30: Cumulative reduction of CO2 emission by 10%, 20%, 30% over BAU							

Source: IGIDR Model results

Table 5: Poverty Effects of Carbon Emission Reduction in India							
	BAU	C10	C20	C30	A10	A20	A30
		Percentage Change from BAU					
Number of Poor (Million)							
Year 3	298.80	0.03	0.03	0.34	0.77	6.58	20.67
Year 5	292.35	0.03	0.03	0.33	0.72	5.04	18.90
Year 10	258.83	0.04	0.04	1.34	1.04	5.70	19.02
Tear 20	139.58	0.08	0.99	5.95	1.85	9.42	33.22
Year 30	39.43	2.10	5.94	17.48	2.45	14.34	49.65
BAU: Business as usual							
A10,A20,A30: Annual reduction of CO2 emission by 10%, 20%, 30% over BAU							
C10,C20,C30: Cumulative reduction of CO2 emission by 10%, 20%, 30% over BAU							

Source: IGIDR Model results

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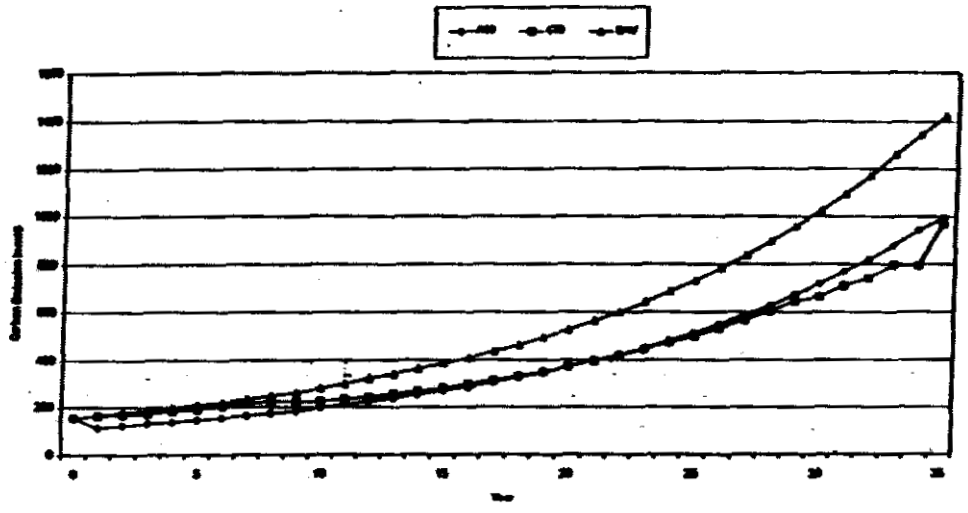
Table 6: Effects of Carbon Emission Reduction on Selected Activities in India							
	BAU	C10	C20	C30	A10	A20	A30
	Absolute Levels in Rs. Billion						
Selected Activity Levels in Year 5							
Electricity-coal	216	216	216	173	162	142	129
Electricity-others	41	41	41	41	52	64	58
Electricity-oil	16	16	16	16	16	10	0
Electricity-CCGT	0	0	0	37	37	42	47
Industry-coal	3962	3961	3961	3895	3734	2330	2074
Industry-oil	0	0	0	0	164	1454	1350
Selected Activity Levels in Year 30							
Electricity-coal	1190	664	635	616	901	704	575
Electricity-others	10	269	289	280	36	197	251
Electricity-oil	4	4	4	0	4	4	4
Electricity-CCGT	0	229	227	224	230	221	202
Industry-coal	17526	17421	4879	1172	17362	16320	14317
Industry-oil	0	0	12689	16193	41	403	801
BAU: Business as usual							
A10, A20, A30: Annual reduction of CO2 emission by 10%, 20%, 30% over BAU							
C10, C20, C30: Cumulative reduction of CO2 emission by 10%, 20%, 30% over BAU							

Source: IGIDR Model results

Figure 2: Annual Emission in Million tC



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References

Blitzer, C.R., Eckaus, R., Lahiri, S., and Meerhaus, A. (1992), *How Restricting Carbon Dioxide and Methane Emissions Would Affect the Indian Economy?*, Background Paper for World Development Report 1992, Policy Research Working Paper Series No 978, The World Bank.

Brooke, A., Kendrick, D. and Meerhaus, A. (1988), *GAMS -- A User's Guide*, The Scientific Press, Redwood City.

Fisher-Vanden, K., P.R. Shukla, J.A. Edmonds, S.H. Kim, and H.M. Pitcher (1997). "Carbon Taxes and India", Energy Economics 19, 289-325.

Gupta, S., and S.G. Hall (1996). " Carbon abatement costs: An integrated approach for India", Environment and Development Economics, 1(1996), 41-63.

Manne, A.S. and Richels, R.G. (1992), *Buying Greenhouse Insurance: The Economic Costs of Carbon Dioxide Emission Limits*, MIT Press, Cambridge.

Nordhaus, W.D. (1994), *Managing the Global Commons: The Economics of Climate Change*, MIT Press, Cambridge.

Panda Manoj (1999): "Growth with Equity: Policy Lessons from the Experience of India" in *Growth with Equity: Policy Lessons from the Experiences of Selected Asian Countries*, United Nations, New York.

Parikh, J., Panda, M. and Murthy, N.S. (1994), *Consumption Pattern Differences and Their Environmental Implications: A Case Study of India*, Discussion Paper No. 116, Indira Gandhi Institute of Development Research, Bombay.

Parikh, J., Parikh, K., Painuly, J.P., Shukla, V., Saha, B. and Gokarn, S. (1991), *Consumption Patterns: The Driving Force of Global Environmental Stress*, Report submitted to the United Nations Conference on Environment and Development by the Indira Gandhi Institute of Development Research, Bombay.

Parikh, K., Panda, M. and Murthy, N.S. (1995), *Modelling Framework for Sustainable Development: Integrating Environmental Considerations in Development Strategies*, Discussion Paper No. 127, Indira Gandhi Institute of Development Research, Bombay.

Shukla, P.R. (1996) The modeling of policy options of greenhouse gas mitigation India, Ambio, 25(4), 241-248.

Appendix 1: Model Equations[3]

The model's objective is to maximize a social welfare function W given as the present discounted value of utility streams $\{U_t\}$ corresponding to the per capita consumption (PC_t) of an average consumer over the time horizon 1,2,....,T. The social discount rate chosen is ρ.

$$\text{Maximize} \quad W = \sum_{t=1}^{T} \frac{U_t}{(1+\rho)^{t-1}} \qquad \text{where} \quad U_t = \log(PC_t) \tag{1}$$

The maximization is subject to several constraints. In the description below, we have omitted what is obvious, that constraints have to be specified for each commodity or each activity and for each period. The first constraint refers to material balance. The total supply of each commodity i, domestic production (Y) plus imports (M), must be no less than the total demand which is the sum of intermediate demand, private consumption (H), public consumption (G), investment (N) and exports (E). All these are real variables evaluated at base year's prices.

$$Y_{i,t} + M_{i,t} \geq \sum_{j=1}^{m} a_{i,j} X_{j,t} + H_{i,t} + g_i G_t + N_{i,t} + E_{i,t} \tag{2}$$

where $[a]$ is the input-output matrix with i commodities and m activities, X is a vector of activity levels and $\{g\}$ is the vector of public consumption budget shares. G_t is specified exogenously while determination of $H_{i,t}$ in relation to the per capita consumption (PC_t) is discussed below later. The input-output matrix need not be square as we distinguish between the set of commodities and the set of activities that produce them. In general, more than one activity is capable of producing a given commodity. A make matrix $[u]$ links each production activity to the commodities they produce. Additionally, this allows the possibility of joint production: an activity may produce more than one output. There is one column vector corresponding to each activity in this matrix and it represents numerically the commodity-wise composition of its gross output.

$$Y_{i,t} = \sum_{j=1}^{m} u_{i,j} X_{j,t} \tag{3}$$

The income generated by each production activity is proportional to their respective level (X) and is equal to the value of the output less the cost of the inputs. Aggregation over all activities (j) gives the gross domestic product (GDP) at market prices.

$$GDP_t = \sum_{j=1}^{m} \sum_{i=1}^{n} (u_{i,j} - a_{i,j}) X_{j,t} \tag{4}$$

The constraints in equations 5 to 9 describe the capacity and investment relations in the economy. All activities must operate within the available domestic capacity.

$$b_j X_{j,t} \leq K_{j,t} \tag{5}$$

where $K_{j,t}$ is the capital stock available for activity j in period t and b_j is the incremental capital output ratio ($ICOR$) for activity j. The production capacities available in different sectors at the beginning of the first period are specified as a part of the initial conditions.

$$\{K_1\} = \{\overline{K}_1\} \tag{6}$$

We have computed $\{\overline{K}_1\}$ using equation 5 as an equality for t=1, assuming that there was full capacity utilization in that year. Capital stock for the later periods is accumulated through investment (Z) which mature into new capacity after a lag of one period.

$$K_{j,t} \leq (1-d_j) K_{j,t-1} + Z_{j,t-1} \tag{7}$$

where d_j is the rate of depreciation of capital stock in sector j.

The aggregate level of investment is constrained by the total savings generated in the economy. The model chooses consumption and savings levels for each period by optimizing the inter-temporal preferences. To counter the possibility of high savings rates resulting in unrealistically low

[3] Taken from Murthy N. Satyanarayana, Manoj Panda and Kirit Parikh (2000): "CO_2 Emissions Reduction Strategies and Economic Development of India", IGIDR, Mumbai. An earlier version of the model appears in Parikh, Panda and Murthy (1995).

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consumption levels we impose an upper limit on the aggregate investment by specifying a marginal savings rate (s).

$$\sum_{j=1}^{m} Z_{j,t} \le S^0 + s(GDP_t - GDP_0) + F_t \tag{8}$$

where F_t is the exogenously specified level of foreign capital inflows in period t.

The investment by sector of destination (Z) such as agriculture or electricity must be balanced against the investment goods available by sector of origin (N) such as machinery or construction. Therefore, we have

$$\sum_{j=1}^{m} k_{i,j} Z_{j,t} \le N_{i,t} \tag{9}$$

where k_{ij} is capital coefficient indicating amount of i-th type of capital per unit investment in sector j.

Turning now to trade, we impose the constraint the total value of imports cannot exceed the foreign exchange available either through export earnings or through inflows of foreign capital (F_t).

$$\sum_{i=1}^{n} M_{i,t} \le \sum_{i=1}^{n} E_{i,t} + F_t \tag{10}$$

The export markets are not unlimited for India and an upper bound on the growth rate of exports is more realistic.

$$E_{i,t} \le E_{i,t-1}(1 + g_i^{EU}) \tag{11}$$

where g^{EU} is upper bound on growth of exports. Similarly, import upper bounds are also used for a few sectors on grounds of food security as well as limited trade possibilities in sectors like electricity and transport.

$$M_{i,t-1}(1 + g_i^{MU}) \ge M_{i,t} \tag{12}$$

where g^{MU} is the upper bound on imports.

While we might restrict our choices to T periods in practice, the economy would continue to evolve beyond this limited horizon. This calls for a minimum level of post-terminal capital stock, $\{\bar{K}_{T+1}\}$ to provide for the future.

$$\{K_{T+1}\} \ge \{\bar{K}_{T+1}\} \tag{13}$$

However, what is $\{\bar{K}_{T+1}\}$? We assume that output, capital stock and consumption grow at a constant rate (ϕ) in the post-terminal period ($T+1,\ldots,\infty$), i.e., the economy attains a stationary state.

$$\{Y_t\} = (1+\phi)\{Y_{t-1}\} \quad \text{for} \quad t > T \tag{14}$$

$$\sum_{j=1}^{m} \frac{u_{i,j}\bar{K}_{j,T+1}}{b_j} = (1+\phi)Y_{i,T} \quad \text{or} \quad \sum_{j=1}^{m} \frac{u_{i,j}(Z_{j,T} - d_j K_{j,T})}{b_j} \ge \phi Y_{i,T} \tag{15}$$

The above simplification might compromise the optimality of the terminal year solution determined by us. However, a compromise is unavoidable in this case.

The objective function is now modified to include the utility from post-terminal consumption, which is assumed to grow at the post terminal rate of ϕ. The revised objective function can be expressed as

$$\text{Maximize} \qquad W = \sum_{t=1}^{T} \frac{U_t}{(1+\rho)^{t-1}} + \alpha U_T \qquad \text{where } \alpha = \frac{1+\phi}{(1+\rho)^{T-1}(\rho - \phi)} \tag{16}$$

Which gives a higher weight (typically, $\alpha > 1$) to the utility derived from consumption in the terminal period because the post-terminal consumption is directly proportional to it. This is in contrast to the objective function defined earlier in equation 1, in which the weight attached to utility is the least in the terminal period. Were the objective function not modified in the above fashion, the model would choose a smaller consumption level for the terminal period as this leads to a smaller requirement of capital investment for post-terminal growth.

The basic framework discussed above suffices to describe the likely growth pattern of an economy. Only one thing remains to be specified: how is $H_{i,t}$, the consumption expenditure by sectors determined in relation to PC_t? We turn to this now.

Consumption Expenditure Distribution and Poverty

Developing countries typically articulate two concerns other than aggregate economic growth: reduction of mass poverty and provision of minimum basic needs to their people. We incorporate aspects related to absolute poverty in our model by focussing on the distribution of consumption expenditure amongst the population.[4] We segment the total population into three different classes by arranging the population in ascending order of per capita consumption expenditure. A fixed pair of lower and upper boundaries (e^{p-1}, e^p) defines the class p. The lowest income households are included under the class $p = 1$, their per capita consumption being less than e^1 which is made equal to the poverty line so that households belonging to this class are identified as poor.

The distribution of population across the three classes is given by a function $f(PC_t; LR, e^p)$ which represents the proportion of total population having per capita consumption expenditure less than e^p. Typically, in the literature, a two-parameter standard lognormal probability density function (SLN) underlies the distribution function f. The two parameters are the Lorenz ratio (LR) and the per capita expenditure (PC). We calculate the proportion, $pop_{p,t}$, of people in the p-th class using the value of PC_t chosen optimally by the model and the class expenditure boundaries (e^{p-1} and e^p) for the p-th class and the value of the Lorenz Ratio (LR), each specified exogenously. The magnitude of population in the p-th class is given as

$$POP_{p,t} = POP_t \cdot pop_{p,t} \qquad \text{where} \quad pop_{p,t} = f(PC_t; LR, e^p) - f(PC_t; LR, e^{p-1}) \tag{17}$$

$$f(PC_t; LR, e^p) = SLN\left(\frac{1}{LR}\ln\left(\frac{e^p}{PC_t}\right) + \frac{LR}{2}\right) \qquad \text{where} \quad SLN(z) = \int_{-\infty}^{z} \frac{1}{\sqrt{2\pi}} e^{-\frac{s^2}{2}} ds \tag{18}$$

Note that $e^0 = 0$ and $e^3 = \infty$ which yields $f(PC_t; LR, 0) = 0$ and $f(PC_t; LR, \infty) = 1$.

The average consumption expenditure $PCC_{p,t}$ of class p can be computed as:

$$PCC_{p,t} = \frac{PC_t \cdot SLN\left(\frac{1}{LR}\ln\left(\frac{e^p}{PC_t}\right) - \frac{LR}{2}\right)}{f(PC_t; LR, e^p)} \tag{19}$$

A representative consumer of the p-th class is allowed to choose a linear combination of R different types of commodity bundles. Her consumption expenditure budget ($PCC_{p,t}$) is allocated across the R bundles in each time period t so that the following identity holds.

$$PCC_{p,t} = \sum_{r=1}^{R} PCB_{r,p,t} \tag{20}$$

Each commodity bundle is composed of different commodities in fixed proportions. For example, $\mu_{i,r,p}$ is the expenditure share of commodity i in the r-th bundle available to a consumer of class p and this value remains fixed in the model. Nevertheless, the consumer achieves a degree of substitution between different commodities by choosing the combination of different bundles and the amounts she spends on each of them. The consumption vector (C) of each class as the aggregate over the set of R consumption bundles.

$$C_{p,i,t} = POP_{p,t} \cdot \sum_{r=1}^{R} \mu_{i,r,p} \, PCB_{r,p,t} \tag{21}$$

The economy-wide consumption vector (H) is then represented by the sum of consumption vectors corresponding to the individual classes.

$$H_{i,t} = \sum_{p=1}^{P} C_{p,i,t} \tag{22}$$

Since the distribution parameter (LR) is fixed in our model, poverty alleviation requires growth in consumption, which is chosen optimally in the model subject to the constraints.

[4] Parikh et al. (1995) describe how provision of basic needs can also be represented in this modeling framework.

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Another point to note in this connection is that we have used the GAMS program to solve the model. GAMS, however, does not permit equations with standard lognormal functions, SLN(.) above. It, however, permits a loop where the SLN function could be computed before obtaining the optimization solution and iterations could be carried out within the loop such that the value of the SLN function converges. We have taken advantage of this facility.

Emissions Inventory

The emissions from the production sectors are computed by considering the scalar product of the two vectors: the activity levels $\{X\}$ and an emission coefficient vector $\{e^X\}$. Apart from the production activities, emissions are also caused by the private and public consumption of fuels like kerosene, LPG and motor gasoline. We account for these by considering two other emission coefficient vectors, $\{e^C\}$ and $\{e^G\}$. The total emissions in period t is therefore given as:

$$EM_t = e^X X_t + e^C H_t + e^G G_t \tag{23}$$

The cumulative stock of CO_2 emissions CEM_t at the end of any period t is computed by adding the emission flows EM_t during the current period to the stock CEM_{t-1} carried over from the previous period.

$$CEM_t = EM_t + CEM_{t-1} \tag{24}$$

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Table A1

Model parameters related to activities

Activities	Agri	Coal	Oil	Electricity produced from				Industry		Trans	S
				Coal	Other	Oil	CCGT	Coal	Oil		
Commodities											
Base Year Input-Output Coefficients : [a]											
Agricult.	0.199		0.000		0.003			0.092	0.092	0.002	
Coal	0.000	0.011	0.000	0.184				0.011	0.004	0.006	
Oil	0.010	0.027	0.469			0.157	0.132	0.016	0.040	0.097	
Electricity	0.007	0.096	0.005	0.248	0.248	0.248	0.186	0.031	0.031	0.015	
Industrial	0.075	0.196	0.042	0.076	0.076	0.076	0.076	0.342	0.342	0.171	
Transport	0.012	0.044	0.012	0.045	0.045	0.045	0.045	0.035	0.024	0.068	
Service	0.038	0.074	0.064	0.045	0.045	0.045	0.045	0.119	0.119	0.079	
Make matrix: [u]											
Agricult.	1	0	0	0	0	0	0	0	0	0	
Coal	0	1	0	0	0	0	0	0	0	0	
Oil	0	0	1	0	0	0	0	0	0	0	
Electricity	0	0	0	1	1	1	1	0	0	0	
Industrial	0	0	0	0	0	0	0	1	1	0	
Transport	0	0	0	0	0	0	0	0	0	1	
Service	0	0	0	0	0	0	0	0	0	0	
Capital composition matric: [k]											
Capital goods											
Agricult.	0.15	0	0	0	0	0	0	0	0	0	
Industrial	0.8	0.958	0.958	0.958	0.958	0.958	0.958	0.958	0.958	0.958	0
Transport	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0
Service	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0
Base Year Output (10^{12} rupees)											
	1.810	0.064	0.219	0.140	0.054	0.022	0.000	3.028	0.000	0.418	1
Incremental capital output ratio: diagonal elements of [b]											
	2.046	1.483	1.500	5.348	6.750	6.750	6.270	0.828	0.845	3.286	1
Initial capital stock (10^{12} rupees)											
	3.704	0.095	0.329	0.749	0.365	0.149	0.000	2.508	0.000	1.374	2
Emision coefficient: [e] in grams/rupee											
CO2	0.55	39.36	13.98	399.52	0.00	221.40	85.00	17.46	12.04	47.92	1

1) I-O table [a] is aggregated from a 60x60 absorption matrix obtained from Planning Commission (1991).
2) Capital Coeff. matrix is obtained by taking the composition of investment demand from 1989-90 I-O matrix and assuming that the investment goods from agriculture sector are entirely used by agriculture sector itself.
3) Base Year capital stock is the product of ICOR and base year output.
4) CO2 emission coefficient are from Parikh, Panda and Murthy (1994).

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Table A2

Model parameters related to commodities

Commodities	Agriculture	Coal	Oil	Electricity	Industry	Transport	Service
Budget shares of different goods in private consumption expenditure of households							
Bottom class: {c1}	0.5594	0.0011	0.0075	0.002	0.23	0.03	0.17
Middle class: {c2}	0.4213	0.0009	0.0135	0.0052	0.2803	0.0457	0.2331
Top class: {c3}	0.2915	0	0.0196	0.01	0.3139	0.075	0.29
Budget shares of different goods in government consumption expenditure {g}	0.0027	0.0001	0.0195	0.0253	0.1716	0.0257	0.755
Upper bounds on annual growth rate of Imports g^{MU}	0.05			0.02		0.05	
Upper bounds on annual growth rate of Exports G^{EU}	0.05				0.12		0.12
Base year values (10^{12} rupees)							
Private consumption: C_0	1.077	0.002	0.042	0.017	0.781	0.172	0.741
Govt. consumption: G_0	0.001	0	0.01	0.013	0.088	0.013	0.386
Export demand: E_0	0.029	0	0.005	0	0.204	0.031	0.099
Import demand: M_0	0.016	0.006	0.056	0	0.345	0.039	0.027

1) Budget shares in private consumption classes are from Parikh, Panda and Murthy (1994). Variations in budget shares are permitted around these base values as discussed in the text.
2) Government budget shares are from 1989-90 I-O matrix.
3)Imports and exports bounds appear only for some sectors indicated above.
4) Base year values are from 1989-90 I-O matrix.

Table A3

Other model parameters

1	Total investment in base year in 10^{12} rupees	0.991
2	Maximum domestic incremental savings rate	0.300
3	Annual growth rate of government consumption	0.050
4	Annual foreign borrowings in the dynamics-as-usual scenario (in 10^{12} rupees): Ft	0.120
5	Annual social discount rate:	0.100
6	Post-terminal annual growth rate	0.055
7	Population in base year in 10^6	821.9
8	Annual growth rate of population (%)	1.8
9	Lorenz ratio of private consumption expenditure distribution: LR	0.38
10	Upper cut-off level of expenditure for bottom class: (rupees)	2250
11	Upper cut-off level of expenditure for middle class: (rupees)	4000

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DRAFT RESEARCH PAPER ON ASSESSMENT OF THE ROLE OF RENEWABLE ENERGY TECHNOLOGIES IN INDIA

- BY DR. RANGAN BANERJEE

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Chapter 1 Overview of Status of Renewable Energy Technologies in India: Share, Potential and Policies

1.1 Introduction

The per-capita electricity consumption in India is about 400 kWh/year, which is significantly lower than the world average (2100 kWh/year/capita) [1]. The level of development and the quality of life in a country correlates with the per capita energy consumption . Any future development path for India will result in an increased per capita consumption of electricity . The power planning strategy in India has been to build large fossil fuel fired power plants and supply electricity through a centralised grid. Despite rapid increases in the supply system, energy and peak scarcity persists in most parts of the country. A large number of villages are yet to be electrified (estimated to be about 80,000). Even in electrified villages a significant proportion of households do not have access to electricity (40% or more).

The limited fossil fuel reserves have made it imperative to explore alternatives. Table 1 shows a summary of the fossil fuel reserves available in India and the reserves/production ratio. It is clear that the oil and gas reserves of India can sustain consumption only for a decade or two. In the conventional nuclear cycle the uranium reasources can only sustain generation of 10000 MW for 50 years. A fossil fuel based electricity sector is clearly not sustainable in the long run. Adverse local environmental impacts (SO_x, NO_x, SPM) and global

Table 1. Summary of Fossil fuel reserves of India

Fuel	Reserves	Production (1998)	
Coal Million tonnes	60000	296	~200+
Oil Million tonnes	660	33.86	19 (9)
Natural Gas Billion m^3	692	26.4	26
Nuclear Natural Uranium	——	——	50

Data source TEDDY [2]

environmental impacts (greenhouse gas emissions mainly due to CO_2) associated with fossil fuel combustion have also intensified the search for clean energy sources. This paper assesses the role of renewable energy technologies (RETs) in the Indian power sector, quantifies the role they can play in the next 20 years and reviews the barriers to RETs and policies required for accelerated diffusion.

1.2 Status of Renewable Energy Technologies

Figure 1 shows the share of the installed capacity of different sources in the Indian power sector. It is seen that Wind energy accounted for about 1% of the country's installed power capacity in 1998 [3,4] The aggregate data does not include some of the renewables viz.. Biomass and dispersed options. Small hydro is also not accounted for separately. If these are included, the share of renewable energy was about 2% in 1998.

The renewable energy installed capacity was 205.5 MW in 1993 (104.6 MW small hydro, 39.9 MW Wind). This increased to 2978 MW in 2001 (as on 31st March 2001) and accounted for almost 3% of India's installed power capacity. The growth rate of installed renewable power capacity during the period 1993-2001 was 39% per year. During (January 1) 2000-2001(March 31st) the installed capacity increased from 1600 MW to 2978 MW (an annual growth rate of 49%).
Figure 2 shows the installed capacity of different renewable energy technologies [5].. The major contributors are small hydro (< 25 MW), which accounts for 1341 MW (45%) and Wind, which accounts for 1267 MW (42%). The installed capacity in Biomass based power generation is 308 MW (10.3%), with most of it coming from Bagasse based cogeneration.

