Chapter 4
India's Emission Projections

4.1 Introduction

The objective of this study is to project future Indian GHG emissions using appropriate models for the business-as-usual case and three other Indian scenarios developed in an earlier chapter. The three Indian scenarios developed were "high growth", "sustainable development", and "self reliance" named IA2, IA1, IB1 and IB2 scenarios respectively. The results of the models and the scenarios analysis would essentially generate information required for policy analysis. The analysis presented covers the period 2000-2030 in steps of five years.

The Indian emissions inventory borrows heavily from coal consumption which is the prime source of carbon based GHGs. Coal continues to dominate the Indian energy sector accounting for about half of commercial energy consumption, although its share is showing a decreasing trend. The present Indian emissions of carbon are steadily increasing from about 214 MT in 1995 to 261 MT in 2000 at a CAGR of above 4% (Table 4.1). The percentage shares of contributing sectors for each greenhouse gas reveal that power sector emissions account for around 45% of the total carbon emissions followed by industry and transport. The industrial emissions at 34% of carbon emissions in 2000, is reducing in overall share as industrial energy efficiency improves and due to the declining share of industry in GDP.

Table 4.1 Indian Emissions inventory

Gases (MT)	1995	2000	% increase over 1995	CAGR
Carbon	214	261	22.0%	4.05%
Methane	17.6	18.6	5.7%	1.11%
N_2O	0.213	0.251	17.8%	3.34%
CO_2 equivalent	1219	1424	16.8%	3.16%
SO_2	4.76	5.44	14.3%	2.71%
NO_X	4.12	4.66	13.1%	2.49%
Particulate	3.1	4.1	32.3%	5.75%
CO	37.1	39.3	5.9%	1.16%

Source: Garg A., 2000

Developing countries like India, can ill afford wrong policies, which may be realized only in post-facto analysis. Assessment of sector vulnerability (forestry, agriculture and coastal zones etc.) to climate change impacts and the required adaptation measures requires estimation of GHG emissions and their effect on local and global environment. The results of the models and the scenarios analysis would essentially generate information required for policy analysis. Scenario projections help identify such development paths and give much more clarity to development planning. It helps establishing a clearer link between emissions scenarios and mitigation options thus helping better use of scarce resources in a sustainable manner. It also helps in assessment of various development strategies that would address multiple state-level and regional priorities in overall sustainable