Both wind and small hydro are technologies that are commercially available. Potential sites have been mapped and there is likely to be a steady growth in the capacity. However these are only applicable at some sites where there is sufficient wind or water flows and heads. Figure 3 shows a listing of the options for power generation from Renewables. The solar energy route has a variety of configurations possible based on either solar thermal or solar photovoltaic technologies. These will be assessed in detail in this report. Wind and Small Hydro are commercially available technologies that will also be covered in this report.

1.3 Tidal, OTEC and Wave Energy

The remaining process routes are restricted to only a few regions near the coast. This report will not cover Tidal, Ocean Thermal Energy Conversion and Wave Energy in detail. Of these technologies, power generation from OTEC is only at a prototype stage. There have been experiments at the Natural Energy Laboratory of Hawai (USA) . Power generation is based on utilization of the temperature differences existing in the ocean. Since the temperature differences are small (20°C) the cycle efficiencies are poor (approx 3%). A mini OTEC closed cycle (ammonia working fluid in a Rankine cycle) of 50 kW was installed in 1979 in NELHA with a 10 kW net power output. A 210 kW gross output open cycle plant (working fluid – sea water) was operated between 1992-98 with a net output of 40 kW. These technologies are in the prototype/ development phase and are not yet commercialized. A 1 MW demonstration unit is being planned off the coast of Tamil Nadu. This is being funded by the Department of Ocean Development and the implemented by the National Institute of Ocean Technology with a consortium of private companies.

India has experimented with a 150 kW wave energy system at Thiruvananthpuram (Kerala). This is based on an oscillating water column with a Wells turbine and an electrical generator [7]. The system average output was 25 kW during December-March

and 75 kW during April–November. The average wave energy available is 10 kW per m of the oceanfront. The estimated cost of electricity is 9-10 c/kWh. However though prototypes have been built and some operating experience obtained, this is not yet a commercially available technology.

Tides are caused due to the gravitational attraction of the moon. The difference in levels between the high tide and low tide can be utilized. This is done by creating an artificial basin, trapping the high tide and releasing the water during the low tide. The difference in head (water height) is used to run a water turbine and generate power. A 240 MW Tidal power plant in France (La Rance) has been operating since the last two decades. Potential sites are the Gulf of Kutch (900 MW), Gulf of Cambay (7000 MW) and the Durgaduni Creek in the Sundarbans Delta (1000 MW). There is at present no tidal power station in India. A 3 MW tidal plant is being planned in the Durgaduani Creek. A detailed project report has been prepared and is likely to be implemented by the West Bengal Renewable Energy Development Agency. The capital cost for a 100 MW installation is expected to range between $1200-$1500 /kW (Rs 60,000-75,000 /kW). The capacity factor also will be low as the power will be available only during low tide.

1.4 Renewable Energy Policies

The Government of India established the Department of Non-Conventional Energy Sources (DNES) in 1982 to support new and renewable sources of energy in India. In 1987 DNES proposed a plan of 15,425 MW by 2000/ 2001 through renewables [8]. The actual realization is significantly lower. A review of the renewable energy programme by Sinha[9] in 1990 indicated that this target was unlikely to be met. In the initial years of the renewable programme, the emphasis was on biogas that received more than 50% of the total funding. The funding emphasis shifted in the 1990s with wind, small hydro and biomass programmes getting a larger share of the budget.

The DNES upgraded to the Ministry of Non-Conventional Energy Sources (MNES) in July 1992. A separate agency – the Indian Renewable Energy Development (IREDA) was set up to provide financing for renewables. IREDA has attracted significant multi-lateral funding (GEF, World Bank..) in addition to the Government funding. There has also been a shift in the approach of MNES/ IREDA from direct subsidies to a greater emphasis on fiscal incentives and funds for concessional financing of renewables.
MNES is structured with divisions based on technology areas – solar thermal, biomass, solar PV, small hydro. The divisions are also clubbed together into groups based on end-use areas like the Power group and the Rural Energy group. MNES has also set up a Solar Energy Centre a Centre for Wind Energy Technology and a National Institute for Renewable Energy. In addition to the central government ministry, different states have set up their energy development agencies like the Maharashtra Energy Development Energy (MEDA), Gujarat Energy Development Agency, West Bengal Renewable Energy Development Agency. Each state nodal agency is responsible to promote and support renewable energy in their state. Another development has been the creation of 26 Aditya Solar Shops with seed funding from IREDA to market and sell renewable energy products in the region.

The MNES recently formulated a renewable energy policy, which targets 10% of the additional generation capacity to be realized through renewables by 2012. The power generation potential from renewables, as per MNES estimates [10] is shown in Table 2. The potential estimates are uncertain. It is clear that the renewable energy potential is significant. The key factor is to determine the economically viable potential. This point will be discussed after we examine some of the renewable energy technologies in more detail.

Table 2. Renewable Energy Power generation potential [10]

Source	Potential (MW)	Harnessed (MW)
Wind	45000	1267
Biomass/ Bagasse	19500	292
Small Hydro	15000	1341
Waste-to-Energy	1700	16.2
Solar PV	20 MW/km^2	1.67

References

1. http://www.eia.doe.gov/emeu/international/electric.html#Intl Consumption, Energy Information Administration, US Dept of Energy, International Statistics, Washington DC, USA.
2. Tata Energy Data Directory 1999, Tata Energy Research Institute, New Delhi, 2000.
3. http://www.indiainfoline.com
4. Ministry of Power Annual Report, 1999, New Delhi, India.
5. Renewable Energy in India, Business Opportunities, Ministry of Non Conventional Energy Sources, Govt of India, March 2001.

6. Ministry of Non-Conventional Energy Sources, Annual Reports, New Delhi, 1993, 2000,2001.
7. S.P.Sukhatme, Solar Energy, 2nd Edition, McGraw Hill, 1998, New Delhi.
8. DNES Energy 2001: Perspective Plan for Non-Conventional Energy Sources, Department of Non-Conventional Energy Sources, Government of India, New Delhi, 1987.
9. C.S. Sinha, Renewable Energy Programmes in India, A Brief Review of experience and prospects, Natural Resources Forum, November 1992, pp 305-315.
10. A.K.Gupta, Renewable Energy Policy in India: Policy Approaches, Invited talk presented by Advisor, MNES at IIT Bombay, 6th August 2001.

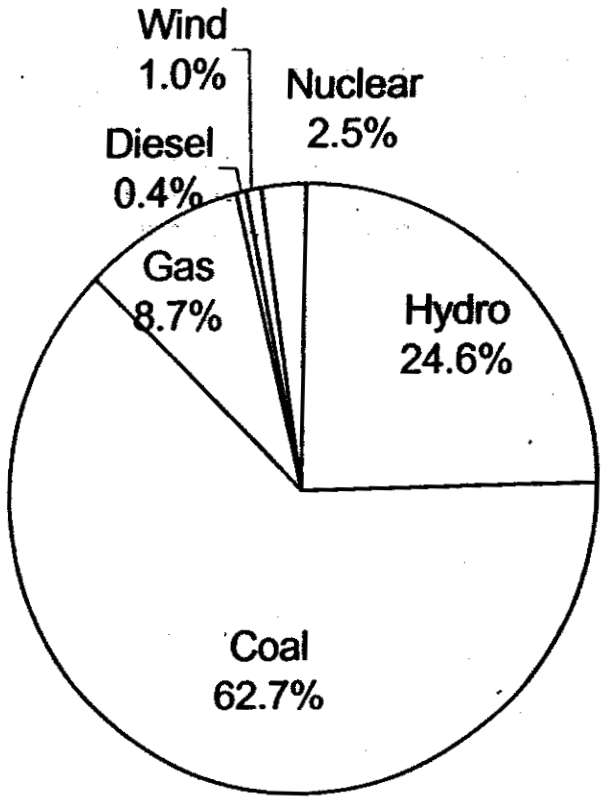

Figure 1 Share of Power Installed Capacity (1998)

2.1.2 Resources Assessment

The Wind Resources Assessment Programme (WRAP) carried out in India to reassess the wind potential was one of the largest programmes of this kind in the world covering about 900 wind monitoring stations and mapping stations in 24 states and union territories. WRAP has so far identified 192 potential sites in 13 states. States with high wind potential are Tamil Nadu, Andhra Pradesh, Karnataka, Kerala, Madhya Pradesh and Maharashtra.

Wind energy potential in India has been estimated at 45,000 MW (at 50-m hub height), however, the technical potential is estimated at about 10000 MW assuming 20% grid penetration. This is expected to grow up with the augmentation of grid capacity in the potential states. State-wise gross and technical wind power potential is shown in Table 4.

Table 4 : Wind Power Potential

States	Gross Potential (MW)	Technical Potential (MW)
Andhra Pradesh	8275	1290
Gujarat	9675	1450
Karnataka	6620	900
Kerala	875	400
Madhya Pradesh	5500	875
Maharashtra	3650	2500
Orissa	1700	400
Rajasthan	5400	500
Tamil Nadu	3050	1220
West Bengal	450	450
Total	45195	9985

Source : MNES Annual Report 2000-2001

2.1.3 Technology

Wind electric generators ranging from 55 to 750 KW rating have been developed and manufactured in the country by using the latest technologies. State-of-the-art wind power technologies are now indigenously available in India. Wind turbines in the megawatt scale are envisaged to enter the Indian market in the near future. An annual production capacity of 500 MW has been established. Wind electricity generators upto 750 KW unit capacity are now being manufactured. Rotor blade, a crucial component of wind turbines, is manufactured in India. Nearly 80 per cent indigenisation has been achieved.

Research & Development Efforts

- State-of-the-art wind R&D centres and field-test stations have been established
- Electronic Research and Development Centre (ERDC), Thiruananthpuram has fabricated an Intelligent Power Controller for wind electric generators to maximise generation and to reduces reactive power requirements. The Controller is under field-testing
- Electronic Research and Development Centre (ERDC), Thiruananthpuram is also preparing guidelines for integration of wind turbines with weak grids

Chapter 2 Assessment of Renewable Energy Technologies

Introduction

This chapter reviews some of the important renewable energy technologies for power generation. For each technology there is a brief description of the technology and its current status in India. The technologies considered are Wind, Small Hydro, Solar Photovoltaic, Solar Thermal, Biomass Combustion, Cofiring, Cogeneration, Gasification and Biogas. Typical values of costs are indicated for each of the technologies.

2.1 Wind Energy

Among the different renewable energy sources, wind energy has made a significant contribution to the installed capacity and has emerged as a viable and cost effective renewable option for grid quality electricity. This is due to the multidimensional initiatives under the Wind Power Programme taken up by the Ministry of Non-conventional Energy Sources. This programme involved research & development, survey and assessment of wind resources, implementation of demonstration and commercial projects, capacity building for manufacturing, installation, operation and maintenance, promotional policies and institutional and infrastructure development.

2.1.1 Status

India is fifth largest wind power producers in the world with a wind power generating capacity of 1,267 MW. Table 3 shows the installed wind power capacity in India as on December 2000. Some 26 project sites have been developed in the high potential states under the demonstration programme, resulting in a capacity of 57 MW. 1,210 MW of power has come through commercial projects. About 6.5 billion units of electricity have been fed to various state grids from wind power projects.

Table 3: Wind Power Installed Capacity (MW) : December 31,2000

State	Demonstration Project	Commercial Projects	Total capacity
Andhra Pradesh	3.1	86.5	89.5
Gujarat	17.3	149.6	166.9
Karnataka	2.6	35.3	37.8
Kerala	2.0	-	2.0
Madhya Pradesh	0.6	22.0	22.6
Maharashtra	6.4	149.0	155.4
Rajasthan	4.3	-	4.3
Tamil Nadu	19.4	767.7	787.1
Others	1.6	-	1.6
Total	**57.2**	**1210.0**	**1267.2**

Source : MNES Annual Report 2000-2001

2.1.4 Economics and Policies

- Capital cost of wind power projects ranges from Rs. 4.0-4.5 crore per MW
- Cost of generation is estimated to be Rs. 2.0-2.5 per kWh (depending upon the site)
- These costs compare favourably with new conventional power project
- Gestation period for wind energy projects is short and it also allows modularity
- Cost can be brought down and profitability increased with technology improvements, increased size of turbines and optimal planning and site selection

Aims and Targets: The wind power programme in India aims at catalysing commercialisation of wind power generation in the country through:

- a country wide wind resources assessment
- R&D support
- implementation of demonstration projects to create awareness and opening up of new sites
- close involvement of utilities and industry
- development of infrastructure capability and capacity for manufacture, installation, operation and maintenance of wind electric generators
- adaptation of technologies for improved performance of turbines at low to medium wind speeds and improved capacity utilisation, cost reduction and high reliability and increased life of turbines
- policy support

Target achievements of wind energy in the Eighth Five Year Plan period are shown in Table 5. Targeted capacity for the next five years is about 1,000 MW. This will require an investment of Rs. 40,000 million.

Policy Measures and Incentives: The policy framework and incentives for wind energy projects are:

- Fiscal and financial incentives
- Wheeling, Banking, Third Party Sale and Buy-back facility by State Electricity Boards (SEBs)
- Capital subsidies and Sales Tax incentives in certain states

Soft loans from the India Renewable Energy Development Agency Ltd. (IREDA)

Table 5 : Target Achievements of Wind Energy in the Eighth Five-Year Plan Period

Category	1992-93	1993-94	1994-95	1995-96		1996-97
	Actual	Actual	Actual	Target	Actual	Actual
Wind power (MW)	12.68	61.09	235	10	382.11	100
Wind pumps (No.)	93	41	200	200	29	200
Wind battery chargers (No.)	4	6	15	35	1	35
Urjagram (No.)	29	25	25	-	-	-

Source : Tata Energy Data Directory & Yearbook 2000-2001

Fiscal and Promotional Incentives :Indian Renewable Energy Development Agency (IREDA) has been playing a significant role in promoting renewable energy projects in general and wind energy projects in particular. It has attracted bilateral and multilateral financial assistance from the World Bank, the GEF, the ADB, etc. Major national financial institutions have also been financing wind power projects. Another major development has

been the entry of central and state power generating entities such as the National Thermal Power Corporation and the State Power Corporation, in the wind sector. Other public sector undertakings are also in the process of diversifying into the wind sector, and a few have already initiated developing large wind farms.The following fiscal and promotional incentives are available from the Central Government:

- Concessional import duty on specified wind turbine parts
- 100 per cent accelerated depreciation in the first year
- Sales Tax, Excise Duty relief
- Loans through IREDA
- Five year Income Tax holiday
- Sales Tax incentives in certain states

Fourteen states have introduced policies based on MNES guidelines:

- 2 per cent Wheeling charges
- Banking upto one year
- Third Party Sales at remunerative prices
- Buy-back facility at minimum price of Rs. 2.25 per kWh
- 5 per cent annual escalation in tariff

In case of state government projects, 60 per cent of the wind turbine equipment, maintenance spares and erection and commissioning (subject to a benchmark cost of Rs. 3.2 crore/MW) would be borne by the Central Government. All other costs will be met by the state government.

IREDA loans for wind power projects are available under different schemes, as follows:

- Project financing
- Equipment financing (up to 1 MW per party per financial year for grid-connected projects)
- Manufacturing equipment.

Financing norms of IREDA have been given in Table 6.

2.2 Small Hydropower

Small hydro projects (SHP) are environmentally benign and economically viable source of energy and are very useful for remote and hilly areas where extension of grid is not possible or is uneconomical. The environmental and social constraints involved in large hydro projects are not concerns in small hydro projects. These projects have short gestation period. Small hydro projects have received sharp focus in recent years. Due to preferential policies and incentives given to this sector by Ministry of Non-conventional Energy Sources, it has grown four fold from 63 MW to 226 MW in the last 10 years. Small hydro power projects upto 25 MW capacity have now been brought under the purview of MNES. There is a renewed interest among many state governments to exploit their SHP potential and 13 states have announced their policies to encourage private sector participation in commercial SHP project. These are Himachal Pradesh, Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Karnataka, Kerala, Andhra Pradesh, Tamil Nadu, Orissa, West Bengal, Maharashtra and Rajasthan.

2.2.1 Resource Assessment

The Central Electricity Authority (CEA) has conducted a study for potential sites for small hydro power of up to 15 MW in all states. MNES has a database of 4,096 potential sites with an aggregate capacity of about 10,071 MW for projects up to 25 MW. There lies a potential of about 15,000 MW of small hydro power in India.

2.2.2 Status

The number of projects set up / ongoing in different states and their capacity has been given in Table 7. India has so far set up 387 small hydro power plants of up to 25 MW capacity totalling 1,341.05 MW. 170 projects of 25 MW with a total capacity of nearly 498.28 MW are under implementation. Most SHPs are grid connected. However, there are a few projects, being managed by local community organisations or NGOs. MNES has recently started a programme on development and upgradation of water mills to enable the direct use of mechanical power for different uses. MNES has also launched a demonstration project to study the performance of portable micro-hydel sets under field conditions. Fifty portable micro-hydel sets of 5-15 kW capacity have been provided to local bodies / communities in seven states.

Table 6 : IREDA'S FINANCING NORMS FOR 2000-2001

No	Sector	Interest Rate (exclusive of Interest Tax) (% p.a.)	Repayment Period including Moratorium (Maximum) (Years)	Moratorium (Maxi.) (Years)	Minimum Promoters' Contribution (%)	Term Loan/lending Norms of IREDA	Remar
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A. PROJECT FINANCING							
	Wind Energy						
	(i)Development of Wind Farms on lease basis	13.75	10	1	25	Upto 75% of total project cost	
	(ii)Development of Wind Farms on ownership basis	13.50	10	1	25	100% of eligible equipment cost limited to a maximum of 75% of total project cost in case on project sanctioned from international funds	
	(iii)Development of Wind Farms by Machine suppliers/manufacturers upto 5 MW/Party per year on built, operate, own lease, transfer basis	13.00	10	1	25	Upto 75% of project total cost	
	(iv) Development of Wind Farm/estate with minimum station capacity of 10 MW by Co-operative Sector /Public Sector/Joint Sector/Private Sector Companies on built, own, operate, lease, transfer basis subject to following conditions: - Applicant having minimum net worth of Rs. 100 crores - Applicant having AAA	12.75	10	1	25	Upto 75% of project total cost	• Existin Compa es to ge preferen e • Loan to be provide lines of credit • Co-operativ Societie if sanctio

	(or equivalent) rating						d lo: shou prof maki
	(v) New Technology above 750 kW machines	12.50	10	1	25	Upto 75% of project total cost	Loan i provid only u internal line credit

Source : IREDA News

2.2.3 Research & Development

India has a well-established manufacturing base for a full range and type of SHP equipment. However, R & D is required to improve the efficiency and reduce costs of equipment. The main objectives of R & D efforts are:

- simplification and optimisation of the system and equipment designs and engineering practices
- reduction in the cost of different elements
- improvement in equipment reliability
- development of techniques for speedy construction in order to reduce gestation period

New concepts such as rubber dams, COANDA systems, SCADA system for computerised project monitoring etc. are being tried out in various demonstration projects.

2.2.4 Economics and Policies

Aims and Targets: The Government of India is encouraging private sector participation for setting up SHP projects. All the states have suitable policies in this direction, to be achieved through:

- a nationwide SHP resource assessment
- Encouragement to commercial SHPs
- Special incentives to northeastern states to exploit SMALL HYDRO POWER potential
- Projects aggregating 65 MW under the renovation and modernisation programme
- Demonstration projects based on commercially viable and environmentally sound technologies
- Upgradation of 100 existing water mills to multi-purpose units

Cost Economics

- Engineering, Procurement and Construction cost of a small hydro is US$ 1,000/kW
- Evacuation cost is about US$ 4,000 / Km
- Total project cost

Fiscal and Promotional Incentives: The facilities available in the states include Wheeling, Banking, attractive Buy-back rate and facility for Third Party Sale

Table 7 : State-wise Details of Small Hydro Power Projects Set up / Ongoing

State	Projects set up		Projects ongoing	
	Number	Capacity (MW)	Number	Capacity (MW)
Haryana	4	48.20	1	0.10
Himachal Pradesh	36	87.28	9	21.73
Jammu & Kashmir	25	85.14	11	29.81
Punjab	15	100.90	3	3.30
Rajasthan	10	23.85		
Uttar Pradesh & Uttaranchal	72	73.40	27	67.28
Goa	1	0.05		
Gujarat	2	7.00		
Madhya Pradesh & Chattisgarh	8	39.16	3	22.60
Maharashtra	23	195.33	6	14.00
Andhra Pradesh	36	128.21	20	44.81
Karnataka	27	138.35	11	28.20
Kerala	10	69.52	11	75.50
Tamil Nadu	10	73.85	3	10.40
Bihar & Jharkhand	10	48.95	9	35.85
Orissa	4	1.30	7	9.93
West Bengal	15	87.94	5	8.42
Sikkim	9	30.50	2	3.20
Arunachal Pradesh	36	33.07	12	20.61
Assam	1	2.00	10	51.11
Manipur	7	4.70	4	3.50
Meghalaya	3	30.71	7	0.28
Mizoram	14	11.76	3	15.50
Nagaland	6	3.87	4	26.80
Tripura	3	16.01	1	0.10
A & N Island			1	5.25
Total	**387**	**1341.05**	**170**	**498.28**

Source : Tata Energy Data Directory & Yearbook 2000-2001

among others. In order to accelerate development of SHP power in the country, MNES is providing incentives for:

- Detailed survey and investigation
- Detailed project report preparation
- Interest subsidy for commercial projects - up to 7.5 per cent in the hilly regions and up to 5 per cent in the plains
- Under special incentives for the northeastern region and Sikkim, a capital grant of Rs. 7.5 crore per MW is available for SHP projects in the region
- Financial support for renovation and modernisation and capacity uprating of old SHP stations

- Financial support for development / upgradation of water mills
- IREDA provides soft loans for setting up of SHP projects up to 25 MW. The Financing norms of IREDA have been given in Table 8.

2.3 Solar Photovoltaics

Solar Photovoltaic (PV) technology based on solar cells provides one of the most environmentally friendly source of electricity generation. PV can be used both in stand-alone and in grid connected applications. It is useful for rural remote areas, urban domestic and commercial establishments as well as for specialised applications such as in railways and telecommunications.

Solar cells are semiconductor devices, which convert sunlight into electricity directly without involving any moving parts. Wafers sawn from mono or multi-crystalline ingots of high grade silicon are the most used semiconductor materials for making solar cells today. Thin film solar cells is being regarded as the technology for the future. A complete PV power system has a PV array, an energy storage system and necessary electronic, electrical and mechanical subsystems.

India receives about 300 clear sunny days in a year. This is equal to over 5,000 trillion kWh. year, which is far more than the total energy consumption of the country in a year. The daily average solar energy incident over India varies from 4-7 kWh/m^2, depending upon location. Table 9 shows potential of PV in different states on a scale of 1 to 4.

Table 8 : IREDA'S FINANCING NORMS FOR SMALL HYDRO (2000-2001)

No.	Sector	Interest Rate (exclusive of Interest Tax) (% p.a.)	Repayment Period including Moratorium (Maximum) (Years)	Moratorium (Maxi.) (Years)	Minimum Promoters' Contribution (%)	Term Loan/lending Norms of IREDA Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
A. PROJECT FINANCING						
	Hydro Energy *(upto 25 MW Station Capacity)*					
	Mini Hydro					
	(i) Upto 1 MW Capacity	13.50	10	3	20	Upto 80% of total project cost. 100% of eligible equipment cost and 90% of civil cost limited to a maximum of 80% of total project cost in case of project sanctioned from international funds
	Small Hydro					
	(i) Above 1 MW and	13.75	10	3	25	Upto 75% of total project cost. 100% of eligible

	upto 3 MW Capacity					equipment cost and 90% of civil cost limited to a maximum of 80% of total project cost in case of project sanctioned from international funds
	(ii) Above 3 MW and upto 25 MW Capacity	14.00	10	3	25	Upto 75% of total project cost: 100% of eligible equipment cost and 90% of civil cost limited to a maximum of 80% of total project cost in case of project sanctioned from international funds

Source : IREDA News

Table 9 : Index of PV Potential by State

Very High Potential		High Potential		Low Potential		Very Low Potential	
Maharashtra	3.8	Bihar	2.8	Jammu & Kashmir	2.3	Sikkim	1.9
Karnataka	3.5	Madhya Pradesh	2.8	Meghalaya	2.2	Pondicherry	1.7
Gujarat	3.4	Delhi	2.8	Tripura	2.2	Lakshadweep	1.5
West Bengal	3.3	Assam	2.8	Himachal Pradesh	2.1	Daman & Diu	1.5
Goa	3.3	Manipur	2.7	Arunachal Pradesh	2.1	Andaman	1.5
Andhra Pradesh	3.3	Orissa	2.6			Dadra & Nagar	1.0
Tamil Nadu	3.3	Rajasthan	2.6				
Punjab	3.2	Nagaland	2.5				
Uttar Pradesh	3.2	Chandigarh	2.4				
Kerala	3.2	Mizoram	2.4				
Haryana	3.1						

Source : Indian Solar PV Market Assessment and Publicity Campaign Development Study 1994

2.3.1 Market Base in India

India has both the need and the opportunity to use solar energy on a large scale. Annual production volumes are of the order of 10 MWp. India is one of the largest markets and manufacturers of PV modules in the world after US, Japan and the European Union.

In India, where more than 70% of its one billion population live in the rural sector, water pumping (especially for irrigation) presents one of the biggest markets for PV. India today has about 13 million electrical pump sets in operation with a potential for six million more. Of these, open wells total about two million. Even if 10% of these open wells are

energised (i.e. 200,000 open wells), this would translate to a demand for PV of the order of 200 MW, assuming 1 kW stand-alone PV systems. There are 100 million kerosene lanterns in use in the remote villages of India. This represents a market for 1 GW of PV (assuming replacement by 10Wp solar lanterns).

Assuming 25% of India's population live in the urban sector (i.e. 0.25 billion or 250 million) and an average family consists of 5 members, this would represent 50 million households. Even if 2% of this figure i.e. one million-households / houses opt for 500 Wp PV stations, on an average, the demand for PV would be 500 MW. We have not talked about commercial complexes, corporate buildings and farmhouses. With the kind of demand anticipated, prices will no doubt plummet down to Rs. 50 a Watt in the next 5 to 10 years.

2.3.2 Status

About 65 MW aggregate capacity (about 8,00,000 systems) stand-alone PV systems have been installed for various applications. 7,50,000 systems, aggregating to about 58 MW have been installed under MNES's PV programme. This includes 3,60,000 solar lanterns, 1,60,000 homelighting systems, 43,000 street lighting systems and 3,575 water pumping systems.

MNES is implementing two major schemes for the deployment of stand-alone PV systems in the country:

- Lighting systems, stand-alone power plants and other specialised systems
- Water pumping systems for agriculture and related uses

Prominent regions where SPV homelighting systems and power plants are in demand are West Bengal, Rajasthan, hilly regions of Uttar Pradesh, Laddakh, Lakshdweep, Andaman and Nicobar Islands. Eleven power plants of 250 kWp aggregate capacity have been installed in Sagar Island in West Bengal.

Target achievements of SPV in the Eighth Five Year Plan period are shown in Table 10. In the last two decades, the cost of PV has gone down by more than 10 times, increasing accessibility for dispersed rural applications.

Table 10: Target Achievements of SPV in the Eighth Five-Year Plan Period

Category	1992-93	1993-94	1994-95	1995-96		1996-97
	Actual	Actual	Actual	Target	Actual	Actual
Power units (kWp)	143.36	122	100	30	89	50
Community lights (No.)	-	-	-	-	-	-
Domestic lights (No.)	3,043	6,399	500	1000	-	-
SPV Lanterns (No.)	-	-	-	-	-	-
SPV Street lights (No.)	-	-	-	-	-	-
SPV Water pump (No.)	106	1894	1000	-	738	1000

Source : Tata Energy Data Directory & Yearbook 2000-2001

Aims and Targets: An all India SPV programme to develop cost-effective PV technology and its application for large scale diffusion in different sectors, especially in rural and remote areas is under implementation by MNES. Major components of PV programme include:

- Research and development
- Demonstration and utilisation

- Testing and standardisation
- Industrial and promotional activities

2.3.3 Promising PV Technologies for Terrestrial Use

Monocrystalline silicon technology is the oldest and most enduring WorkHorse of all PV technologies. While laboratory efficiencies have reached 25%, manufactured efficiency is in the range of 15.3 to 17.5 (14-16% module level). PV module efficiencies which are close to 15% at present are expected to increase to 22% by 2010. The prices are also expected to come down to $2/Wp by 2010. The basic raw material is sand (quartzite or silicon dioxide), which is reduced to metallurgical grade silicon and then purified to semiconductor grade (99.9999% pure). Mono-crystalline Si technology is of the 'indirect band gap' type with very poor absorptivity. Minimum thickness of silicon material required for absorption would be of the order of 100 microns or so. Today single crystal wafers of 250 microns thickness are available. Ingot pulling is energy-intensive and wafer slicing wastes material (Kerf loss) upto 40-50%. Optical enhancement of incident light entering the solar cell is achieved by various techniques including anti reflection coating, texturing of the surface and laser grooved buried contact design and PERL (passivated emitter rear locally diffused) structure.

Silicon Film: Today quite a few companies like Astropower are growing silicon film epitaxially on low cost surfaces (like ceramic). The thickness of material would be of the order of 50 micro-meters or less. The active layer (< or = 50 micro-metres) is supported by a substrate consisting of non-silicon material or low grade Si. Efficiencies of cells exceeding 16% have been achieved. PV module efficiency of 8-10% was achieved in 1998 and is expected to reach 12% this year. The price of silicon film on low-cost substrate is expected to come down to $2/Wp shortly and is predicted to come down to $1.25/Wp by 2010.

Polycrystalline Si technology is gradually overtaking single crystal silicon technology in terms of production capacity and shipments. Polycrystalline Si ingots are cast (and not pulled with the help of a seed crystal) in square or rectangular shapes as opposed to the round and pseudo-square shapes of single crystal Si cells. In 1998, polycrystalline Si PV modules recorded efficiencies of 13-15% which are predicted to increase to 20% by 2010, while prices are expected to fall to $ 2/Wp.

EFG (Edge defined film fed growth) technology, patented by ASE Americas, involves the pulling of crystalline silicon tubes from growth furnaces. Si pellets are melted in furnaces at 1410°C. From the molten material, hollow octagonal tubes are grown to a height exceeding 16 feet before being removed from the furnace and laser-cut cells to 100 mm squares, that are processed to make electrically active thinner cells. Wire sawing & consequent kerf losses etc. are avoided. Cells are then sealed in a clear encapsulant material, specially developed by ASE Americas, and then assembled into modules. Glass is used as substrate and also as superstrate. 14% module efficiencies were reported in 1998. The efficiency is expected to increase to 17% this year and to 25% by 2010 and the price per watt is expected to come down to $ 1.25/Wp by 2010.

Concentrator technology. Concentrator technology which involves the concentration of sunlight to a point or line focus through an optical interface got its impetus through liberal funding in U.S. during the oil crisis of the early and late 70s. The PV concentrator companies still active include Amonix (cell type m-Si, concentrator factor 260), BP Solarex (m-Si, 30), Daystar (m-Si/Cis, 45), Entech (m-Si, 20), Hitachi (BI, mono facial Si, 2), PVI (m-Si, 9) and Solar Systems (Si, GaAs, 300-500). Amonix is well known for its huge concentrator systems based on point focus fresnel lens system and on high efficiency

silicon cells (26.5% efficiency). Currently 300 kWp of Amonix systems are installed in Arizona (PHOTON International, Jan 2000). It is believed that a niche market for Concentrators in the future could arise from BIPV (Building integrated PV) sector in countries with higher diffused solar radiation.

Amorphous Silicon (a-Si) is using a p-I-n structure ('p' layer, undoped intrinsic layer and a 'n' layer) is perhaps one of the oldest of all this film technologies, initially finding use in consumer (including non-PV) applications. The major advantage of a-Si technology is its high absorptivity (40 times more than mono-crystalline Si) and hence the requirement of much less material (one micron or so). a-Si can be deposited on any substrate such as glass (window glass), stainless steel (4 to 8 mm thickness) or plastics (kapton, polyimides). But the biggest disadvantage of a-Si technology is its light induced degradation (in the first 12 to 16 weeks of its exposure to the sun) called the Staebler - Wronski effect. This 'effect' has been partially overcome by stacking cells (tandem cells) and using very thin 'p' layers or window layers or using micro crystalline 'p/n' layers in the top junction.

Due to the use of less material and to the ease of the manufacturing process (deposition is by PECVD generally), a-Si holds the promise of the prices of modules coming down to $ 1.25/Wp by 2010. Today prices are about $ 3/Wp. Module efficiencies are expected to increase to 14% by 2010.

Cd-Te Cadmium Telluride offers the best match to the solar spectrum with its band-gap of 1.43eV. It uses a CdS (Cadmium Sulfide) window layer and Cd-Te 'p' layer. The advantages of the cd-Te technology are :

a) High absorptivity.
b) Cd-Te sublimes congruently upon heating, liberating Cd & Te in equal amounts (1:1 ratio), the residue remaining stoichiometric Cd-Te. Cd-Te condenses stoichiometrically as long as the substrate is heated about 400^0 Centrigrade (approx). Films deposited at lower temperatures (not in stoichiometric ratio) can be heated to create the single phase stoichiometric compound.
c) Because of b) above, it is amenable to many deposition technologies such as closed space sublimation, chemical spraying, screen printing, sputtering, spray pyrolysis, galvanic deposition, CVD, atomic layer epitaxy etc.
d) Module efficiencies which are 6-8% today are expected to increase to 14% by 2010. Prices are expected to come down to $1.25/Wp by 2010.

Copper Indium Diselenide CIS or CIGS i.e. copper indium gallium diselenide is another promising thin film technology that uses CdS as a window layer. Sometimes gallium or sulphur are also added. CIGS cells are self repairing. They are stable and long-lived. The material probably tends to repair itself because of the natural tendency of copper atoms to distribute themselves evenly and at great speed. They spread into damaged spots and carry out the repair.

Gratzel cell or Dye-sensitised Tio2 cells The Gratzel cell (also referred to as dye-sensitized mono-crystalline TiO_2 or Photo-chemical solar cell) is a new type of PV cell, a photochemical device that is based on dye-sensitization of thin (10-20 micro-meter) nano-crystalline films of TiO_2 nano-particles in contact with a non-acqueous liquid electrolyte.

Research & Development

Materials and Devices

- Development of crystalline silicon thin film layers and low-cost substrates for deposition of films
- Development of large size solar cells / modules based on crystalline silicon thin films

- Development of multi-junction amorphous silicon solar cells / modules, pilot plant demonstration
- Development of devices based on new materials such as TiO_2, carbon cells etc.
- Improvement in solar cell efficiency to 14-15 per cent at commercial level and >20 per cent at research level
- Improvement in PV module technology, higher packing density, suitability for solar roofs etc.
- Development of light-weight modules for use in solar lanterns and similar application

Applications:

- Improvements in system design for PV lighting systems, including development of a new design of electronics used in solar lanterns
- Development of high efficiency invertors, charge controllers and power conditioning units
- Development of spill proof tabular plate lead acid batteries
- development of maximum power point trackers
- Development of high efficiency water pumps and motor pumps and water pumping systems
- Development of integrated power conditioning units
- Development of new PV systems
- Reliability and performance studies of technologies and instruments
- Development of solar roof systems and electronics used in solar roof systems .

*PV Products:*Solar lanterns, home lighting systems / solar home systems, street lighting systems, stand alone PV power plants, refrigerators for medicines and vaccines, solar PV water pumping systems for agriculture and related uses, and other applications of PV technology, including new applications.

Investment Opportunities

- Opportunities exist in all major thrust areas
- Grid interactive SPV power projects of 500 KW capacity: manufacturers of solar cells and modules, industry and private sector, can set up these projects by entering into suitable power purchase agreement with SEBs
- Joint ventures with global PV manufacturers
- Setting up manufacturing plants as 100 per cent export oriented units
- Technology transfer for PV module especially for PV models based on thin film materials

Incentives & Duties

- 100% accelerated depreciation available in the first year.
- 5 years tax holiday on power projects.

Concessions to Entrepreneurs Belonging to SC/ST, Women, Ex-Servicemen and Handicapped Categories

i) Exemption from payment of following:
   - Initial Processing and Documentation charges
   - Inspection Fees
   - Legal Charges
   - Expenditure incurred on Nominee Director(s)
   - Front-end Fee @ 1.00%

ii) Concession of 5% in Promoter's contribution

2.4 Solar Thermal

Apart from the solar photovoltaic route, discussed in the previous section, which has been commercially exploited in the low power range, it is possible to obtain power from the solar thermal route. Figure 4 lists the technology options for power generation from Solar. Solar Thermal options involve using solar radiation to heat water or a heat transfer fluid and then operate a power cycle with the fluid. Sukhatme [1,2] reviewed the options for solar thermal power generation and classified the thermodynamic cycles as low (about 100°C maximum temperature), medium temperature (upto 400°C) and high temperature cycles (above 400°C). One option for the low temperature cycles is to solar flat plate collectors and use an organic ranking cycle with working fluids like methyl chloride, toluene or refrigerants like R-11. The overall cycle efficiency is low. The high capital cost ($ 6000 /kW) and the low capacity factor (25-30%) makes this unviable. Two concepts have been proposed in order to reduce the cost - solar ponds and solar chimney. A 5 MW Solar pond based power plant was set up in 1984 in Bet HA Arava with an area of 250,000 m^2 (50,000 m^2/MW). Though this has been shown to be technically viable this is still not an commercial technology. In India there has been some experience with solar pond for thermal applications (hot water for a dairy) – operated by TERI in Bhuj but there has been no attempt to use a solar pond for power generation.

An alternative concept that has been demonstrated is a solar chimney power plant [3,4]. In the Solar chimney plant ,a transparent cover glazing is provided over a circular area around a tall chimney (Figure 5). This glazing is maintained

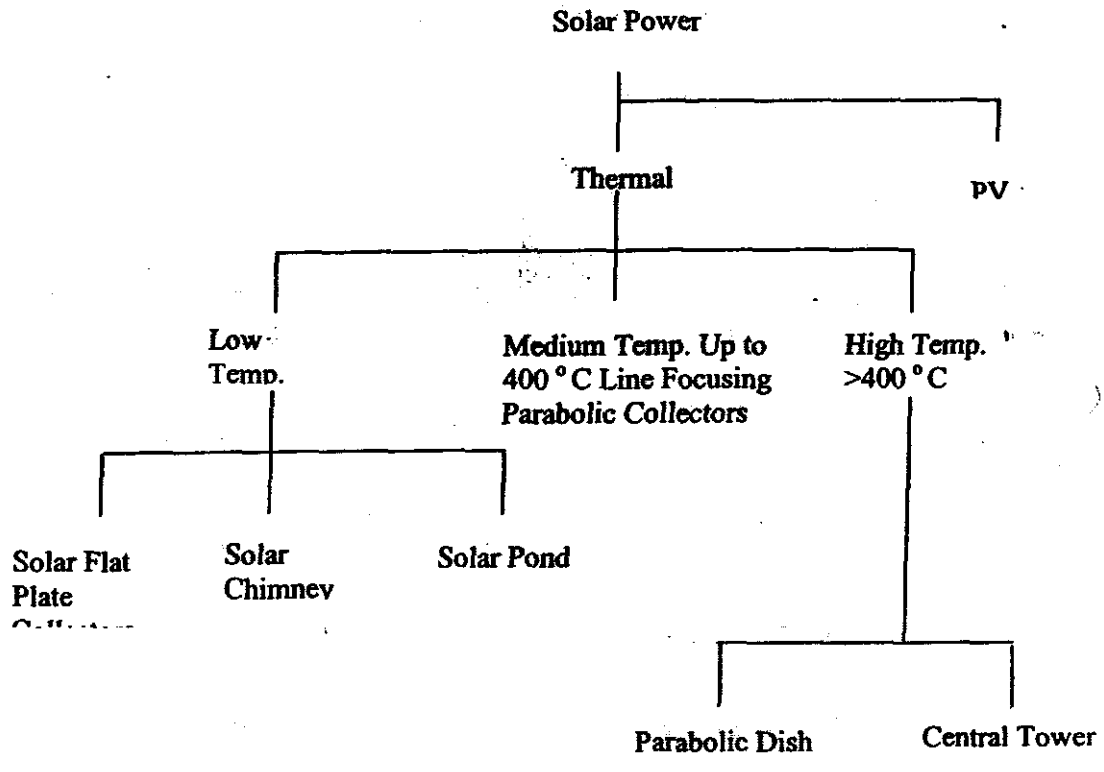

Fig. 4 Technology Options for Solar power

iii) Rebate of 0.50% in Interest Rate for all NRSE schemes of IREDA for projects involving project costs upto Rs. 25.00 lakhs.

Concessions in IREDA'S Lending Norms to Entrepreneurs for Setting Up Projects in North Eastern States, Hilly Areas, Islands Including Estuaries and Desert Areas

- Concessions in interest rate @ 2% per annum on all sectors of Renewable Energy Projects (other than Grid connected Projects. Entrepreneurs belonging to SC/ST/Women/Ex-Servicemen/Handicapped category will be eligible for concessions. Concessions would, however, be subject to the condition that minimum interest rate @1% p.a. would be chargeable.
- The definition of Hilly Areas, Desert Areas, Islands etc. would be as notified/announced/declared by way of Gazette/Government Order/Circular/Executive Order/Specific Clarification letter by competent authorities of Central/State Governments/Local Authorities in the prescribed form of IREDA.

References for 2.1 to 2.3

- Annual Report, 2000-2001, Ministry of Non-conventional Energy Sources Indian Solar PV Market Assessment and Publicity Campaign Development Study 1994, prepared for IREDA by ADMAR Services Pvt. Ltd.
- IREDA News, Millennium Special, Vol 10, No.4, Oct.-Dec. 1999
- Photovoltaics in Energy Conservation, Energy Efficiency & GHG Reductions, an Article by Col. T. S. Surendra, Executive Director, Polyene Film Industries Ltd., Hyderabad, India
- Profile on Wind Energy Programme, IREDA
- Renewable Energy in India - Business Opportunities, Ministry of Non-conventional Energy Sources, 2001
- Solar Photovoltaics - Market Development Programme (World Bank Line of Credit), guidelines for Loan Assistance, IREDA leaflet
- Tata Energy Data Directory & Yearbook, 2000-2001, published by Tata Energy Research Institute, New Delhi.

above the ground by a metal frame. The air trapped in the enclosed circular area get heated and a natural convection system get established with the hot air getting drawn up through the chimney. This hot air is replaced by fresh air from the edges of the circular glazing. A Solar chimney plant of 50 kW capacity was built in Spain in 1983 with a 195m high, 10.3m diameter chimney and a glazing 2m above the ground covering a radius of 126m. A Solar chimney plant with a

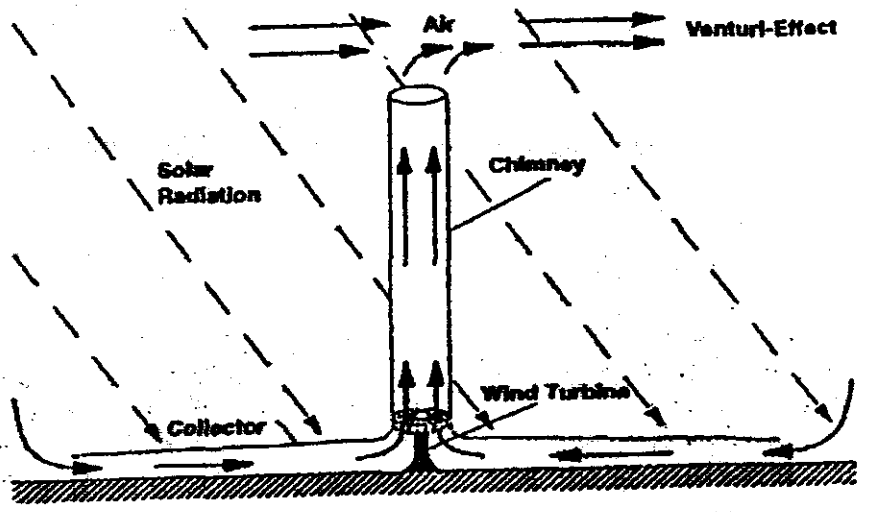

Fig.5 Schematic of Solar Chimney[4]

1km chimney and 100 million m^2 of collector area generating 200 MW was planned in Rajasthan [3]. However the project idea has not been pursued. The cost is estimated at $4600/kW. Though it has been estimated that this system might have the lowest life cycle energy cost [4], this is not yet commercially available. Since 1983, no new plants have been set up.

Of the solar thermal technologies, the maximum experience globally is with the line focussing parabolic trough technology. These are medium temperature systems. Figure 6 shows a schematic of a parabolic concentrator. The parabolic concentrators focus the solar energy on the working fluid (synthetic heat transfer oil) that is heated to a temperature of 400 °C. This is used to generate superheated steam that drives a conventional Rankine cycle. This is

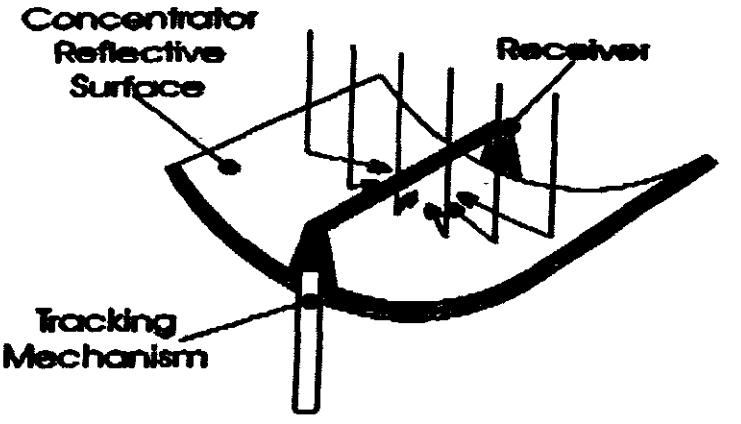

Fig 6 Schematic of a parabolic concentrator

the only solar thermal power technology that is commercially available with 354 MW (9 plants) of grid connected power plants in operation in California. The plant ratings vary from 4 to 80 MW. The collector area for the 80 MW plant is 464340 m^2 (5800 m^2 /MW). The cost for the 80 MW plant is estimated to be $2900/kW.

A 50 kW solar power plant has been in operation in the Solar Energy Centre at Gurgaon. Due to maintenance problems, the unit has been derated.

A 35 MW solar power plant in an Integrated Solar Combined Cycle (ISCC) plant of 140 MW is planned in Mathania, Rajasthan with GEF funding. Figure 7 shows a schematic of the proposed ISCC plant. The total collector area is about 219000 m^2 . The parabolic collectors heat a heat transfer fluid to 391°C. This fluid is used to generate steam (103 bar, 371° C) in a heat exchanger. This steam is superheated to 500°C using the heat available from the

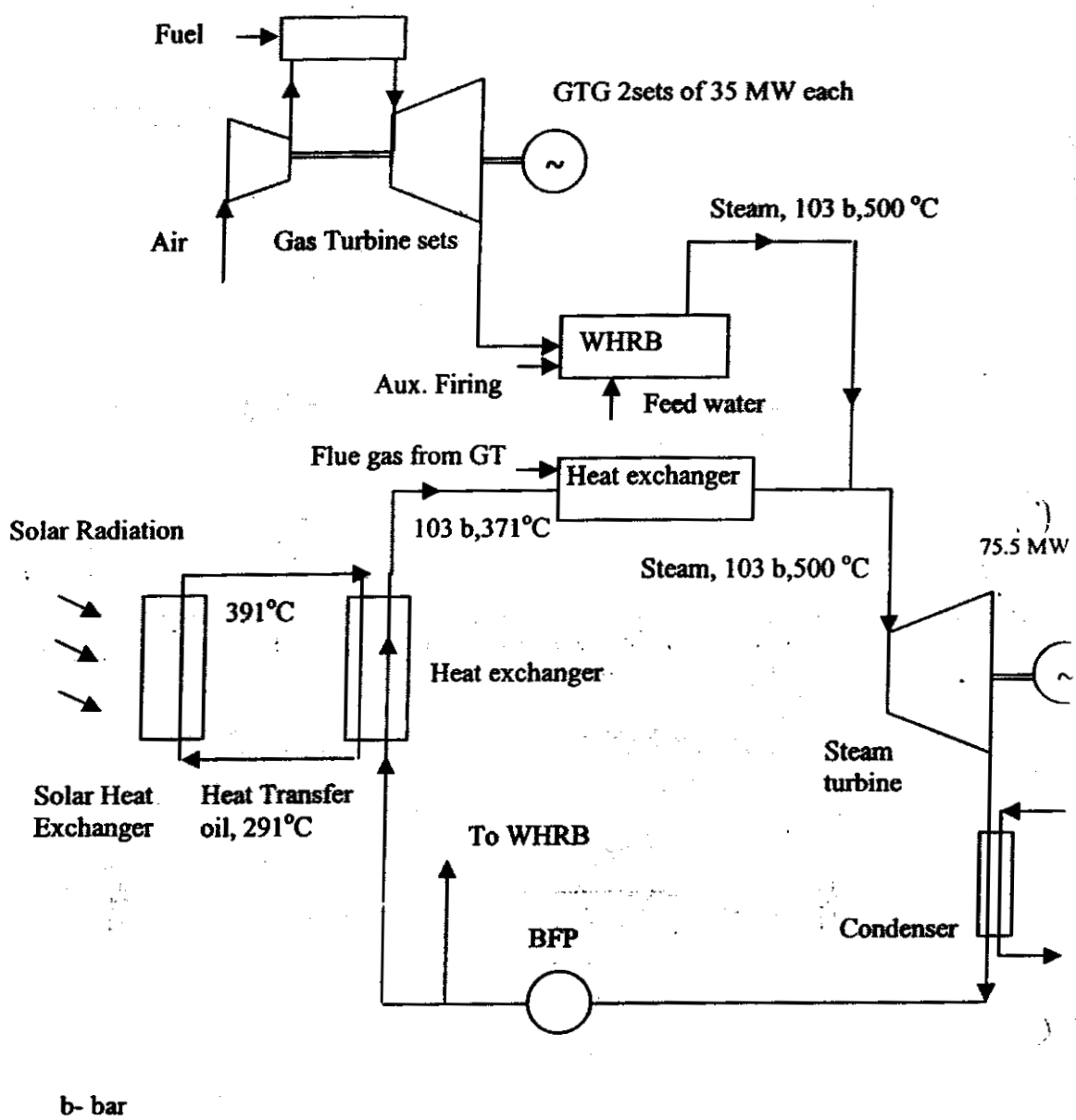

Fig.7 Schematic of the proposed ISCC plant

exhaust of a gas turbine. Two gas turbines of about 35 MW each will be operated with naphtha as fuel. The exhaust gases generate steam at 103 bar 500°C in waste heat recovery boilers that have an option for supplementary firing. The steam from the waste heat recovery boilers and the solar supplied steam are used to drive a condensing steam turbine of 75 MW rating. The total capital cost of the plant is Rs 872 crores ($245 million). The Global Environmental Facility is providing $ 45 million towards incremental costs. The

total ISCC cost works out to Rs 62,000/kW. However the incremental cost for the solar component is likely to be about Rs 90,000/kW.

The highest efficiencies possible are with concentration using the paraboloid dish or the solar tower concept. Figures 8 a and b show schematics of the paraboloid dish and the central receiver plants. In the paraboloid dish the concentrator tracks the sun by rotating about two axes and the solar radiation is focused on the receiver (point focus). The heat absorbed in the receiver is used to drive a prime mover normally a Stirling engine. The efficiencies are the highest obtained in the solar thermal route- around 29%. Systems of rating 8-50 kW have been developed internationally. A 20 kW experimental unit near Hyderabad has been installed and an additional demonstration 10 kW plant is being installed at Vellore. These are both based on imported technology.

In the central tower power plant the solar radiation is reflected from arrays of large mirrors (heliostats) and focussed on a receiver located at the top a tower. A 10 MW solar tower plant (Solar One) was installed at Barstow California and operated from 1992 to 1998. This had 1818 heliostats of 39.3 m^2 reflective area each. Solar One was converted to a molten salt transfer system using a mixture of sodium and potassium nitrate. Since solar radiation is only available for 5-6 hours in a day, storage systems are also required. The central tower is a costly concept ($4700/kW),but continues to be explored since the molten salt receiver acts as a storage and the system can have high capacity factors. Table 9 shows a comparison of Solar Thermal Power Generation Technologies.

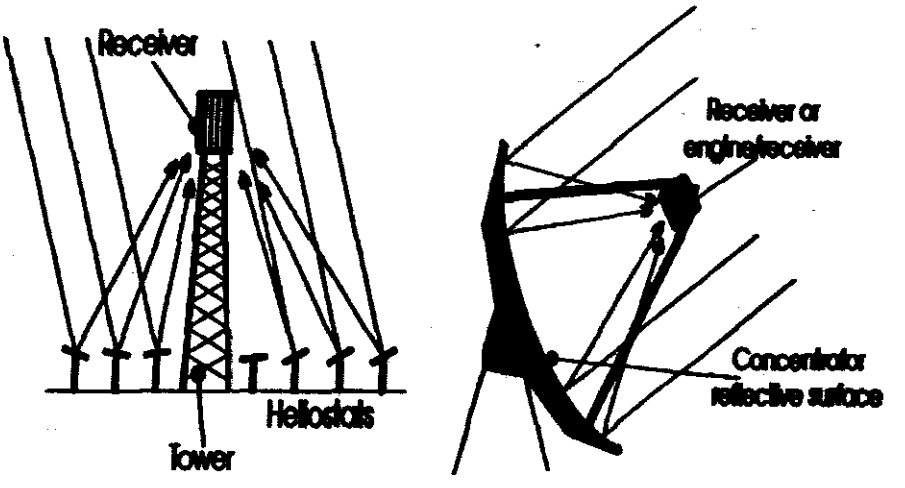

Fig. 8 (a) Central receiver (b) Paraboloid dish [7]

Table 9. Comparison of Solar Thermal Power Generation Technologies

Technology	Efficiency	Indian Experience	Status	Capital Cost (Rs/kW)	Electricity Cost (Rs/kWh)
Solar Flat Plate Collectors	2%	10 kW exptl unit at IITM	D	Rs 300,000	———
Solar Chimney	1%	No experience 50 kW Spain	D	Rs 200,000 ($4600/kW)	———
Solar Pond	1-2%	Experience for hot water Bhuj (Israel 5 MW power)	D		
Line focussing Parabolic	Peak 20% Average 11-14%	50 kW system in SEC installed Planned 35MW solar in 140 MW ISCC at Mathania	C	Rs 140,000 ($3000/kW) ~ 390 MW of operating plants	15 c/kWh Rs 6/kWh
Paraboloid Dish	29% peak 12-18%	Demo unit 20 kW near Hyderabad 10 kW Vellore	D	Rs 150,000	
Central Tower	23% peak 7-14%	No experience	D	~Rs 200,000 ($4700/kW)	

D- Demonstration

C- Commercially available technology

Data Sources [2-6]

2.5 Biomass

Fuelwood, agricultural residues (rice husk, sugarcane trash, coconut shells...) and animal waste are the main biomass fuels. The advantage of biomass fuels is that it is available throughout the country. Different biomass sources are available in different regions. Biomass accounts for about 40% of India's primary energy use [8]– mainly fuelwood (about 20%), crop residues and cattle dung. The present biomass usage is mainly for cooking in chulhas (cookstoves) with poor efficiency.

Aggregate estimates of biomass availability can be made based on the crop production data and the residue to product ratio by Mukunda[9] estimated the biomass produced in 1997-8 to be 545 million tonnes. Of this about 150 million tonnes is expected to be available for power generation. This is estimated to be made up of 23% rice straw, 18% wheat straw, 16% other straw ,15% bagasse and 12% plant stalks. These residues are estimated to have a generation capacity of 16000 to 18000 MW with a plant load factor of 68.5% (6000 hours

per year). The MNES estimates a potential of 3500 MW from Bagasse based power generation and an additional 16000 MW from other biomass that is already available [10].

In addition to residues that are available, it is possible to have dedicated plantations on waste land or degraded lands that are not normally used for agriculture. In social forestry programmes sustainable yields of 7-8 tonnes/hectare/year have been achieved [11]. The waste land available in the country has been estimated to be between 66-130 million hectares [9]. Using an average productivity of 5 tonnes/hectare/year and 100 million hectares of waste land the total biomass available annually is 500 million tonnes which can fuel power generation of 60000 MW at a PLF of 68.5% (6000 hours/year).

Biomass based power generation can have higher capacity factors than solar or wind. Figure 9 lists the different options for power generation from biomass. The conversion options are thermochemical or biochemical. The thermochemical processes involve combustion, gasification or pyrolysis. The calorific value of biomass (on a dry basis) typically ranges around 3000-3500 kcal/kg.

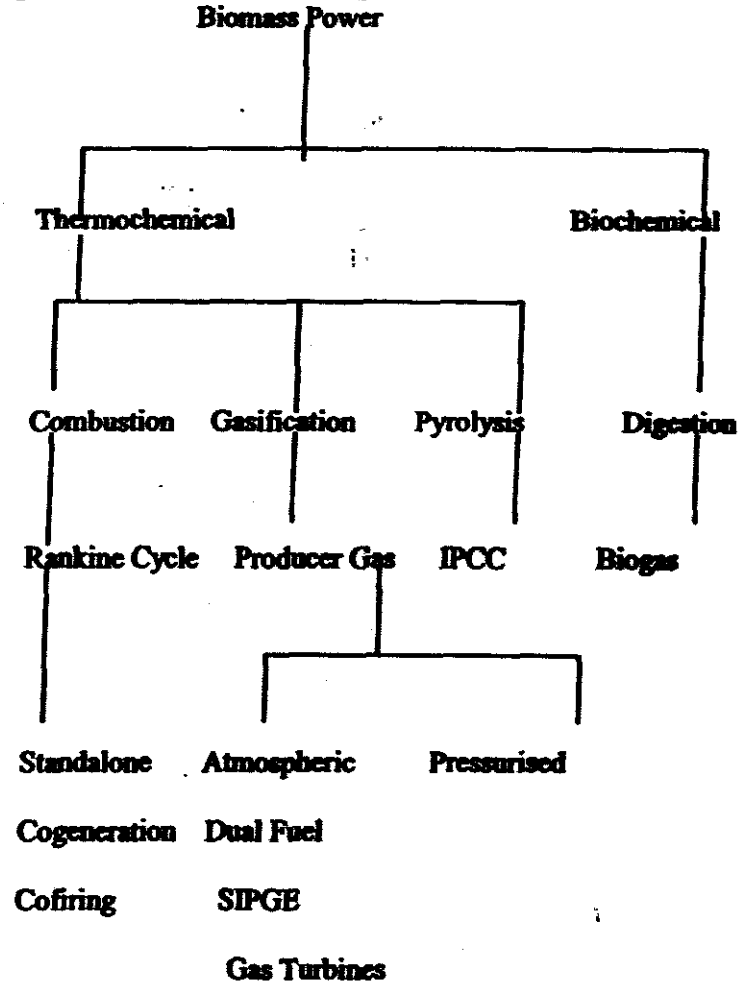

Fig 9. Technology Routes for Biomass Power

2.5.1 Combustion

The most commonly used route is combustion (thermochemical). The cycle used is the conventional Rankine cycle with biomass being burnt in the boiler to generate steam which is expanded through turbines to generate work output. The biomass power plants account for 63 MW of existing capacity (15 projects). The average rating of the power plants is 4 MW. This includes a 6 MW rice husk based power plant in Andhra Pradesh. A 5 MW project in Madhya Pradesh with rice husk as the fuel uses an atmospheric fluidised boiler operating at 65 ata 485° C. A 12 MW multi-fuel biomass power plant has been set up in Tamil Nadu [10,12]. Five grid connected projects accounting for a total capacity of 24 MW were commissioned during 2000-2001. An additional 29 projects with a total capacity of 135 MW are under implementation (average project capacity of 4.6 MW).

The net power cycle efficiencies that can be achieved are about 23-25%[5]. Most of the boilers used are of spreader stoker (moving grate) type. The boiler efficiency is expected to be around 70%. The use of a biomass dryer is likely to help improve the boiler efficiency. The advantage of the combustion route is that the technology used is similar to that of a thermal plant based on coal, except the boiler. In order for this technology to be economically viable it is necessary to have larger plants (5 MW and higher). This wil' require biomass collection and transport over a larger geographical area. It is preferable to link these power plants with dedicated biomass plantations. A 5 MW power plant operating for 6000 hours per year would require a biomass plantation spread over 7500 hectares (with an average yield of 5 tonnes/hectare). The actual generation from these plants and their operating experience needs to be reported to help decide future policies. The capital cost is expected to be about 1500$/kW (Rs 60000 -70,000/kW).

Technologies are commercially available with Indian manufacturers like BHEL, Thermax, Triveni.

2.5.2 Biomass Cofiring

Cofiring of biomass along with coal in thermal power plants is another option which has been adopted in some European countries and the US. This has not been tried in Indian coal plants. This has been developed by utilities as a response to portfolio standards and developing markets for green power. Cofiring results in reduced greenhouse gas emissions (since biomass is almost carbon neutral) and reduced local NOx and SOx emissions. Reviews by Tillman [13] and Hughes [14] provide an overview of cofiring experience in the US, economics and policy.

Biomass cofiring tests have been carried out in the US in coal power plants of rating between 32-700 MW. Cofiring has been attempted for both pulverised coal and cyclone boilers. The biomass used in cofiring has been wood /sawdust. Tests show that cofiring at a level of 7-10% (by heat input) results in a drop in boiler efficiency by 0.3-1.0%. The Net Station Heat Rate(NSHR) increases with cofiring (by about 1%) for a 10% biomass contribution by heat input. The NSHR for the cofired biomass component [13] works out to 11,000 BTU/kWh (11.6 MJ/kWh) which is 10% higher than the NSHR of coal only operation [10000 BTU/kWh (10.5 MJ/kWh)] . Apart from the deterioration in the heat rate there is a change in the properties of the ash. It must be ensured that the ash is acceptable as an input to the cement process.

Cofiring can be done by a) blending biomass with coal or b) firing biomass separately. The capital cost of modification is lower for blending ($50-$100/kW of biomass capacity) than for separate biomass firing ($175-$200/kW of biomass capacity). The cost is about Rs 9000/kW of biomass capacity. This has been found to be the most cost-effective way to increase the biomass share in the power generation mix and reduce

carbon dioxide emissions. Cofiring does not increase system capacity. Hence the capital cost comparisons are not appropriate with new generation facilities. The economics depend on the differential between the coal price and biomass price and is unlikely to justify the incremental capital cost in the absence of any credits due to reduced local and global emissions. It is suggested that a few pilot cofiring experiments could be tried in India to evaluate the economics and gain operating experience.

2.5.3 Cogeneration

Cogeneration in sugar factories using bagasse is a viable option. Cogeneration is the simultaneous generation of power (electricity or motive power/shaft work) and process heat (steam). The process steam required in sugar factories is at low pressures - most of the steam is required at 2 ata, a small portion is required at 6 ata. Traditionally sugar factories have been designed to meet most of their power requirements during the crushing season from the bagasse itself . All sugar factories already have cogeneration of steam and power. However the steam generation pressures are low (usually 21 atm absolute [ata]). Figure 10 shows the typical configuration for a 2500 tonnes crushed per day (tcd) sugar factory. The mill turbines and power turbines are old and inefficient.

If the steam generation pressures are increased by using a high pressure boiler, the sugar factories can export surplus power to the grid. A large number of options are possible. The following options have been proposed [15]:

a) Replace the milling turbines by efficient electric motors and the power turbine by an efficient backpressure turbine.
b). Increase the generation pressure to 43 ata and steam temperature to 480 °C (new boiler). The milling drives are retained and additional turbine generators are included.
c) Include an additional steam turbine and a high pressure boiler generating steam at 65 ata 480° C
d) In addition to c) replace the milling turbines by an efficient back pressure turbine
e) Similar to d) but with a condensing extraction turbine.

A schematic of the configuration for (e) is shown in Figure 11. The power output in each of the cases is given in Table 10. In case e) the power available for export is maximum 9.5 MW for a 2500 tcd plant.

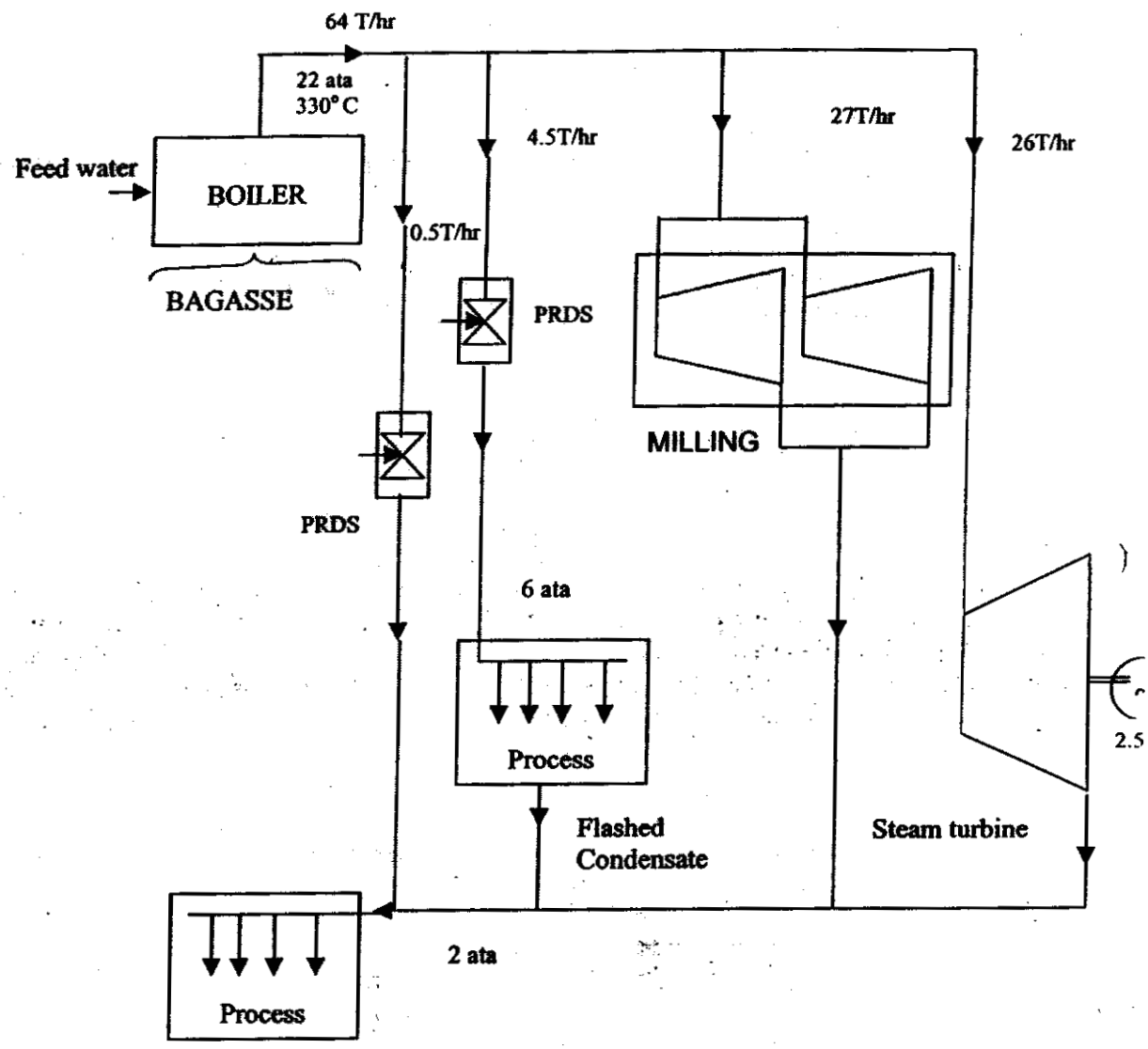

Fig. 10 Schematic of a Typical existing Cogeneration configuration in a 2500 tcd sugar factory [15]

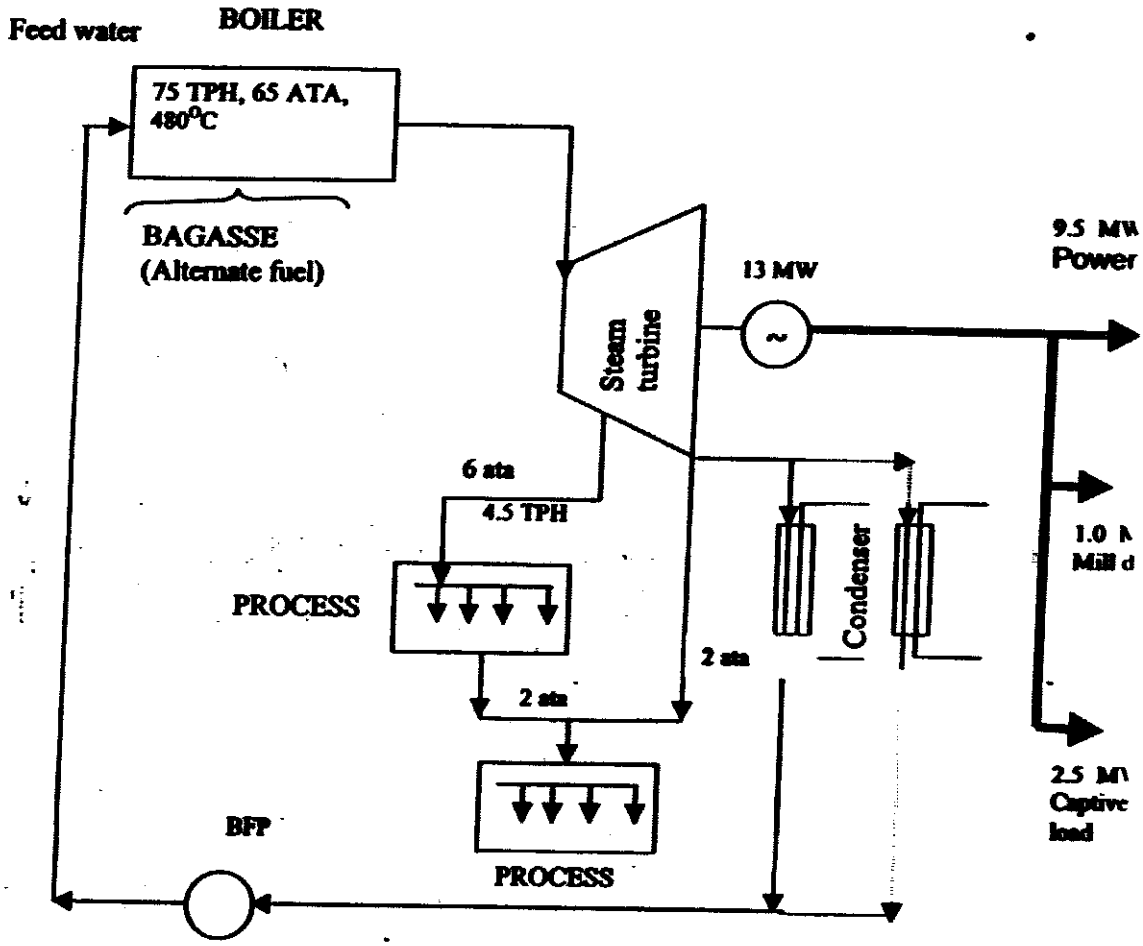

Fig. 11 Schematic of option (e) for a 2500 tcd sugar factory [15]

Table 10 Comparison of different options for a 2500 tcd plant.

CASE	Power Output	Export	KWh export/tc
A	5.4 MW	1.9 MW	18
B	7.5 MW + milling	5.0 MW	48
C	6.8 MW + milling	4.3 MW	41
D	10.7 MW	7.2 MW	69
E	13 MW	9.5 MW	91

Source [15]

Other estimates [16] indicate that the power export potential ranges between 60-80 kWh/tonne of cane crushed and can be increased to 100 kWh/tonne of cane crushed with efficient condensing extraction turbines. This is similar to the range shown in Table 10. The average steam consumption per kWh is 10-12 kg as compared to 7-9 kg of steam/kWh in sugar factories in Hawai[16]. Energy efficiency options to reduce the steam requirement can increase the power export by an additional 20-30 kWh/tonne crushed [16,17].

MNES estimates indicate a potential of 3500 MW net (additional) exportable capacity from the Indian sugar factories. Thirty four bagasse - based cogeneration projects aggregating 210 MW have been commissioned till March 2001. The average export capacity of these plants is 6 MW per plant. The projects implemented have been with steam conditions of 60 ata (some are lower). New cogeneration projects designed with steam conditions of 87 ata and 515 °C are being implemented [10]. There are proposals to have cogeneration plants with higher pressures of 105 ata in Maharashtra and Karnataka. The gross calorific value of bagasse (mill wet basis) is 2300 kcal/kg [16]. None of the sugar factories in India have installed bagasse dryers. Bagasse dryers would improve the efficiency of the cogeneration plants.

Bagasse based cogeneration has the problem that the mill operates only during the crushing season (7-9 months a year). Bagasse can be supplemented using other biomass fuels such as cane trash and rice hulls so that there is power export throughout the year. An Advanced Bagasse Cogeneration project component in an USAID sponsored pilot phase of the Greenhouse Emissions Prevention project [16] focussed on the use of alternative fuels in sugar factories during off-season.

There are about 430 sugar mills in India. In terms of equivalent 2500 tpd mills, about 360 were in operation during 1996-97 [16]. Based on the option discussed earlier (case- e) this would result in an exportable power output of about 3500 MW. Sugarcane production has been increasing at 3-5% per year. Hence the cogeneration potential can be expected to increase at this rate. The capital cost of the plant is around $ 450/kW of output or $650/kW of exportable surplus . This works out to around Rs 30,000 per kW of surplus power which is cheaper than setting up a new fossil fuel power plant. The incremental fuel cost is low and depends on the alternate use of the bagasse. The total cost of electricity supply is likely to be about Rs 2-3 /kWh .

MNES provides an interest subsidy on term loans for cogeneration in sugar. The interest rate reduction is 3% for 80 ata and above, 2% for 60 -80 ata and 1% for 40-60 ata. Most state governments have announced policies that fix buy back rates, permit wheeling and banking [10]. To encourage co-generation in co-operative and public sector mills a joint venture/ Independent Power Producer model has been proposed by MNES in the major sugar producing states. Capital subsidies are available for the first projects of these types in each state.

Many of the sugar factories are in the co-operative sector. They are traditional industries with limited technical capability. Often the sugar factory does not have the confidence to operate high pressure steam based power plants. The capital investments are significant , about Rs 300 million for a 2500 tcd plant , and the sugar factories are hesitant to make these investments. At present boilers and turbines are available in India from suppliers like BHEL, Thermax, ISGEC, Triveni. Grid interconnection and recovery of dues from the State Electricity Board is a problem. In the context of the Dabhol Power Corporation controversy and the MSEB financial situation, MSEB is reluctant to sign fresh Power Purchase agreements with sugar cogenerators. There are also difficulties in obtaining off-season fuel that will permit all year operation.

2.5.4 Biomass Gasification

Instead of combustion, it is possible to convert the biomass into producer gas by gasification (partial combustion). Thermochemical gasification involves burning the biomass with insufficient air so that complete combustion doesn't occur but a gaseous product is obtained. Producer gas is a mixture of carbon monoxide and hydrogen. Gasifiers are classified as updraft or downdraft depending on the direction of flow of the biomass and the producer gas. In a downdraft gasifier the biomass and the gases flow in the same direction (downwards). These are also known as co-current gasifiers. Updraft gasifiers have the product gas flow countercurrent to the biomass flow. Figure 12 shows a schematic of a downdraft gasifier [18]. Gasification can also be classified based on the medium used as air, oxygen or hydrogen gasification. These gasifiers are also known as fixed bed gasifiers and operate at atmospheric pressures. Moving bed and fluidized bed gasifiers are other technology options. The updraft gasifier is more efficient than the downdraft gasifier but the producer gas has a greater amount of tar and particulates that might create problems in the engine operation.

In a typical downdraft gasifier the biomass is fed from the top. It passes through the gasifier and undergoes the following sequence of processes -drying, pyrolysis, oxidation and reduction. These processes are controlled by the zone temperatures. A controlled amount of air is passed through the tuyeres at the oxidation zone. The gas formed is passed through a cooling and cleaning sub-system that usually consists of a cyclone for particulate removal and a scrubber for cooling and cleaning the gas (removing the tar). Some ash is formed from the oxidation reactions. The ash moves through the reduction zone and gets removed from the ash disposal system (grate and ash collection system). The

typical composition of producer gas is 20-22% CO, 15-18% H_2, 2-4% CH_4, 9-11% CO_2 and 50-53% N_2 (by volume). This is a low calorific value fuel with a calorific value of 1000-1200 kcal/Nm^3. This is primarily due to the presence of a large proportion of nitrogen. The

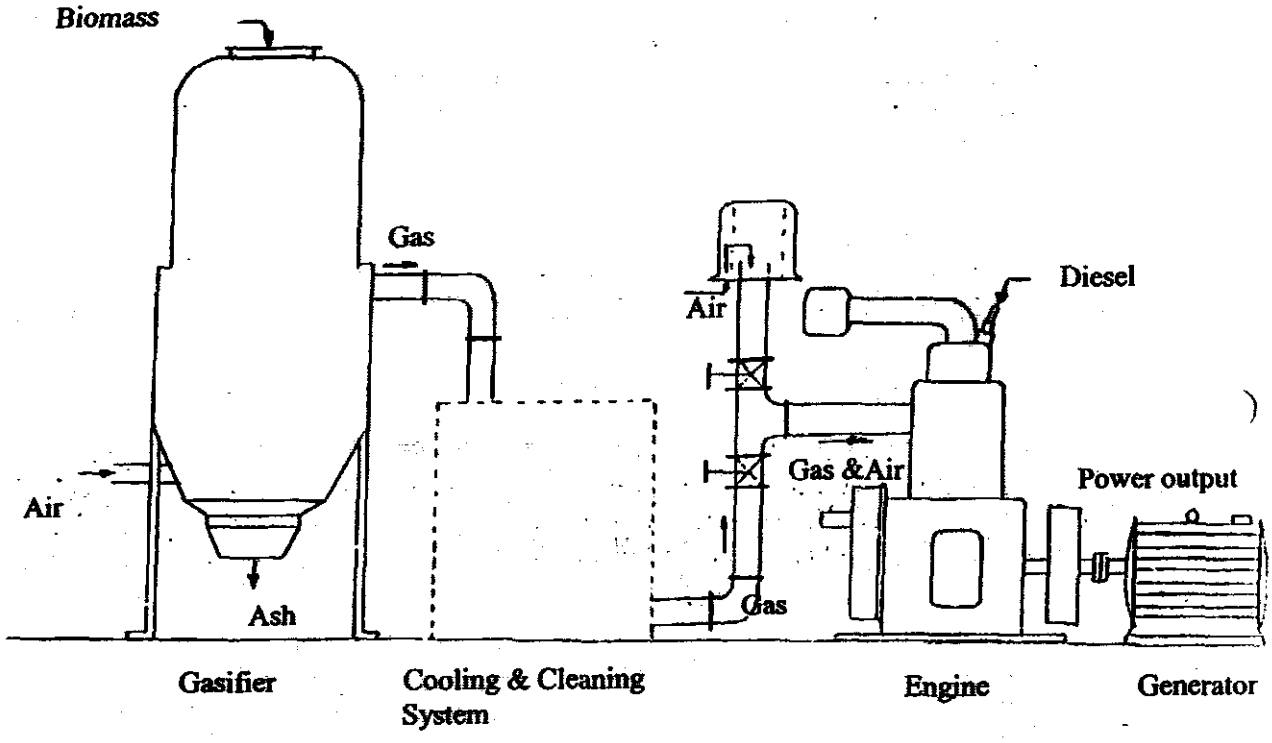

Fig.12 Schematic Diagram of Gasifier –Engine System [18]

(compression-ignition) in a duel fuel mode. Typical gasification efficiency obtained is about 70%. Diesel replacements of upto 70-75% have been reported.

India has significant experience in atmospheric fixed bed gasifiers. About 1700 gasifiers have been installed with a total installed capacity of 34 MW. The average size of the gasifiers is 20 kW. Biomass gasifiers were initially developed for diesel replacement in agricultural pumpsets. Gasifier models were indigenously developed around 1986. During the initial years of the National Demonstration Programme (1986-1994) the emphasis was on agricultural pumpsets of 5 and 10 hp rating. A feature of this programme was heavy subsidies on gasifiers, pump-sets and diesel engines. It is estimated that the majority of installations (80%) during this phase become inoperative within one to three years of the system installation[19]. Target beneficiaries took little interest in the programme and reverted back to full diesel operation, after the initial few hundred hours of operation. Subsidies were misused to obtain a diesel engine pump-set at a cheaper rate. Despite this

there was important technology demonstration and experience obtained in the installations that continued to operate with the gasifier.

Since 1994, the Government policy was changed with subsidies being reduced Subsidies were now restricted only to the gasifier. This initially resulted in a drop in the number of annual installations, but the programme is now more market oriented. A large proportion of installations are now from interested beneficiaries.

Biomass gasifiers typically have been developed either for wood or for rice-husk. Other fuels that have been used are cotton stalks, coconut shells, saw dust, palm shells, corn cobs. Installations range from 3 - 500 kW capacity. The biomass input required ranges from 5-500kg/hour for electrical outputs ranging from 5-500 kW. The largest installation size is 500 kW in Gujarat that is being connected to the grid. A 500 kW (5×100 kW) rural electrification system has been installed at Gosaba in Sunderbans (West Bengal). A 100 kW rice husk based gasifier has been installed in a rice mill in Andhra Pradesh. Almost all gasifiers systems installed are stand alone. Most installations use diesel engines in the dual fuel mode. The economics of a gasifier power plant depends on the load factor, extent of diesel substitution, price of diesel and biomass. There are a number of manufacturers- Ankur Scientific (Ascent, Baroda), Netpro, Cosmos (Raipur), AEW and Tanaku. Four Gasifier Action Research centers have been established at the Indian Institute of Technology (IIT) Bombay, Indian Institute of Science (IISc) Bangalore, Indian Institute of Technology (IIT) Delhi and Madurai Kamaraj University (Tamil Nadu) to provide technical support to the gasifier programme. Decentralised Energy Systems India (DESI Power) has set up six projects as independent rural power producers (IRPP) in various parts of the country. The first installation was at Orchcha in Madhya Pradesh (100 kW rating – 2 units of 50 kW each). DESI power estimates that a 100 kW IRPP will directly employ 11 persons and another 56 downstream jobs in new small scale industries (because of the availability of electricity).

The cost of a biomass gasifier engine system is Rs 45000- Rs 50000 per kW of installed capacity. Using a consumer discount rate of 12%, the price of electricity ranges from Rs 3/kWh (at a load factor of 70%) to Rs 4.3/kWh (at a load factor of 30%) for 70% substitution and a diesel price of Rs 16 per litre and biomass price of Rs 1000/tonne. At higher discount rates that are normally prevalent for companies (30%), the prices increase to Rs 3.7 –5.7/kWh at the respective load factors. The electricity supply price is sensitive to the diesel price and the substitution.

A more viable option is likely to be a dedicated producer gas engine as there is no diesel cost. There is some experience in IISc Bangalore with a dedicated producer gas engines. There is an inter-university collaborative project funded by the UN foundation with Carnegie Mellon Univ, IISc Bangalore, IIT Bombay, National Aeronautical Laboratory and TERI that is planning to install a dedicated producer gas engine of 100 kW operated using biomass in a milk chilling plant in Karnataka.

The gas turbine route is potentially more efficient, but there is no experience with the Biomass Integrated Gas Turbine Combined Cycle (BIGCC) in India. International experience in BIGCC is limited and the technology is still in the demonstration phase. The BIGCC systems are in in the MW range , have higher efficiencies but are costly and not yet proven. Figure 13 shows a block diagram of the different components of a BIGCC plant. A BIGCC demonstration plant has been set up at Varnamo, Sweden [20] using a circulating fluidised bioler operating at 22 bar. The power plant cogenerates heat and power and is rated to produce 6 MW of electricity and 9 MW heat. The plant cost was $ 39 Million in 1993. The plant operates on wood powder from forest industry waste and has an electrical efficiency of 32%.

There is a wide variation in cost estimates of the different technological routes for power generation from biomass. Research on conversion of biomass into liquid products by Pyrolysis is a relatively new technology which might be worth exploring especially with high biomass prices [21].

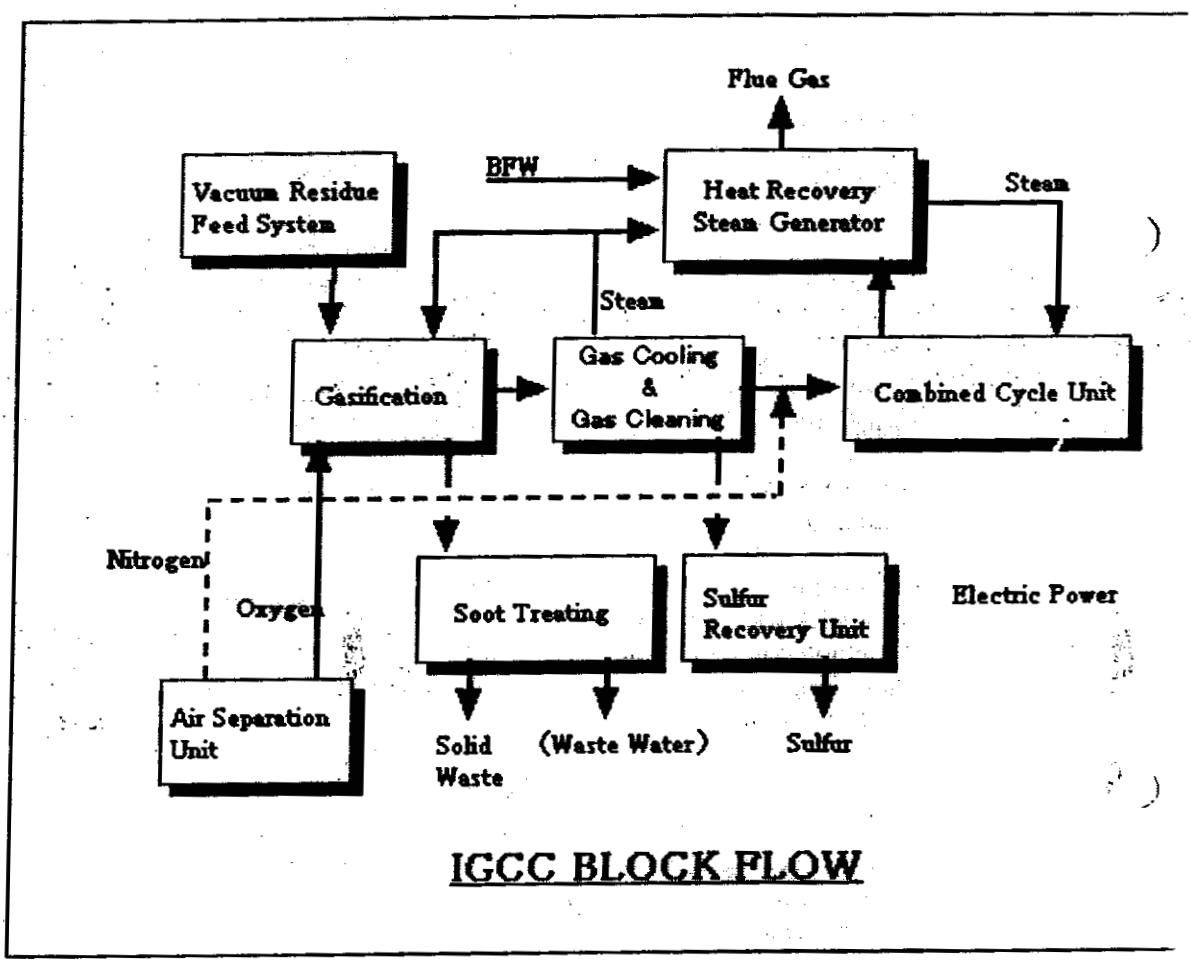

Fig. 13 Schematic of an IGCC plant

2.5.5 Biogas

Biogas plants ,both family and community sizes, use biochemical digestion by anaerobic bacteria. Biogas has a higher calorific value than producer and can be directly used in a diesel engine or a dedicated gas engine. Biogas consists of 45-70% methane (CH_4) with the

is estimated to be Rs 6.5/kWh for 5 hours a day operation. This can reduce to about Rs 4/kWh at load factors of about 70%. Capital subsidies are available for biogas plants from MNES and concessional loans are available from IREDA.

About 3.1 million biogas plants have been installed in India till 2001 March. This is about 25% of the estimated potential of 12 million plants. About 3000 community biogas plants have been installed. Most of these installations are only for heating and lighting.

References (for sections 2.4-2.5)

1. S.P.Sukhatme, Solar Energy, 2nd Edition, McGraw Hill, 1998, New Delhi.
2. S.P.Sukhatme, Proc. Indian Acad Sci (Chem Sci), Vol 109, No 6, December 1997, pp 521-531.
3. S.P.Sukhatme and J.K.Nayak, Solar Energy in western Rajasthan, Current Science, Vol 72, No 1, pp 62-68.
4. S.Beerbaum, G, Weinrebe, Solar Thermal Power Generation in India- A Techno-economic analysis, Renewable Energy, 21, p 153-174, 2000.
5. Renewable Energy Technology Characterizations, EPRI/TR-109496, December 1997, US Department of Energy, Washington DC.
6. http://www.eren.doe.gov/RE/solar.html
7. Energy after Rio, UNDP publication, New York,1999.
8. Tata Energy Data Directory 1999, Tata Energy Research Institute, New Delhi, 2000
9. H.S.Mukunda, A Biomass Option for Enhancing Energy Security, NIAS Report R4-99, National Institute of Advanced Studies, IISc Bangalore, 1999.
10. Ministry of Non-Conventional Energy Sources, Annual Reports, New Delhi, 2000,2001.
11. N.H. Ravindranath, D.O. Hall, Biomass, energy, and environment, A developing country perspective from India, Oxford University Press, New York, 1995.
12. Renewable Energy in India, Business Opportunities, Ministry of Non Conventional Energy Sources, Govt of India, March 2001.
13. D.A.Tillman, Biomass Cofiring: the technology, the experience, the combustion consequences, Biomass and Bioenergy, 19(2000), pp 365-384.
14. E. Hughes, Biomass Cofiring: economics, policy and opportunities, Biomass and Bioenergy, 19(2000), pp 457-465.
15. Special Issue on Cogeneration, TIDE, 1993.
16. S.M.Smouse, G.E.Staats, S.N.Rao, R.Golman, D.Hess, Promotion of Biomass Cogeneration with power export in the Indian Sugar Industry, Fuel Processing Technology, 54 (1998),227-247.
17. S.Kartha, E.D. Larson, Bioenergy Primer, Modernised Biomass Energy for Sustainable Development, United Nations Development Programme, New York, 2000.
18. P.P.Parikh, State of the Art Report on Gasification of Biomass, Report submitted to DNES, Govt of India, 1984.
19. Status of Biomass Gasification Technology at ASCENT, India, Ocober 1998, http://www.bgtechnologies.net/ankur.htm.
20. E.Skog, Biomass Gasification Combined Cycle Power Plant Demonstration in Varnamo, Sweden, Sydkraft Kunsult AB, Malmo, Sweden, 2000.
21. A.Ganesh, R.Banerjee, 'Biomass Pyrolysis for Power Generation,- A Potential Technology, Renewable Energy, 22, 9-14, 2001.
22. A.K.N.Reddy ," Energy as an Instrument for Socio Economic Development", Chapter 8 , Community Biogas Plant: The Pura Case Study.,UNDP, 2000.

remaining being carbon dioxide (CO_2). Figure 14 shows a schematic of a floating dome biogas plant. The digestor is a well containing the animal waste slurry. The dome floats on the slurry and acts as a

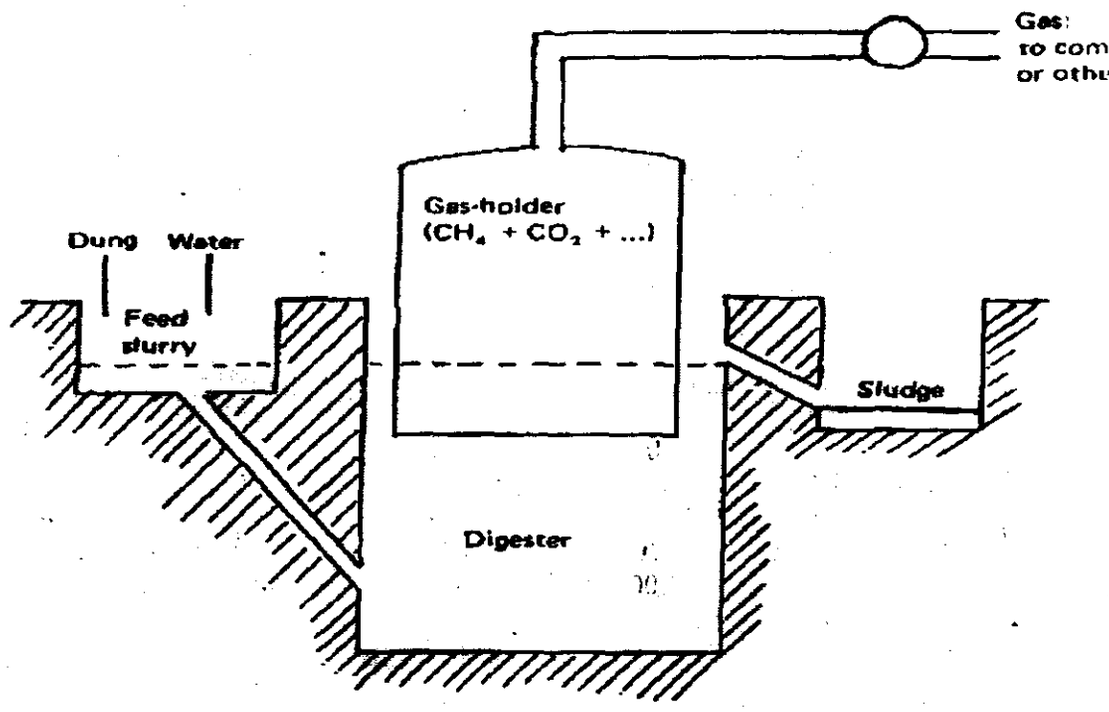

Fig. 14 Schematic of a floating drum Biogas Plant [17]

gas holder. The spent slurry is sludge that can be used as a fertiliser. The reaction is anaerobic (in the absence of air) digestion that occurs by bacterial action. Family size plants are typically rated at $2m^3$/day while community biogas plants have ratings of 12-150 m^3/day. A family sized unit needs to have 2-3 stall fed cattle to supply it. The calorific value of biogas is 16-25 MJ/m^3. The biogas can be used for cooking or can be used as a fuel driving a diesel engine in the dual fuel mode. Indian designs typically have been the floating dome type (Khadi Village Industries Corporation KVIC design). Several modified Chinese designs of fixed gas storage dome design (Deenbandhu type) have also been manufactured because of their low cost. Most Indian biogas plants have been designed to operate on cattle waste (cow dung).

A successful biogas plant case study is the Pura [17, 22] community biogas system that was installed in 1987. The biogas plant is a KVIC type floating drum plant rated at 42 m3/day. The capital cost of installed capacity was Rs 31,400/kW (in 1992 prices). The biogas plant operates a 5 kW diesel engine that is connected to a 5 kVA, 440 V three phase generator for electricity generation. The power generation system operates for 4 hours per day with 77% diesel substitution.

The current capital cost for a biogas plant connected to a diesel engine-generator is estimated to be Rs 50000-60000/kW. The cost of electricity depends on the load factor. It

Chapter 3 Conclusions

3.1 Renewable Power Projections

Since renewables are still in the initial stage of development it is difficult to project future growth profiles accurately. The growth in the last 8 years (1993-2001) has been significant with annual growth rates of 39%. If this growth persists for another decade, the 2011 renewable capacity would be 80,000 MW. Is this a realistic future growth rate? Consider the total installed capacity of India – approximately 100,000 MW. If this capacity grows at 7% per year, the total installed capacity in the Indian power sector in 2011 will be 196700 MW (an increase of 96,700 MW or 9600 MW capacity addition per year). The estimate for renewable capacity would account for 80 % of the new generation capacity. This seems unrealistic since renewables currently accounts for only 3% of the total installed capacity.

By 2011 if it is planned to have a 10% renewable share, it would imply a total renewable capacity of 19670 MW or 20% of the new installed capacity from renewables. Is this feasible? Most of the renewable growth has been from Wind and Small Hydro. The wind potential has been estimated at 45000 MW. The MNES itself has assumed that the technical potential is about 10000 MW. The wind capacity addition per year has been an average of 200 MW/year over the last few years. This could be increased to an average of 400 MW/year (annual manufacturing capacity of 500 MW already exists). Hence the final estimate for Wind power in 2011 is likely to be between 3000- 5000 MW depending on the diffusion rate. The small hydro installed capacity is 1341 MW and the projects under construction account for about 500 MW. The potential for small hydro is estimated at 15000 MW. The estimate for Small Hydro in 2011 is 5000-6000 MW. These two technologies are currently market driven, though government policies and incentives can affect the diffusion. The key to achieving the 10% renewable share depends on the growth of Biomass based power generation. The Biomass based cogeneration potential in 2011 would be about 4700 MW (estimating a 3% growth in the sugar production annually). Since the economics are extremely attractive, it should be possible to tap 40-50% of this potential. This would require significant policy interventions. Hence the Biomass cogeneration target in 2011 is estimated as 1700-2300 MW. At present about 135 MW of Biomass combustion power plants are under construction while 24 MW were added in 2000-2001. Biomass combustion based power plant capacity can be added at an average rate of 50-100 MW/year. This would result in a 2011 estimate ranging between 560-1060 MW. Biomass gasifiers, Biogas based power generation and Solar Photovoltaic are expected to cater to the requirements for stand-alone dispersed power generation. Official statistics indicate that 18,000 un-electrified villages are remote and will not be feasible to connect to the grid. These are expected to be electrified using renewables. The average population of a village in India is 1125 (around 200 households). Almost 50% of the total number of villages has a population less than 500 households. The average number of households in the unelectrified villages is likely to be lower than the electrified villages. Assuming an average of 100 households, the installed capacity required would be about 30 kW per village. This would imply a total potential of 540 MW in decentralized power systems. Significant policy interventions and institutional changes would be required to meet this potential. A capacity of 19700 MW corresponds to an annual growth of 20% that is about half of the actual growth rate achieved during 1993-2001 (39%).

In addition to the technologies that are proven and available commercially, it is necessary to try out and obtain experience in some of the renewable energy technologies by a series of demonstration projects. A list of technology demonstrations that should be tried in India is provided in the next section.

3.2 Technology Demonstrations

The following technology demonstration projects would be useful for deciding future alternatives:

a) Tidal power plant – 3-5 MW range
b) OTEC – already in progress – 1 MW
c) ISCC- 35 MW – In addition to this there is a need to develop capability to manufacture parabolic concentrators for steam generation.
d) Biomass Gasifier running a gas turbine of about 1 MW range
e) Cofiring of biomass in a coal based power plant
f) Bagasse dryer installation in a sugar factory with a condensing extraction steam turbine
g) BIGCC for a sugar factory – This would result in a significant increase in the surplus power generation from bagasse. However the technology needs to be tested at least at a pilot scale for a sugar factory.
h) Biomass gasifier/Biogas based micro-turbine operation
i) Power generation from large scale municipal waste biogas plant

3.3 Policies

A target of 10% renewables by 2011 is not going to happen in a business as usual scenario. Several policy changes are required to facilitate this. A few policy issues and directions are discussed here.

a) **Externalities** – Most renewables have the benefit of being clean, green fuels. They have significantly lower local and global emissions. Fossil fuel based power generation technologies have adverse health impacts due to local emissions of sulphur dioxide, nitrogen oxides and particulate matter. Studies in Europe have shown that most of the external social costs of energy supply and use are due to the health impacts. There is a need to devise metrics and techniques for incorporating externalities in the social choice of deciding appropriate power generation technologies.

Life Cycle Assessment or fuel cycle analysis techniques can be used to determine the total emissions and impacts associated with a particular option. The need to stabilize and control greenhouse gas emissions globally is providing a new impetus to the development of clean fuels. Table 11 shows the carbon dioxide emissions per kWh of electricity generated by different technologies.

Table 11. Carbon dioxide emissions from power technologies in g/kWh [1]

Coal	Advanced Coal	Oil	Gas	Nuclear	Biomass	PV	Hydro	Wind
960-1300	800-860	690-870	460-1230	9-100	37-166	30-150	2-410	11-75

A life cycle analysis of a biomass gasification combined cycle (BIGCC) plant [2] revealed a net carbon dioxide emissions of 46 g/kWh. This consists of 28 g/ kWh associated with the feedstock production, 6 g/kWh with transportation and 12 g/kWh with power plant construction. The net carbon dioxide emissions from this biomass route are only 5% of the carbon dioxide emissions from a conventional coal based power plant.

b) **Monitoring and Verification** – In the initial period a lot of the renewable development has been on upfront subsidies and incentives. It is necessary to evaluate the track record of different renewables for power generation in India. There is competition between renewables. Most technology developers and marketers try to overstate the benefits and conceal the problems. It is necessary to have independent monitoring and verification agencies that would do energy and financial audits of the facilities. The information regarding the performance of different renewable power plants needs to be collected and compiled and made publicly available. This is important to convince skeptics and also to get the true picture.

c) **Cost Recovery**- In the case of rural electrification , recovery of costs is a key issue. The price of electricity from dispersed renewables (isolated) is likely to be high if the load factors are low. The average price can be reduced only if this is linked with some rural industries like cold storages, oil mills.. Different models for cost recovery need to be tried. Issues of metering and billing need to be addressed.

d) **Utility Mindset**- In case of grid connected systems the utility attitude towards renewables critically affects its adoption. Indian utilities are facing a crisis of payment . They are hesitant to enter into power purchase agreements with renewable power plants. Even rates regarding wheeling and banking have suddenly been revised in some states. The utility has traditionally been interested only in large power plants. Hence there is a need to increase the awareness of utilities about renewable power generation and influence attitudes regarding dispersed generation.

e) **Change Incentive structure**- It is necessary to devise incentives based on performance. This could be included in the tariff structure.

f) **Strategy Think tank**- It is necessary to have a collaboration between the Government (MNES, State govts), industry and academics to evolve appropriate policy interventions, thrust areas and technology development and research plans for renewable power.

g) **Manpower training**- The renewable installed capacity is similar to the nuclear capacity. The trained manpower, institutions and research facilities established for nuclear power is significantly better than the renewable field. There is a need to train quality manpower for the renewable power sector.

h) **Institutions** – A separate joint venture for Biomass Power Generation on the lines of the National Thermal Power Corporation or the Nuclear Power corporation is likely to help effectively plan and implement new biomass power capacity.

i) **Policy experiments**- In the case of rural electrification there is a need to try out alternative implementation strategies with private, co-operative ownership, different recovery mechanisms. The results from policy experiments in different states should be well documented and critically assessed before deciding on replication models.

India has the potential to tap significant renewable resources. This will need flexible and innovative approaches by policy makers.

References

1. World Energy Assessment, Energy and the Challenge of Sustainability, UNDP, New York, September 2000.
2. M.K.Mann and P.L.Spath, Life Cycle Assessment of a Biomass Gasification Combined Cycle System, National Renewable Energy Laboratory, Colorado, USA, December 1997.

DRAFT RESEARCH PAPER ON MUNICIPAL SOLID WASTE MANAGEMENT FOR CLIMATE CHANGE MITIGATION

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MUNICIPAL SOLID WASTE MANAGEMENT FOR CLIMATE CHANGE MITIGATION

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MUNICIPAL SOLID WASTE MANAGEMENT FOR CLIMATE CHANGE MITIGATION

STRUCTURE OF PRESENT PAPER

Methane is a Greenhouse Gas (GHG), twenty one times more potent than the carbon dioxide. Decomposition of organic components of the municipal solid wastes is one of the major sources of methane generation. Proper management of municipal solid waste through reduction of waste, utilisation of reusable parts, and transformation of waste into economically useful products will reduce the volume of waste disposed and left out for decomposition and would thus reduce methane emission.

This paper starts with a brief introduction to climate change, sources of greenhouse gas emissions and contribution etc. The main thrust of the paper is how through proper management of municipal solid waste, methane emission could be brought down which is a step towards climate change mitigation. The paper gives a brief introduction to various solid waste management techniques and discusses in detail the biomethanation process where methane generated could be transformed to energy for useful purposes.

INTRODUCTION

Sources of Methane Emissions

Methane is produced from a wide variety of anaerobic processes. Two main pathways for methane production have been identified. These are (i) reduction of CO_2 with hydrogen, fatty acids or alcohols as hydrogen donors and (ii) transmethylation of acetic acid or methyl alcohol by CH_4 producing bacteria. The major anthropogenic sources of methane emissions include rice cultivation, livestock and other animals, biomass burning, coal mining, oil and gas systems, and landfills. It is estimated that 525 Tg CH_4 is emitted per year into the atmosphere from all natural and anthropogenic sources as indicated in the Table 1.

Table 1 : Global Estimated Sources of Methane[1]

Source	Annual Release (Tg CH_4) (Best estimate)	Range (Tg CH_4)
Natural		
Natural Wetlands	115	100-200
Enteric Fermentation (animal)[2]	80	65-100
Termites	40	10-100
Oceans	10	5-20
Freshwater	5	1-25
CH_4 Hydrate Destabilisation	5	0-100
Human Activities		
Rice Paddies[3]	110	25-170
Gas Drilling, venting, transmission	45	25-80
Biomass Burning	40	20-80
Coal Mining	35	19-50
Landfills	40	20-70
Total	525	

[1] *Scientific Assessment of Climate Change Intergovernmental Panel on Climate Change (IPCC), 1990.*
[2] *Indian domestic livestock population increased from 450 million in 1978 to 467 million in 1992, expected to increase to 625 million in 2020.*
[3] *The paddy-harvested area is 42.32 mha in India – largest in Asia.*

Table 2 gives an estimate of methane emssions from India due to various anthropogenic activities.

Table 2 : Methane Emissions from human activities in India[4]

Energy		Annual Release (Gg CH_4)
1	Biomass burning	1579
2	Solid Fuels	330
3	Oil and natural gas	626
Agriculture		
4	Enteric Fermentation	7563
5	Manure management	905
6	Rice cultivation	4,070
7	Field burning of agricultural residues	116
Wastes		
8	Solid waste disposal on land (landfills)	334
9	Domestic and commercial waste water	49
10	Industrial waste water	2,905

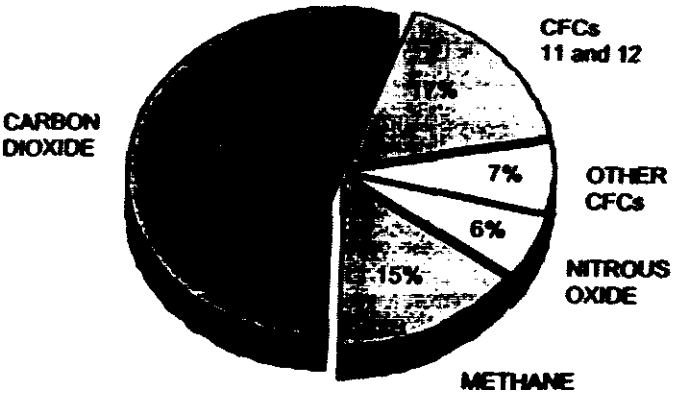
Ice core data indicate that the atmospheric concentration of methane (CH_4) averaged around 0.8 ppmv between two hundred and two thousand years ago, increasing to 0.9 ppmv one hundred year ago.

Atmospheric methane concentrations have been measured directly since 1978 when the globally averaged value was 1.51 ppmv. Currently, methane concentration in the atmosphere is 1.72 ppmv corresponding to an atmospheric reservoir of about 4900 Tg ($1Tg = 10^{12}g$) and it is increasing at the rate of 14.617 ppmv per year (40 to 48 Tg per year) or 0.8 to 1.0 per cent per year. The atmospheric concentration of CH_4 in the Northern Hemisphere is 1.76ppmv, compared to 1.68ppmv in the Southern Hemisphere.

While methane's concentration in the earth's atmosphere is small, it has a significant contribution to future global warming because it is a potent greenhouse gas with its global warming potential 21 times more than that of carbon dioxide. The contributions of various gases to the total increase in climate forcing during the 1980s is shown as a pie diagram in Figure 1. Methane currently contributes for over 15 percent to the change in radioactive forcing (global warming) from 1980 to 1990.

[4] *Asia Least-cost Greenhouse Gas Abatement Strategy : India (ALGAS), 1998*

Figure 1 : The Contributions of Human Induced Greenhouse Gases to the Change in Radiative Forcing from 1980 to 1990 (IPCC, 1990)



Concentration of methane in the atmosphere is increasing rapidly. Its strong ability to absorb infrared radiation, combined with its relatively short atmospheric lifetime of 10 years against 50-200 years for carbon dioxide, makes its control an important opportunity for mitigation of climate change.

Climate Change : Contribution of Methane, particularly from Municipal Solid Waste

The solid waste arising from domestic, commercial and industrial activities have become one of the major environmental problems causing excessive pollution and threat to human health. The problem gets worse because of the fact that solid wastes are often indiscriminately disposed. The problems are already acute in cities and towns as disposal facilities are not keeping pace with the quantum of waste generated.

In India, ironically only a small fraction of the total waste generated is disposed though various disposal techniques available, a large part of the waste is simply dumped in open dump-yards. Decomposition of solid waste, when dumped into dump-yards without any disposal, gives rise generation of methane which is a greenhouse gas and responsible for global warming, climate change and related impacts.

Methane emissions from solid waste is a major cause of concern in developed countries and these countries have started recovery of methane from landfills and its re-use for energy recovery. However, in India, there are no landfills and solid waste is simply dumped in open dump-yards. This does not provide us an opportunity for methane recovery. In view of this, other options for disposal of waste and recovery of resources from the waste shall be tried out so that methane emissions from municipal solid waste are reduced.

MUNICIPAL SOLID WASTES GENERATION IN INDIA

Municipal solid waste is defined as refuse from households, waste from commercial establishments, refuse from institutions, market waste, yard waste and street sweeping (World Bank, 1994). The quantity of MSW generated by a city depends upon a number of factors such as **food habits, standard of living, degree of commercial** and **industrial activity** in the city.

In 1982, a study was conducted by World Health Organisation on 'Rapid Assessment of Sources of Air, Water and Land Pollution'. As per the study, per capita municipal solid waste generated in the lowest income areas in South East Asia is 0.4 kg / day. While National Environmental Engineering Research Institute (NEERI), Nagpur, through its surveys has reported that in metro cities like Bombay, Calcutta and Hyderabad, the generation of solid wastes varies from 0.33 kg / capita / day to 0.5 kg / capita / day.

A similar study, conducted by the Environment Protection Training Research Institute (EPTRI), Hyderabad, has shown that in Indian towns and cities the per capita wastes generated ranges between 0.3 kg / day to 0.6 kg / day. India has about 300 class I cities and towns. A recent survey by Ministry of Non-conventional Energy (MNES) indicates about 56,900 metric tonnes per day of solid waste is generated from the cities / towns in India.

Quantum of Wastes Generated

The generation of solid waste is directly related to consumption patterns. Within India, there is a large inter-city variation as far as per capita waste generation is concerned. According to the Central Pollution Control Board (CPCB, 1995), the daily per capita generation of solid waste in small, medium and large cities/towns is about 0.1 kg, 0.3 to 0.4 kg. and 0.5 kg., respectively. Twenty-three metropolitan cities, which contain as much as 32.5 per cent of the urban population according to the 1991 Census, are the major contributors to the total waste generated in the country. Table 3 shows that 23 cities together generate 37.7 thousand tonnes out of 65.37 thousand tonnes of solid waste generated every day in urban areas of the country. In view of these facts, management of solid waste is primarily an urban issue in India.

Table 3 : Quantity of Solid Waste Generated in Metropolitan Cities

City	Qty of SW (TPD)	City	Qty of SW (TPD)
Mumbai	5000	Jaipur	1021
Calcutta	3500	Kochi	680
Delhi	4600	Coimbatore	710
Chennai	3500	Vadodara	900
Hyderabad	2800	Indore	800
Bangalore	2700	Patna	714
Ahmedabad	1600	Madhurai	711
Pune	1527	Bhopal	500
Kanpur	1314	Vishakapatnam	630
Nagpur	1100	Varanasi	660
Lucknow	1043	Ludhiana	656
Surat	1000		
Total		37,666	

Source: Central Pollution Control Board, 1995

Composition of Indian Msw

The composition of MSW in India indicates lower organic matter and high ash or dust contents. It has been estimated that recyclable matter in Indian solid wastes varies from 13 to 20 per cent and compostable materials from 35-45 per cent. A typical composition of Indian Solid wastes is given in Table 4.

Table 4 : Composition of Indian MSWs

Description	% in weight
Vegetable, leaves	40.15
Gram	3.80
Paper	0.81
Plastic	0.62
Glass/Ceramic	0.44
Metal	0.64
Stones / ashes	41.81
Miscellaneous	11.73

Physical & Chemical Characteristics of Indian Msw

Knowledge of the chemical characteristics of the MSW is essential for selecting and designing the waste processing and disposal facilities. The physical and chemical characteristic of Indian MSWs is been given in Table 5 and Table 6 below.

Table 5 : Physical characteristics of MSWs in Indian Cities

Population range (in million)	No. of cities surveyed	Paper *	Rubber*, Leather & Synthetics	Glass*	Metals*	Total Compostable Matter	Inert Material
01. to 0.5	12	2.91	0.78	0.56	0.33	44.57	43.59
0.5 to 1.0	15	2.95	0.73	0.56	0.32	40.04	48.38
1.0 to 2.0	09	4.71	0.71	4.56	0.49	38.95	44.73
2.0 to 5.0	03	3.18	0.48	0.98	0.59	56.67	40.07
5.0 and above	04	6.43	0.28	0.94	0.80	30.84	53.90

** all values are in per cent and are calculated on net weight basis*
Source : Background Material on SWM, NEERI, 1996

Table 6 : Chemical characteristics of MSWs in Indian Cities*

Population range (in million)	No. of Cities	Moisture %	Organic matter %	Nitrogen as Total N %	Phosphorus as P_2O_5	Potassium as K_2O %	C/N ratio	Caloric Value in KCal/kg+
0.1 - 0.5	12	25.81	37.09	0.71	0.63	0.83	30.94	1009.89
0.5 - 1.0	15	19.52	25.14	0.66	0.56	0.69	21.13	900.61
1.0 - 2.0	9	26.98	26.89	0.64	0.82	0.72	23.68	980.05
2.0 - 5.0	3	21.03	25.60	0.56	0.69	0.78	22.45	907.18
75.0	4	38.72	39.07	0.56	0.52	0.52	30.11	800.70

** All values except moisture, on dry weight basis*
+Caloric value on dry weight basis
Source : Background material for Manual on SWM, NEERI, 1996

The chemical characteristics indicate that the organic content of the samples on a dry weight basis ranges between 20 to 40 percent. The nitrogen, phosphorus and potassium content of the MSWs

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ranges between 0.5 to 0.7%, 0.5 to 0.8%, and 0.5 to 0.8%, respectively. The calorific value ranges between 800-1000 KCal/kg.

Methane Emissions from MSW

In India, after taking out the recyclable and re-useable materials by the ragpickers, the waste is dumped in open pits also called dump-yards around the outskirts of the cities. This is an unorganised way for waste disposal and leads to a number of sanitary and health problems, besides contributing to methane generation.

MSW dumped in landfills worldwide are estimated to produce 20 to 60 teragrams (Tg) of methane per year, as a direct result of the natural decomposition of the organic component of waste streams. Based on currently available technologies, it is technically feasible to reduce annual methane emissions from landfills globally by 50 percent of current emissions or by more than 10 to 25 Tg per year.

Chemistry of Methane Emissions Produced from MSW[5]

Bacterial decomposition of MSW under anaerobic condition (in the absence of oxygen) in landfills produces landfill gas (LFG). The degradation process takes place in different steps, in which the raw organic materials degrade to smaller materials which in course of time will be converted into LFG. The formation of LFG can be influenced by various factors e.g., composition of the waste, waste treatment, site characteristics, local and regional climatic conditions etc. These aspects vary from site to site.

Major constituents of the LFG are methane and carbon dioxide. Methane accounts for approximately 45 to 50 percent of LFG, while carbon dioxide and small quantities of other gases comprise the remaining 50 to 55 percent. Methane production begins six months to two years after waste disposal and may last for decades, depending on disposal site conditions, waste characteristics and the amount of waste in the landfill[6]. Methane migrates out of landfills and through zones of low pressure in soil, eventually reaching the atmosphere.

Emission Characteristics

The amount and rate of methane production over time in a landfill depends on five key characteristics of the landfilled material and the surrounding environment. These characteristics are :

- *Quantity of Organic Material*
  The most significant factor driving landfill methane generation is the quantity of organic material, such as paper and food and yard wastes, available to sustain methane-producing microorganisms. **The methane production capacity of a landfill is directly proportional to its quantity of organic wastes.** Methane generation increases as wastes continue to be dumped and gradually declines after the site stop receiving waste. However, landfills may continue to generate methane for decades even after their closure.
- *Nutrients*
  Methane generating bacteria need nitrogen, phosphorus, sulphur, potassium, sodium and calcium for cell growth.
- *Moisture Content*
  The bacteria need water also for cell growth and metabolic reactions. Landfills receive water from incoming waste, surface water infiltration, ground water infiltration.
- *Temperature*

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[5] *US Methane Emissions 1990-2020 : Inventories, Projection and Opportunities for Reduction*
[6] *Guidebook on landfill gas extraction and utilisation : Netherlands agency for energy and the environment, August, 1997*

Warm temperature in a landfill speed up the growth of methane producing bacteria. The temperature of waste in the landfill depends on landfill depth, the number of layers covering the landfill and climate.

- *pH*
  Methane is produced in a neutral environment (close to pH 7). The pH of most landfills is between 6.8 to 7.2.

Degradation of MSW

Anaerobic decomposition of MSW in landfills starts sometime after the dumping of the waste. This process consists of several phases. These are :

- *Aerobic phase*
  In this phase the oxygen present in the landfill is consumed in the (aerobic) degradation of organic compounds. This phase is relatively short (several days to several weeks) since the quantity of oxygen present is limited.
- *Hydrolysis phase*
  In this phase, the large organic molecules are converted into small soluble molecule such as lower fatty acids, simple sugars and amino acids.
- *Acidogenic phase*
  Under anaerobic conditions (absence of oxygen), hydrolised compounds are degraded by bacteria into fatty acids. In this way, the acidity level (pH) is reduced. The gases that are formed in this phase are mainly hydrogen (H_2) and carbon dioxide (CO_2).
- *Methanogenic phase*
  During the methonogenesis phase, the fatty acids formed in the acidogenic phase are decomposed mainly into methane (CH_4) and carbon dioxide (CO_2). The methanogenesis can sometimes takes several months to years before methane is formed. In contrast to the microorganisms in the acidification phase, the methane forming bacteria are sensitive to sudden changes in the environmental condition. It is, therefore, important that during the methanogenic phase the landfill remains under anaerobic conditions.

Because a landfill is highly heterogeneous, the stages described above will occur simultaneously in a landfill.

The rate of degradation is determined mainly by the temperature and moisture content of the wastes. The temperature in the landfill remains initially rather high as a result of heat released in the aerobic degradation (temperature rises to 30-50°C). Due to heat loss to the environment, the temperature falls after a period of time, to values, which result in a far slower growth of methane forming bacteria. This fall in temperature occurs over a period of several years. Ultimately, the temperature will reach a level similar to the temperature of the environment.

Mobility of free water in the landfill body (leaching) ensures that enzymes and bacteria present in the water obtain access to the organic material, which had so far not been degraded. The slow movement of water is one of the reasons that the formation process of landfill gas can take many years.

MUNICIPAL SOLID WASTES MANAGEMENT PRACTICES IN INDIA

With about 300 class I cities and towns, India produces nearly 56,900 metric tonnes of municipal solid wastes per day. In urban areas, the responsibility of solid waste management *lies exclusively* with the urban local bodies, that is, municipal governments. However, the municipalities in most states in India are not *statutorily responsible* for collecting garbage from the households. They usually perform the third and fourth stages of the SWM function.

Government of India has brought out Gazette Notification in September, 2000 on "The Municipal Wastes" (Management and Handling Rules, 2000). These rules shall apply to every municipal authority responsible for *collection, segregation, storage*, transportation, processing and disposal of municipal solid wastes. This 'Notification' will be discussed in greater detail later in this status report

Solid Waste Management (SWM) usually refers to the collection, recycling, resource recovery (composting, waste to energy, etc.), transfer, and disposal of municipal solid waste.

Three major activities involved in the management of MSWs are the following :

- *Collection*
- Transportation
- Disposal of wastes

These CTD activities can be further sub-divided into the following :

i. Waste generation
ii. Waste handling, sorting and storage and processing at source
iii. Collection
iv. Sorting, processing and transportation
v. Transfer and transport
vi. Disposal

The inter-relationship between the different activities in the MSWs management process is schematically depicted in the Figure 2.

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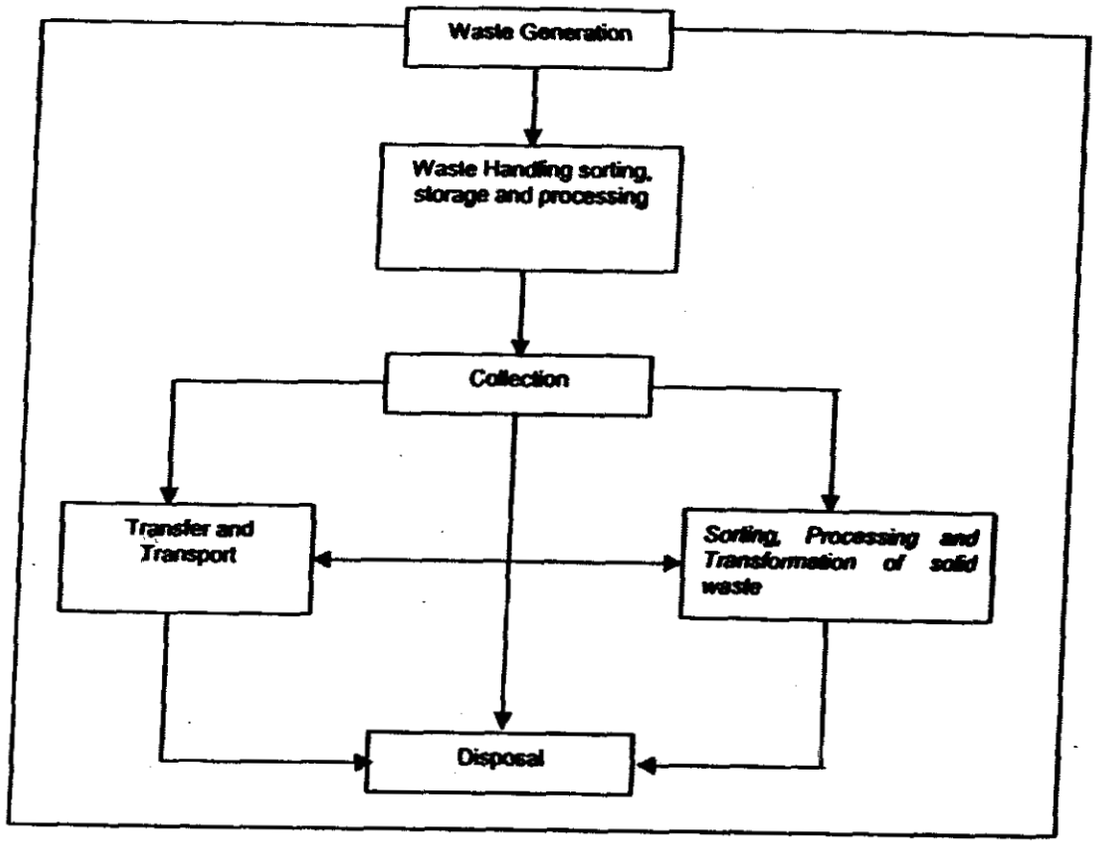
Figure 2 : Functional Elements of a MSW Management System



Source : Manual on Municipal Solid Waste Management, Ministry of Urban Development, Central Public Health and Environmental Engineering Organisation (CPHEEO), GOI, New Delhi, January 2000

The highest rank of the Integrated Solid Waste Management (ISWM) is waste minimisation or reduction at source, which involves reducing the amount of wastes produced. Reduction at source is the first in the hierarchy because it is the most effective way to take care of all the issues related to solid wastes and its management, the environmental impacts and the cost associated with its handling.

The second highest rank in the hierarchy is recycling which involves (a) separation and sorting of wastes materials; (b) preparation of these materials for reuse or reprocessing; and (c) reuse and reprocessing of these materials. Recycling is an important factor, which helps to reduce the demand of resources and the amount of wastes requiring disposal by landfilling.

The third in rank is waste processing which involves alteration of wastes to recover conversion products (e.g. compost) and energy. The processing of waste materials usually results in the reduced use of landfill capacity. Shredding, compaction may also be undertaken to reduce waste volume. Moreover, such an ISWM has other associated benefits that also include reduced public health hazards, reduced surface and ground water pollution, air pollution, and production of compost material for use as fertiliser etc.

Landfilling / dumping is the last in the hierarchy and involves controlled disposal of MSWs on or in the earth's surface.

Primary Collection of Garbage from Households and its Transportation to Collection Points

Community efforts

The task of collecting garbage from households and taking it to a collection point primarily is an activity performed by the households themselves. In many cases where the residents are economically better off and hygienically conscious with active resident welfare associations (RWAs), efforts are made to organise the collection of garbage from each household and transport it to the collection point. These efforts, although still nascent, are now visible in many cities of India.

Instances of finding door-to-door collection of garbage are more in group housing societies, people staying in high-rise apartments and RWAs in colonies of individual houses. In most of these cases safaiwallas (cleaners) are employed privately who collect garbage from every household and transport it to a common collection point from where the municipality picks it up. In fact, in Delhi, in the residential colonies constructed by Delhi Development Authority (DDA), it is stipulated that RWAs have to be formed to provide these facilities since neither the DDA nor the municipality provides the facility of door-to-door collection of garbage. In Mumbai in many high-rise apartments, the garbage from all the flats is collected and placed in large bins at the entrance of each apartment. The municipality pickup vehicle comes at a pre-decided time to collect this garbage. In many areas, the pick-up vehicle announces its arrival by ringing a large bell or blowing a horn. This method of collection prevents the accumulation of garbage at round-the corner collection point. In Mumbai, a major nuisance is thus avoided since the humidity in the atmosphere causes the garbage to degrade very fast leading to unhygienic conditions. In cities like Delhi, the collection points do become an eyesore especially if the municipality does not collect garbage regularly. The garbage is seen to spill out on the adjacent road attracting cattle, flies and other stray animals.

The practice of garbage collection from households ceases in most unplanned and unauthorised settlements. The responsibility of taking the garbage to a collection point is with the residents. As a result, the garbage is thrown anywhere along the road or in a vacant plot and sometimes even in parks. In such places, garbage is swept away by the safai karmacharis.

Segregation of Waste and Resource Recovery

A stage between the collection of garbage and its disposal is that of resource recovery. The municipality in any city in India does not do segregation of garbage into biodegradable and non-biodegradable waste. Since the volumes of garbage handled by the municipality is very large, it would be a very labour-intensive job. Segregation, however, does happen in an informal way before the garbage is disposed. In door-to-door collection of garbage, the workers involved remove all recyclable items that have a resale value like plastic items, unsoiled paper, metal pieces, glass, etc. Ragpickers in every city, of course, most efficiently perform segregation.

In India, paper, plastic, glass, rubber, ferrous and non-ferrous metals – all the material that can be recycled – are salvaged from the waste to produce low-cost products extensively used by the lower-income groups of the society. Of the wide array of recyclable material present in the Indian household waste, it is paper and plastic that get maximum attention, because the two together form the single largest component of household waste. The reusable materials are sold off in waste recycling centres, which are small-scale industries.

The municipalities, however, are unable to take up any projects on segregation and recycling due to the high costs involved. Segregation of waste into biodegradable and non-biodegradable is done more efficiently in programmes run by NGOs. A few efforts have been initiated by NGOs to involve households in separating the garbage into bio and non-biodegradable waste. However, these efforts have never paid off. Such efforts were tried at residential areas of highly academic and aware people like IIT and JNU in Delhi, but they have not been sustained. Ultimately paid workers have to be engaged in the task of waste segregation.

Secondary Transportation of Garbage

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The situation of secondary transportation of garbage is very dismal. On an average, 20 to 30 percent of the total waste generated remains uncollected, creating environmental hazards in urban settlements. The collection, transportation and disposal of waste are labour-intensive activities. In large metros like Mumbai some of the Municipal wards have started using modern, automated system of collection thereby increasing efficiency. However, in cities like Hyderabad and Ahmedabad, in many areas when the municipality does not collect garbage, the sweepers resort to burning the garbage on the spot thus creating air pollution problem locally. Very often, the garbage is swept into the open gutters / drains causing problems of choking and stagnation which leads to unhygienic conditions.

Solid waste is usually transported in open trucks, compaction vehicles, tractor-trailers or carrier-containers. The vehicles are normally owned and maintained by municipal authorities. Lately, however, a few corporations have resorted to hiring vehicles from private contractors. Hired vehicles have been found to work more effectively and efficiently, if monitored and held accountable for the services rendered by them. In smaller (rural) towns, bullock carts, tractor-trailers, power tillers, tricycles etc. are mainly used for the transportation of waste. These vehicles are being used for the primary collection of waste from the streets, as well as for the collection of waste from the dust-bins.

Some of the problems faced in transporting MSW in large towns and cities are listed:

- The number of vehicles is inadequate and the percentage of vehicles remaining off the road is large
- The fleet of vehicles is not optimally utilized
- Transportation fleet does not synchronize with the types of dust-bins provided
- The Hydraulic vehicles need proper maintenance and well-trained staff in the work shops
- Double handling of waste becomes inevitably necessary
- Waste handling is done manually and loading and unloading is time consuming. This reduces the productivity of manpower and vehicles
- The system is a potential health hazard for the workers as all type of waste including hospital infectious waste, human excreta etc., are disposed off in the common dust-bin
- Arrangement for collection of infectious hospital waste separately is practically non existent
- Dust-bins are not cleared on day-to-day basis. Many bins are cleaned once or twice in a week or even later. The backlog thus built up gives rise to insanitary conditions

Actual Disposal of Waste

There are a variety of methods for the disposal of the refuse collected from different collection points of the municipality. According to CPCB (1994), the prevailing technological options for municipal solid waste disposal includes :

- Sanitary landfill
- Incineration
- Anaerobic digestion
- Composting
- Fuel pelletisation

The wastes are normally brought to a designated landfill site, normally a low-lying area on the outskirt of a city. The choice of a site is more a matter of what is available than what is suitable. Only a few cities follow such good practices as organised tipping of wastes, using mechanised equipment for leveling and compacting the wastes, and covering the top layer with earth before compacting it further. In small towns and cities very often the garbage is dumped in ponds or banks of a river. In hill towns, the garbage is dumped along the hillside on the outskirts of the town, which attracts monkeys and various other animals. Collection of recyclable items like plastic, paper, etc. and transporting it to large towns for recycling is not an economically sound option. Efforts are required to organise the collection of these recyclable material from hill towns or else these towns will be enveloped by waste.

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Lack of a scientific and efficient Municipal Solid Waste Management (MSWM) system in most of the cities and towns poses a serious health and environmental problem. Therefore there is an urgent need to improve the MSWM by capacity building of the municipal managers to modernise (i) collection, (ii) transportation and (iii) disposal systems with a view to wastes minimisation and reduction of methane emissions. Such a MSWM system must reduce the local and global environmental impacts of municipal wastes and should operate at a cost acceptable to community.

REGULATORY PROVISIONS OF THE GOVERNMENT OF INDIA FOR MANAGEMENT AND HANDLING OF MSW

Ministry of Environment and Forests, Government of India through the Gazette Notification of 25 September, 2000 has brought into force the Municipal Solid Wastes (Management and Handling) Rule, 2000, applicable to every municipal authority responsible for collection, segregation, storage, transportation, processing and disposal of municipal solid wastes. As per the notification the municipal authorities are required to furnish its annual compliance report to the State Government or the District Magistrate on or before the 30 June every year and the State Boards and the Committees have to prepare and submit to the GoI an annual report with regard to the implementation of these rules by the 15 September every year.

The Rule stipules detailed compliance criteria and procedures for the management of municipal solid waste by the Municipalities in India.

Under the provisions of management of MSW by the municipalities, detailed compliance criteria for (1) collection, (2) segregation, (3) storage, (4) transportation, (5) processing and (6) disposal of MSW have been notified under Schedule II of the Notification. Under the Schedule III, 'Specification for Landfill Sites' have been brought out particularly under 'Site Selection', 'Facilities at the Site', 'Specification for Landfilling', 'Pollution Prevention', 'Water Quality Monitoring', 'Ambient Air Quality Monitoring', 'Planting at Landfill Site', 'Closure of Landfill Site and Post-care' and 'Special Care for Hilly Areas'. Each of the specifications for landfill sites are further discussed briefly. For details, one should refer to the original Notification of the GoI.

Specification for Landfill Sites

Site selection must be based on examination of environmental issues. While selecting such sites, either the site should be in the vicinity of wastes processing facility or the wastes processing facility shall be planned as an integral part of the landfill site. The landfill site selected must be enough to last for 20-25 years. The landfill site has to be away from habitation clusters, forest areas, water bodies, monuments, National Parks, wetlands and places of important cultural, historical or religious interest. Further, a zone of no-development has to be maintained around landfill site. This aspects must be incorporated in the landuse planning while doing the Town Planning. The site selected should be away from airport / airbase and approval of airport or airbase authorities must be obtained before setting up of the landfill site.

Among facilities at the site, the landfill site has to be well protected to prevent entry of unauthorised persons and stray animals. Other important facilities that need to be provided are (i) wastes inspection facility to monitor wastes brought in for landfilling, pollution monitoring equipment, weigh bridge to measure quantity of waste brought at landfill site.

Specification for Landfilling

MSWs should be compacted using compactors to achieve high density of wastes. Wastes should be covered immediately or at the end of each working day with minimum 10 cm of soil, inert debris or construction material till such time waste processing facilities for composting, recycling or energy recovery are set up as per Schedule I. Special precaution are needed during and prior to monsoon season (a cover of soil, 40-65 cm thick must be spread over the MSW in the landfill).

Pollution Prevention

In order to prevent pollution problems from landfills operations, the following provision are required

to made :

- diversion of storm water drains to minimise leachate generation, prevent pollution of surface water and also to avoid flooding and marshy conditions
- a non-permeable lining system at the base and walls of waste disposal areas is to be provided with high density polyethylene (HDPE), geo-membrane as per specification given in the 'Specification for Landfilling'
- provision for management of leachates collection and treatment
- prevention of run-off from landfill area entering any stream, river, lake or pond

Water Quality Monitoring

As regards water monitoring, water quality baseline within 50 meters of the periphery of landfill site should be established and recorded properly for future reference. Monitoring of water quality has to be taken up within the 50 m of the periphery of landfill periodically to ensure that ground water is not contaminated beyond acceptable limit.

Ambient Air Quality Monitoring

Landfill gas control system and collection of LFG are needed to be installed at the landfill site to minimise odour generation, prevent off site migration of gases and to protect vegetation planted on rehabilitated landfill.

Plantation at Landfill Site

The landfill site when exhausted has to be provided with vegetative cover.

Closure of Landfill Site and Post-Care

As per the notification, post-closure care of landfill site has to be conducted for at least fifteen years. A long term monitoring or care plan should consist of the following :

- maintaining the integrity and effectiveness of final cover on the landfill site
- monitoring leachate collection
- monitoring ground water as required under the provision
- maintaining and operating the LFG collection system to meet the standard

The Notification stipulates compliance criteria for the municipalities as follows :

1	Setting up waste processing and disposal facility	By 31-12-2003
2	Monitoring the performance of waste processing and disposal facilities	Once in six months
3	Improvement of existing landfill sites as per provision of these rules	By 31-12-2001 or earlier
4	Identification of landfill sites for future use and making site (s) ready for operation	By 31-12-2002

Disposal of MSW

Landfilling must be restricted to non-biodegradable, inert waste and other wastes that are not suitable either for recycling or for biological processing. Landfilling also has to be carried out for residues of wastes processing facilities as well as pre – processing facilities.

TECHNOLOGICAL OPTIONS FOR METHANE EMISSIONS REDUCTION

The problem of waste mis-management can be addressed through the adoption of improved methods of collection, transportation and scientific and environment friendly technologies for treatment and processing of waste before it is disposed off.

Resource Recovery through Waste Processing

Processing of MSW may provide us energy (electricity) or rich compost, depending upon the technology adopted. It has been estimated that there is a potential of generating about 1000 MW of power from urban and municipal wastes and about 700 MW from industrial wastes in the country. The total Indian market for Municipal Solid Waste treatment and disposal technologies (excluding collection and transportation) in 1997 is estimated at US $ 270 million[7]. The market is projected to grow at an average annual growth rate of 20 percent during the next 3 years. Composting technology, due to its simplicity and low capital requirements, accounts for almost 50 percent of the market. The breakdown of the market in terms of technologies for municipal solid waste treatment and disposal is given in Table 7.

Table 7 : Market Share for MSW Treatment

	Technology	Percent market share
a)	Composting	50
b)	Anaerobic Biodigestion (Biomethanation)	30
c)	Pelletisation	10
d)	Sanitary Landfill	10

Advantage of Recovery of Energy from MSW

Generation of energy from MSW has certain distinct advantages such as -

- The total quality of waste gets reduced substantially
- The quality of leftover waste, from the point of causing environmental degradation, is improved
- Demand for land for disposal of wastes is reduced
- Carriage cost is reduced as garbage need not be carried to a far away place for dumping
- Proceeds from sale of energy / products (e.g. pellets) improve the commercial viability of a waste disposal project

Choice of Technology

The technologies mentioned above have their advantages and disadvantages. Selection of technology for a certain location will depend on factors like quantity and quality of garbage, climatic conditions (such as temperature, rainfall and humidity), local requirements and life style of the people.

Some of the important physico-chemical parameters that need be considered for selection of

[7] *Field Survey, Ministry of Non-conventional Energy Sources, New Delhi*

technology are :

- Size of constituents
- Density
- Moisture content
- Mixed carbon/inert content
- Calorific value.

Waste-to-Energy Initiative World-wide

Cities in the developed countries have well organised waste management systems. Until some years back landfill had been the accepted system of waste disposal in most developed countries. But there is now a general trend worldwide to discourage disposal of combustible and organic wastes into landfills. Some of the countries like Austria, Belgium, Canada, Denmark, Finland, France, Germany, Netherlands, Norway and Sweden have already banned landfills or have decided to reduce reliance on landfills. Landfills occupy very large space and also create some environmental problems. The wastes produce methane, which is a greenhouse gas affecting the ozone layer.

Incineration is becoming more popular with growing difficulties in locating landfill sites. But it is found that incineration also produces a lot of pollution from the smoke emitted in the process. Waste left after the process is substantial and have high concentration of toxic materials. It is found that by gasifier system of proper design (based on pyrolysis process) it is possible to process MSW with extremely low contaminating emission and very low left out after the process. The gas produced can be directly used in an IC engine. However, factors like greater capital, operation and maintenance cost and also frequent changes in pollution control regulations are retarding the widespread application of such plants.

The Indian Scene - Potential of Power from MSW

The urban areas of India produce about 30 million tons of solid waste from household and commercial activities every year. It is estimated that there is a potential of generating about 1000 MW of power, from MSW in India. If this potential be effectively used, it will not only contribute substantially to the overall power generation capacity but will also give a good return on investment, apart from improving the environment.

But so far the vast energy potential of MSW of urban areas of the country remains almost totally untapped. Unlike in developed countries, the waste of Indian cities have a high fraction of degradable organic matter, between 35% to 75% of garbage compared to only 12% to 15% of U.S.A and U.K. As such, garbage of Indian cities has a very high energy potential.

There are at least 7 domestic companies offering technologies and/or turnkey project services for implementing municipal solid waste treatment and disposal projects in the country. Of these companies, only Excel Industries Ltd. has been able to successfully implement projects to produce compost based on the aerobic process. Excel Industries Ltd. has almost 60 percent share of the composting technology market in India at present. The company has developed the low cost composting technology indigenously and has been able to make an impact on the market, creating more demand for its technology. The main reason for the company's success has been its ability to partially fund these projects, and also provide assistance in marketing the end product - ***compost***. However, a number of projects under implementation by the different municipalities, are using newer, more capital intensive technologies such as Biomethanation and Sanitary Landfilling.

This market was virtually non-existent until a few years ago. Several key factors and pressing environmental concerns led to the creation of this market, which has been growing at a fast pace. The

The main characteristics of anaerobic composting are :

- The process is a lengthy one extending over a period of 4 to 12 months.
- It is a low temperature process and the destruction of pathogens is accomplished by their exposure to an unfavourable environment over a long period.
- The gaseous products of reduction are methane, hydrogen sulphide and other gases with offensive odours

The main characteristics of aerobic composting are :

- Rapid decomposing, normally completed within 4-6 weeks.
- During the composting period high temperatures are attained leading to speedy destruction of pathogens, insect eggs and weed seeds.

Following factors affect the rate of successful composting :

- Moisture content (20 to 30%) and temperature maintenance (65-70°C)
- Regular turning of the heap to ensure uniform moisture content, innoculant content and proper aeration.
- Carbon-to-Nitrogen ratio (20 to 25)

Vermicomposting is composting aided by earthworms. Certain specific species of earthworms can consume organic residue very rapidly and fragment them into much finer particles. For vermicomposting, the most significant aspect is the selection of earthworms. There are broadly three varieties of earthworms; surface variety, subsoil and deep burrowing. For vermicomposting the best variety is the surface variety because they feed on the surface. Some of the species of earthworms that aid in vermicomposting are *Eudrilus eugeniae*, *Eisenia foetida*, *Perionyx excavatus*, *etc.* The following products are obtained from the whole process of vermicomposting :

- **Vermicompost** (end product), which is the castings (excreta) of the earthworms; this is rich in plant nutrients
- **Vermiwash** (bye product), which is a solution of nutrients obtained from the percolation of water through the vermicastings
- The earthworms themselves, which are very good sources of proteins; this is used as feed for fish, poultry and pigs

Vermicomposting has immense potential and has been very successful at community level. So far it is taken up only at small scale at community level. There are no examples of vermicomposting at large scale. However, the present techniques may be modified and tried to handle large amount of waste and significantly address to solid waste management.

Biomethanation / Anaerobic Digestion

This is a process used for production of methane from solid wastes. In this process the organic fraction of the waste is segregated and fed to a closed container (Biogas digestor) where, in the presence of methanogenic bacteria and under anaerobic conditions, it undergoes bio-degradation producing methane-rich biogas and effluent. Biogas mainly consists of methane (about 60%), carbon-dioxide (about 40%) besides small quantities of NH_3 and H_2S. It has a calorific value of about 5000 k.cal/cu.m. Depending upon the waste composition, the biogas production ranges from 50-150 cu.m./tonne of wastes. This biogas can be utilised either for cooking or heating applications or for generating power or electricity through gas engines, gas turbines or steam turbines. The sludge from anaerobic digestion, after stabilisation, can be used as a soil conditioner or manure.

PHYSICO-CHEMICAL OPTION

Pellitisation

Pelletisation is the production of fuel pellets from solid waste. The process is essentially a

major factors[8] that will lead to market growth and are likely to play a dominant role in the future are as follows :

- Strict environmental regulations enforced by Central Pollution Control Board and the Ministry of Environment and Forests.
- Judicial intervention by the Supreme Court of India, directing municipal corporations / Urban Local Bodies to ensure better municipal solid waste management.
- Financial and fiscal incentives offered by the Ministry of Non - Conventional Energy Sources to encourage the promotion of waste-to-energy projects based on municipal solid waste.
- 74th Constitutional Amendment Act empowering the urban local bodies to take independent decisions on promoting municipal solid waste disposal and treatment projects.
- Emphasis on privatisation and allowing private entrepreneurs to promote such projects on Build-Own-Operate and Build-Own-Operate-Transfer basis.

Various technologies are available for utilising MSW profitably and these can be classified under the following heads :

Biological option (with or without the aid of oxygen)
- Composting
- Biomethanation

Physico-chemical option
- Pellitisation

Thermal option
- Pyrolysis
- Gasification
- Incineration
- Plasma arc

Sanitary landfilling

All these options of waste processing and recovery of energy and other useful products are discussed one by one. Their comparative advantages and limitations have also been highlighted.

BIOLOGICAL OPTIONS

Composting

Composting can be defined as the biological decomposition of the organic constituents of wastes under controlled conditions. This process can take place in the presence or absence of oxygen, that is, aerobic or anaerobic composting. Aerobic composting, if efficiently carried out, can rapidly produce a pathogen free product; anaerobic composting requires more time and is seldom free of pathogen or odour problems.

The end product, organic manure has a very good acceptability among the farmers for agriculture as well as horticulture crops. The organic manure improves soil fertility, soil texture and water retention capacity of soil, there by increasing production.

There are two main groups of organisms, which decompose organic matter
- Anaerobic bacteria which work in the absence of oxygen, and
- Aerobic bacteria which work in the presence of oxygen.

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[8] *US Department of Commerce, 1998-05-13*

method that condenses the waste or changes its physical form and enriches its organic content through removal of inorganic materials and moisture. Pellets can be used for heating plant boilers and for the generation of electricity. They also act as a perfect substitute for coal/wood used in home/industry. Pelletisation offers the possibility of decentralised garbage treatment facilities.

Pellitisation of MSW involves the processes of segregating, crushing, and mixing high and low heat value organic waste material and solidifying the same to produce fuel pellets or briquettes, also referred to as Refuse Derived Fuel (RDF). This can be conveniently stored and transported and used as a supplementary fuel for combustion processes and utility boilers. The calorific value of RDF is about 4000 kcal / kg. and it depends upon the content of combustible organic materials in the waste, additives and binder materials, if any, used in the process.

Table 8 : Evaluation of Pelletisation

Merits	Demerits
1. This process results in production of high calorific value pellets 2. Pellets can be conveniently stored and transported 3. Pellets can be used as a supplementary fuel for combustion process and boilers	1. The garbage processing unit cannot be operated during rainy season , as the garbage is too wet 2. High moisture content of Indian MSW increases the cost of drying 3. The process consumes more energy than the biological process, such as composting 4. Uncontrolled burning of pellets may lead to harmful emissions 5. Even a trace amount of plastic content in the pellets can be harmful

THERMAL OPTION

Gasification

Gasification is the process involving partial combustion of a carbonaceous fuel to generate a combustible fuel gas rich in carbon monoxide and hydrogen. A gasifier is actually an incinerator operating under reduced conditions. Heat to sustain the process i.e. derived from the exothermic reactions, while the combustible components of the low-energy gas are primarily generated by the endothermic reactions. The kinetics of the gasification process is quite complex and a subject of considerable debate.

When a gasifier is operated at atmospheric pressure with air as oxidant, the end products of the gasification process are a low-energy gas typically containing 10% CO_2, 20% CO, 15% H_2 and 2% CH_4 (by volume), with the balance being N_2 and a carbon-rich char. Because of the diluting effect of nitrogen in the input air, the low-energy gas has an energy content in the range of 5.2 to 6.0 MJ/m^3. When pure oxygen is used as the oxidant, a medium-energy gas with energy content in the range of 12.9 to 13.8 MJ/m^3 is produced.

The gasification process converts solid waste materials into clean useable energy in the form of a high calorific value gas. The system uses a thermal conversion reactor, which operates, at a high temperature in an oxygen deficient environment.

The waste stream is pre-treated to remove materials that are recycled, including glass, metals and other non-combustibles. It can then be dried, utilising waste heat from the process and finally shredded to increase the surface area and maximise the gasification reaction.

Immediately prior to being introduced into the reactor the feedstock is purged with an inert gas such as carbon dioxide in order to remove the entrained air. The reactor operates at a very high temperature and the feedstock is gasified. Any solid carbon or ash produced during the reaction is removed by the separator system.

The produced gas is quenched to ambient temperature immediately as it leaves the reactor by direct injection and further cleaned by a wet gas scrubber utilising sodium hydroxide. The gas thus produced is suitable for being fed into a boiler or another prime mover for power generation.

Incineration

It is the process of direct burning of wastes in the presence of excess air (oxygen) at high temperatures (about 800°C) liberating heat energy, inert gases and ash. Net energy yield depends upon the density and composition of waste, percentage of moisture and inert materials, which add to the heat loss, ignition temperature, size and shape of the organic matter into hot air, steam and hot water.

Incineration is a thermal process for burning the waste at a very high temperature. It requires high calorific value waste, which can burn without any external fuels. Indian waste contains only 3-7% of combustible material like plastics, paper by the time the waste reaches the disposal site. This is principally because most of the material that can be burned; is recovered by the ragpickers from the waste lying on the streets, dust-bins and dump yards. Thus calorific value of Indian waste at dump yards is found to range from 800-1000 Kcal/kg, which is very low.

The combustion temperature of conventional incinerators fuelled only by wastes is about 760°C in the furnace (insufficient to burn or even melt glass) and in the excess of 870°C in the secondary combustion chamber. These temperatures are needed to avoid odour from incomplete combustion. Temperatures upto 1650°C, which would reduce volume by 97% and convert metal, and glass to ash are possible with supplementary fuel. Wastes burned solely for volume reduction may not need any auxiliary fuel except for start-up.

The incineration technology is not exactly suited for Indian MSW because of the high ash and dust contents of Indian wastes. Excessive moisture and inert content in waste affects net energy recovery; auxiliary fuel may be necessary to sustain combustion. There are chances of toxic metal concentration in the ash. In addition to particulate, SO_x and NO_x emissions, chlorinated compounds ranging from HCL to dioxins , and heavy metals are a cause for concern; which requires elaborate pollution control equipment. Additionally it involves high operation and maintenance costs as well as a lot of money has to be diverted for training the personnel to handle the incinerators effectively. Incineration of MSW thus results into a lot of air emissions and for adequate control of such emissions a lot of pollution control equipment need to be installed. All this adds up to the cost.

SANITARY LANDFILLING

Sanitary landfilling is an engineered method of disposing solid waste on land in a manner that minimises environmental hazards and nuisances. It is a controlled disposal of solid wastes on or in the upper layer of the earth's mantle.

A sanitary landfill site should be carefully selected, designed and prepared. The wastes are to be spread in thin layers, compacted to the smallest practical volume and at least at the end of each operating day, covered with earth, which is also compacted. In India, however, there is no sanitary landfill; here the waste is simply dumped in low-lying areas. 91% of the waste meets this fate in these so-called 'landfills'.

Proper planning and site selection, combined with good engineering design and operation of a sanitary landfill, can normally minimise the possibility of surface and ground water pollution. The landfill sites in India suffer from the following deficiencies :

- Lack of proper drainage to prevent flow of rainwater into and out of the site
- Non- application of cover material on garbage on a daily basis
- Lack of proper gas venting facility
- Absence of overall environmental management plan for solving pollution problems

According to NEERI, June 1996, examination of the water environment in major landfill sites indicates a high concentration of TDS in contiguous ground water sources. Solid waste samples from various depths of the landfills contained high values of faecal coliforms and faecal streptococci.

Landfill gas recovery

The waste deposited in a landfill gets subjected, over a period of time, to anaerobic conditions and its organic fraction gets slowly volatilised and decomposed, leading to production of landfill gas, which contains a high percentage of methane (about 50%).

Typically, the production of landfill gas starts within a few months after disposal of wastes and generally lasts for 10 years or even more depending on the composition of wastes and the availability of moisture.

This gas can be recovered through an active system of vertical or horizontal wells, which are placed/drilled into the wastes where methane is being produced. A main collection header connects the wells and a blower pumps the gas out under negative pressure. The gas is passed through a moisture trap, gas-cleaning unit, a flame arrester, a non-return valve and a gate valve before its connection to the compressor. As the gas has a calorific value of around 4500 Kcal/m3, it can be used as a source of energy either for direct heating/cooking applications or to generate motive power or electricity.

The following biological, physical and chemical events occur when solid wastes are placed in a sanitary landfill :

- biological decay of organic materials, either aerobically or anaerobically, with the evolution of gases and liquids;
- chemical oxidation of waste materials;
- escape of gases from the landfill;
- movement of liquids caused by differential heads;
- dissolving and leaching of organic and inorganic materials by water and leachate moving through the landfill
- movement of dissolved material by concentration gradients and osmosis; and
- uneven settlement caused by consolidation of material into voids

Gases found in landfills include air, ammonia, CO_2, CO, hydrogen, H_2S, CH_4, nitrogen and oxygen. CO_2 and CH_4 are the principal gases produced from the anaerobic decomposition of the organic solid waste components. Under ideal conditions, the gases generated from a landfill should be either vented to the atmosphere or, in larger landfills, collected for the production of energy. In most cases, over 90% of the gas volume produced from the decomposition of solid wastes consists of methane and carbondioxide. Although most of the methane escapes to the atmosphere, both methane and CO_2 have been found in concentrations of upto 40%. If vented into the atmosphere in an uncontrolled manner, methane can accumulate (because its specific gravity is less than that of air. With proper venting, methane does not pose a problem. Since CO_2 is about 1.5 times as dense as air and 28 times as dense as methane, it tends to move toward the bottom of the landfill. As a result, the concentration of CO_2 in the lower portion of the landfills may be high for years. Ultimately, because of its density, CO_2 will also move downward through the underlying formation until it reaches the groundwater. Since CO_2 is readily soluble in water, it lowers the pH, which in turn can increase the hardness and

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mineral content of the ground water through the dissolution of calcium and magnesium carbonates.

The movement of gas in landfills can be controlled by installing gas recovery wells in landfills. Clay and other liners are used where landfill gas is to be recovered. In some cases, leachate is collected and recycled to the top of the landfill and reinjected through perforated lines located in the drainage trenches.

Initiative of Government of India

The Ministry of Non Conventional Energy Sources (MNES), Govt. of India has identified **"Energy from Waste" as one of the thrust area of its activities** and has initiated a 'National Programme from Urban and Industry Waste'. Besides this the Ministry has launched an UNDP/GEF (United Nations Development Progamme / Global Environment Facility) assisted project entitled, 'Development of High Rate Bio-methanation Processes as a Means of Reducing Green House Gases Emission' in the year 1994. "National Programme for recovery of Urban and Industrial Wastes" is to promote 'waste to energy' projects by creating a conducive environment by providing suitable financial / fiscal incentives. Improvement of waste management practices (with special emphasis on generation of energy from waste wherever possible) by adopting latest and clean technologies is an other important objective of the programme.

Status of Municipal Waste to Energy Projects in India

During 1984 a plant for processing 300 tonnes garbage to produce about 3 MW of power was set up in Delhi with technical assistance from Denmark. The plant was not successful.

The Ministry of Non-conventional Energy Sources (MNES) has taken new initiative in the shape of National Programme for recovery of energy from Urban and Industrial Waste. Under this programme a number of "Waste to Energy" projects have so far been completed in the country with an installed capacity of 16.2 MW. But most of these projects are based on industrial wastes.

There have been some developments in the sphere of generation of energy from Municipal Wastes as well. NEDA has also launched an ambitious programme for promotion of electricity generation from Municipal Solid Waste (MSW) available in major towns/cities of U.P.

Government of India has announced various incentives for setting up MSW based power projects in the country. In case of commercial projects, financial assistance as interest subsidy for reducing the rate of interest for the entire loan repayment period, to 7.5%, capitalized at an annual discount rate of 12% is available through financial institutions. The maximum eligible subsidy amount varies from Rs. 1.00 crore per MW to Rs. 2.00 crore per MW depending upon the type of the waste-to-energy based project. Capital subsidy upto 50% of the project cost limited to Rs. 3.00 crore per MW is also available for some demonstration projects. Financial incentives at the rate of Rs. 15.00 lacs per MW to Municipal Corporation for Providing MSW free at the project site and land on long term lease (30 years on nominal charges) is also available. This is in addition to Rs. 5.00 lac/MW incentives to Nodal Department/Agency for promotion and co-ordination of waste-to energy projects.

In line with MNES guidelines, U.P. State Government has also declared a policy for generation of power from biomass including MSW. Various modifications were also done in the policy to make it more attractive. Specific guidelines / policy for providing land and MSW by Nagar Nigams required for generation of power from MSW were also declared. As per the policy of the State Government, the following major incentives are available for setting up Municipal Solid Waste based power projects in Uttar Pradesh.

- Purchase of electricity by UPSEB/UPPCL as per the policy of the State Government
- Providing land for setting up MSW plant on lease at the rate of Re. 1/m^2 per year
- Providing required quantity, of MSW at dumping site

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Major Steps Required for Handling of Waste and Generation of Power from MSW

For generation of power from MSW, the major role has to be played by Nagar Nigams. Therefore to accelerate the power generation programme based on MSW, it has now been decided that initiative has to come from respective Nagar Nigams. Nagar Nigams have been asked to get offers for setting up such projects in their cities. After receipt of the proposals, they could be processed in consultation with NEDA the Nodal Agency for this programme in this State.

Basically, there are following three types of waste :

- Municipal Waste (Solid & Liquid).
- Industrial Waste
- Hospital Waste

Industrial & Hospital wastes are being managed and disposed by their respective organisations, whereas the responsibility for collecting and disposal of municipal waste lies on Municipal Corporations/Nagar Nigam. So far, Nagar Nigams have been very effective in handling & disposing the liquid waste. With the instructions from High Court more emphasis is being given for scientific collection and management of Municipal Solid Waste. The collection & disposal of MSW has been linked up with power generation as an additional benefit. Since, generation of power from MSW technology is yet to be established in the country and the commercial viability of MSW based power project is not yet proved. Therefore, various incentives have been introduced by Government of India and State Government. However, there is a need to handle this programme as a collective responsibility. To tackle this programme in a more effective manner, following will have to be clearly defined, exercised and implemented by various concerned agencies and stakeholders as well.

- Effective National Policy declaration.
- Strengthening of legal infrastructure & ensuring it's execution.
- Need for separate municipal solid waste management project/plant for each city.
- Appropriate technology suitable to special conditions for short term as well as for long term requirements.
- Availability of adequate funds for MSW based Power Projects.
- Role of various stake holders and their accountability which include the following :
  a. Individual Household,
  b. Non-Governmental Organisations (NGOs)
  c. Municipal Corporation
  d. State Electricity Board/Regulatory Commission
  e. Urban Development Department
  f. Environment Department
  g. Financial Institutions
  h. Health Department
  i. Non-conventional Energy Department
- Awareness & Training at various levels.

Constraints in Setting up of Waste-to-Energy Project using MSW

Inspite of a major initiative taken by the Govt. of India and attractive financial and fiscal incentives being made available, the progress in setting up MSW based Waste to Energy projects in the country so far is rather discouraging. The following are the major constraints in setting up such projects :

- High capital cost of a 'waste to energy' project
- A potential developer/entrepreneur is not keen to take up such a project as there is a risk factor involved due to lack of success stories/ground experiences available in the country on successful running project on MSW
- Due to deficiency in legislation, there is no compulsion on the Urban Local Bodies to take up such projects, techno-economical viability and sustainability of which are not guaranteed
- Most of the technologies were developed in other countries and may not be suitable for Indian

conditions

- Lack of adequate financial resources of Urban Local Bodies and State Govts. to meet even a part of the project cost
- Lack of concrete / long term strategy at the level of State Governments as also absence of clear cut and conducive policy on waste to energy projects' such as supply of wastes, availability of land and sale/purchase of power generated from such projects
- General lack of awareness about hygiene and protection of environment

BIOMETHANATION

The Ministry of Environment and Forests, Government of India has brought out a Notification in September 2000 regarding Management and Handling of Municipal Solid Waste. According to this Notifcation compostable organic waste can not be dumped in the landfills. In view of this Biomethanation seems to be a viable option for transformation of waste into energy. A few demonstration projects have been taken up in India. Following is a brief description of biomethanation process and these demonstration projects.

Microbiology of Anaerobic Digestion

The overall process of anaerobic digestion occurs through the combined action of a consortium of four different types of micro-organism : **Hydrolytic and fermentative micro-organisms** including common food-spoilage bacteria which break down complex organic wastes into their component sub-units and then ferment them to short-chain fatty acids and carbon dioxide and hydrogen gases. **Syntrophic bacteria** convert the complex mixture of short chain fatty acids to acetic acid with release of more carbon dioxide and hydrogen gases to provide the main substrates for the methane bacteria. **Methane bacteria** produce huge quantities of methane and carbon dioxide from this acetic acid and also combine all of the available hydrogen gas with carbon dioxide to produce more methane. **Sulphate-reducing bacteria** are also present. They reduce sulphates and other sulphur-compounds to hydrogen sulphide, most of which reacts with iron and other heavy metal salts to form insoluble sulphides, but there will always be some hydrogen sulphide remaining in the biogas.

The ultimate yield of biogas depends on the composition and biodegradability of the waste feedstock but its rate of production will depend on the population of bacteria, their growth conditions and the temperature of the fermentation. Microbial growth and natural biogas production is very slow at ambient temperatures. As a waste treatment process, the rate of anaerobic digestion is greatly increased by operating in the mesophilic temperature range (35-40°C). For high solid feedstocks such as MSW it can be further increased by operation at thermophilic (50-60°C) temperatures.

Anaerobic Process

The fermentation, when carried out for producing energy, leads to the breakdown of complex biodegradable organics, in a four-state process. If the process is properly controlled so that it proceeds as per these stages, the principal end product, commonly known as biogas, contains about 65% of methane gas, 35% of carbon dioxide and traces of ammonia, hydrogen sulphide and hydrogen. This 'biogas' is a convenient and clean fuel and can either be used directly with or without the removal of carbon dioxide or can be converted into electricity with the help of suitable generators.

Choice of Anaerobic Reactors

Biomethanation requires adequate infrastructure. The first and the foremost among them is the bioreactor in which the treatment is to be carried out. This is all the more so since extremely large volumes of effluents are encountered for treatment. Thus, an optimally designed bioreactor can decrease the treatment time and increase the treatment efficiency leading to an overall lowering of the treatment cost.

Selection and design of bioreactors are dictated by process kinetics. In biomethanation, kinetics of the acidification reaction (acidogenesis) as well as the methane formation reaction (methanogenesis) are taken into account. Since the average growth rate of the methanogens is much lower than that of acidogens, the overall rate of the biomethanation process is therefore controlled by the methanogenic step. It is seen that the rate of biomethanation can be accelerated only by enhancement of the rate conversion of VFAs (Volatile fatty acids) to methane. This can be achieved by two methods :

- By increasing uptake of VFAs. However, the rate at which fatty acids are taken up by the methanogens is an inherent property of the organisms. It depends on their specific growth rate and cannot be increased beyond a certain value.
- By increasing the concentration of the methanogens in the reactor. This is not possible in a completely mixed reactor where the methanogens are suspended in the liquid phase.

Table 9 : Evaluation of Biomethanation

Merits	Demerits
1. The treatment takes place in a closed container, hence the entire operation does not get affected during rainy season.	1. The process does not treat the whole waste, only the organic fraction is treated.
2. The treatment is free from bad odour, rodent, fly menace, visible pollution and easy to manage in hygienic conditions.	2. It is unsuitable for wastes containing low organic materials or recycled materials.
3. Generation of gaseous fuel and soil conditioner as end products.	3. The biogas generation depends upon the composition and nature of organic wastes fed into the reactor and design parameters of the reactor.
4. Modular construction of plant and closed treatment needs less land area.	4. Some amount of water is required to make the feed slurry. Water requirement may be high if it is necessary to operate the digestor at a low solid content.
	5. Cost is a major barrier because it is much more capital intensive than composting in most of the cases.

Biomethanation Projects – Case Studies

Case Study 1 : Nagpur Municipal Corporation

The Nagpur Municipal Corporation plans to treat the city MSW through biomethanation using a Belgian technology called the DRANCO (Dry Anaerobic Composting) process. This project would generate 4.75 MW of electrical power by processing 520 tonnes of MSW everyday. This would additionally generate 150 tons of sludge.

a. Details of the technology

The DRANCO process consists of a thermophilic, one-phase anaerobic fermentation step, which is followed by a short aerobic composting phase. Before the waste is fed to the digestor, it passes a pre-treatment, where the particle size is reduced to a maximum of 40 mm in two dimensions and inert material is taken out of the waste stream. The digestion takes place in an upright, closed fermenter, which is fed from the top and from which the material is extracted at the bottom. Before the fresh waste is pumped into the fermenter, it is mixed externally with inoculum. This inoculum is digested residue coming from the fermenter. During this mixing, steam is added into the mixing unit to heat up the substrate to a temperature of about 55^{0}C, which is needed for the thermophilic digestion. During the anaerobic digestion phase in the enclosed digestor, the degradable organic material is converted into biogas.

The digested residue is extracted from the digestor, dewatered to a dry matter content of about 50^{0}C and then stabilised aerobically during a period of approximately two weeks.

Table 10 : Salient Features of the Project

1	Name of the project	Municipal Solid Waste to Energy, Nagpur
2	Mode of implementation	BUILT, OWN, OPERATE

3	Name and address of Investor/ Promoter	M/s. Enbee Infrastructure Ltd. Plot No.5, Zone -II, M.P.Nagar, Bhopal -462001, M.P.
4	Location of the project	Bhandewali/Nagpur
5	Type of Waste	Municipal Solid Waste
6	Quantity of Waste available from (Corporation/Council/Solid waste/ sewage)	520 MT/day
7	Land Requirement	10 acres
8	Power Requirement	750 Kwh
9	Water Requirement	151cum/day
10	Estimated cost of the project	Rs. 4730 lakhs

Table 11 : Post - Treatment Products and Recovery Per Day

S.No.	Item	Input	Output (proposed)
1	Manure	65100 MT/Year	49500 MT/Year
2	Power	42.77 million units/Year	37.62 million units/year
3	Scrap	4000 MT/Year	3900 MT/Year

b. Proposed power generation capacity

a) Installed Capacity : 5.4 MW (generation)
b) Auxiliary Consumption : 0.75 MW
c) Net generation capacity utilisation (in %)
   1st Year 60% : 25.66 MKwh
   2nd Year 65% : 27.80 MKwh
   3rd Year 75% : 32.08 MKwh
d) Nearest sub station of MSEB : Wathoda
e) Utilisation of power generated :
   i. Captive use : 0.75 MW
   ii. Sale to third party : 4.0 MW

c. Status of disposal of wastewater after power generation

The wastewater generated will be disposed off after proper biological treatment , according to Nagpur Municipal Corporation.

Case Study 2 : Lucknow Project

The Lucknow project would treat MSW using BIMA (Biogas Induced Mixing Arrangement) digestors. This technology has been developed by M/s Entec of Austria. Their technical collaborators in India are M/s Enkem Engineers Pvt. Ltd, a Chennai based environmental engineering company. The plant would treat 350 TPD of MSW in the first phase and generate 5 MW power. The Entech technology is suitable for high BOD waste materials having some sulphate content. The digestor converts the waste materials into biogas and 75 tons of sludge.

a. Details of the technology

The BIMA digestor is an anaerobic digestion system. The salient features of the BIMA system are as follows :

- There are no moving parts for mixing; so this reduces installation, service and maintenance costs
- There are no narrow pipes inside the digestor; so clogging does not occur
- The main chamber of the digestor can take wastes with a dry matter content upto 12% ; *resulting* in shorter residence times , smaller volumes and a reduction in investment costs
- No short passes are possible in the chamber system and hence there is a plug flow effect

BIMA digestors can be operated at mesophilic (15-35° C) or thermophilic (55-65° C) temperature ranges depending on the type of substrate and the process requirements.

It is also possible to design a two stage anaerobic digestion if required. The methane content of the gas is 60-65%.

b. Process description

*The **BIMA** digestor is divided into three separate sections, and inter connected to provide passage for* flow of liquids and gas. The three chambers are the main chamber, the upper chamber and the central tube to which the feed pipe is connected. In the central tube, pre - hydrolysis of the substrate takes place. Most of the biogas is generated in the main chamber through the decomposition of organic materials. By closing an automatic valve in the gas pipe between the two chambers, the gas produced in the main chamber stays there, which in turn displaces an equal amount of digested substrate to the upper chamber. This builds a level difference. When the required level difference is achieved, the gas is released to the upper chamber by an opening in the valve in the gas connecting pipe. Thus the substrate displaced in the upper chamber flows back to the main chamber with high velocity. A portion of the waste flows to the main chamber through the mixing shafts. On account of this fresh substrate, scum and sediments are perfectly mixed with the contents of the main chamber. Thus the new pre-hydrolysed substrate is mixed with active biomass in the digestor. Another portion of the digested substrate, which flows through the mixing shafts, pours onto the surface of the main chamber, thus avoiding scum.

This patented way of mixing ensures that the most important zones of the digestor are optimally *controlled by :*

- The turbulent mixing of the substrate
- The distribution of degradation products from the bacteria as well as the optimum supply of fresh substrate to them
- The control and stirring up of settled sludge
- The control, destroying and mixing of the skimming

Case Study 3 : Tata Energy Research Institute (TERI), New Delhi

TERI has developed a two-stage process consisting of acidification and methanation, called the **TEAM** process. The study has been conducted on mixed vegetable waste ; cauliflower, cabbage , *radish* , *spinach* , *mustard* and carrot, procured from a local vegetable market. Anaerobic batch digestion of this waste has been done at 5% TS concentration in a 10 litre capacity digestor. Digestion of waste after 47 days resulted in 0.16 m3 of biogas per kg of TS added. This biogas had a CH4 content of 68.4%. The decline in COD of vegetable waste slurry was approximately 65%. Degradation of the waste was also studied in a solid bed reactor of 64.3 litre capacity by sprinkling waster at regular intervals. The COD of the leachate obtained from the solid bed digestor ranged between 1500-25000 mg/l.

a. Details of the technology

The **TEAM** (TERI's Enhanced Acidification and Methanation) process is a two - stage process consisting of acidification and methanation. In the acidification phase, the organic content of the solid waste is leached out to make a high strength liquid of 20,000 mg/l COD by decomposition of the

waste with continuous sprinkling of water. In the methanation phase this high strength leachate is treated in a high rate UASB (Upflow Anaerobic Sludge Blanket) reactor to produce biogas. The sludge produced after digestion is dried to produce good quality manure.

b. Process description

- Acidification reactor

Acidification reactor consists of a rectangular digestor, a filter and a reservoir. Rectangular digestor has water seal opening at the top, which provides anaerobic environment in the digestor. Shredded waste is loaded into the digestor from this top opening. The bottom reservoir is filled with fresh water, which is sprinkled over the shredded waste bed in the digestor by means of a perforated sprinkler situated in the door of top opening. Liquid percolates through the bed of the waste and collects in the reservoir through the filter. The collected leachate is recirculated using a small pump. The process continues till extraction of the organic matter from waste into the leachate is complete. Leachate has a COD (Chemical Oxygen Demand) of 20,000 mg/l. An arrangement for the periodic removal of digested solid waste is provided in between the filter and reservoir. Dried digested solid waste is a good quality manure consisting of 2.1% of nitrogen, 1.6% of phosphorous and 24% of potassium.

- Methanation of leachate in the UASB reactor

The leachate collected from the acidification reactor is treated in a UASB reactor. The Microbial consortia in the granular sludge degrade 90% of the organic matter present in the fed leachate and convert it to a high calorific value fuel i.e. biogas. The gas formed constitutes of 70-75% methane, 20-25% of carbon dioxide and traces of hydrogen and hydrogen sulphide. Treated leachate can be recycled back to the acidification reactor for sprinkling. Thus the use of water is minimal, unlike conventional biogas plant.

CONCLUSION

Municipal solid waste and its improper handling and disposal methods pose a serious threat to human being and their environment. A large part of the total waste generated in India is simply dumped in open dump-yards giving rise to unhygienic surroundings, health hazards, contaminators of ground water, an unclean look to the city, generation of methane which contributes to global warming and other obnoxious gases. A proper municipal solid waste management system is a major challenge in the protection of local and global environment.

A number of technological options to minimise the municipal solid wastes and reduce emissions of methane. The municipal managers need to be given adequate exposure and training to these technological options for application in their municipalities to minimise wastes and reduce methane emissions. At present most of the municipalities are constrained due to lack of financial resources and infrastructure facilities to introduce modern municipal waste management in the municipalities.

Keeping in view the ever-growing problem of solid waste generation, its management and associated impacts, the Ministry of Environment and Forests has brought out a set of guidelines for the municipalities for Management and Handling of Municipal Solid Wastes. These guidelines concerns (i) collection, (ii) segregation, (iii) storage, (iv) disposal of municipal solid wastes in sanitary landfilling. The notification makes it obligatory for the municipalities to restrict landfilling to non-biodegradable inert waste, and other wastes that are not suitable either for recycling or for biological processing. With this in mind, the guidelines also prohibit to dump the biodegradable component of the waste into the landfills, thereby avoiding a chance to methane generation.

Under the present circumstances, and in view of the GoI Notification on the disposal of municipal solid wastes, there is hardly any scope for recovery of methane from landfills for re-use for energy purposes. The best technological options to reduce methane emissions for such wastes is to adopt an efficient solid waste management system to reduces wastes and adopt the technological options already well known in the country for dealing with wastes to wealth. Options like biomethanation, however, offer opportunities for waste to energy recovery and avoidance of methane generation. A city, however, needs huge amount of financial resources to adopt any of the technologies mentioned above for handling its solid waste. To address to the problem, involvement of private sector is a must and government policy should provide support for this.

REFERENCES

- Bio Energy News, Vol. 4 No. 1, March 2000; A quarterly Newsletter of the National Bioenergy Board, Ministry of Non-Conventional Energy Sources, Govt. of India
- Bio Energy News, Vol 4, No. 4, December 2000, A quarterly Newsletter of National Bioenergy Board, Ministry of Non-conventional Energy Sources, Govt. of India
- Bio Energy News, Vol 5, No. 1, March 2001, A quarterly Newsletter of National Bioenergy Board, Ministry of Non-conventional Energy Sources, Govt. of India
- Bio Energy News, Vol 5, No. 2, June 2001, A quarterly Newsletter of National Bioenergy Board, Ministry of Non-conventional Energy Sources, Govt. of India
- Guidebook on Landfill Gas Extraction and Utilisation, Netherlands Agency for Energy and the Environment, August 1997
- Management of Municipal Solid Waste, Central Pollution Control Board, 1999
- Manual on Solid Waste Management, Prepared by the Expert Committee, Constituted by the Govt. Of India, Ministry of Urban Development, Govt. of India, January 2000
- Methane Emissions and Opportunities for Control, Workshop Results of Intergovernmental Panel on Climate Change, USEP, September, 1990
- Recycling - A Natural Response to India's Soild Waste Problems, Report prepared by Development Alternatives, New Delhi, 1989
- Solid Waste Management in Class I Cities in India, Report of the Committee constituted by the Hon. Supreme Court of India
- Status of Municipal Solid Waste Generation, Collection, Treatment and Disposal in Class - I Cities, Central Pollution Control Borad, Min. of Environment and Forests, Govt. of India, 1999-2000
- Status of Solid Waste Generation, Collection, Treatment and Disposal in Class - II Towns, Central Pollution Control Borad, Min. of Environment and Forests, Govt. of India, March 2000
- Technologies for Efficient Management of Municipal Solid Waste, Project Report by Sudeshna Roymoulik, Environment Systems Branch, Development Alternatives
- Technology Status Report in the Area of Energy Recovery from Urban and Municipal Wastes (Liquid and Solid Wastes) Prepared by IRAM Consultants Pvt. Ltd., Submitted to Ministry of Non-Conventional energy Sources (MNES), July, 1996
- The Gazette of India, Extraordinary, Min. of Environment and Forests Notification, New Delhi, September 2000
- Training Programme on Solid & Hazardous Waste Management, Course Material, Prepared by Environment Division of National Productivity Council
- Trash to Cash, Control Landfill Bioreactor Project, Project Report Urban Consortium Energy Task Force, Yolo County Division of Integrated Waste Management, Yolo County, California, April 1998

Resources from the Web

- EPA Project XL, Final Project Agreement for the Yolo County Accelerated Anaerobic & Aerobic Composting (Bioreactor) Project, September 2000, USEPA
- Fact Sheet : Final Air regulations for Municipal Solid Waste Landfills, USEPA
- Landfill Methane Outreach Programme, 2000 Update of U.S. Landfill Gas to Energy Projects, USEPA
- Landfill Methane Outreach Programme, Products and Services : Public Health, Safety and the Environment, USEPA, August 2000
- Landfill Methane Outreach Programme, USEPA, August 2000
- Options for Reducing Methane Emissions Internationally; Volume II: International Opportunities for Reducing Methane Emissions, USEPA, Aril 2000
- Towards a Twenty-first Century Landfill : Accelerating Landfill Gas Generation for Energy Production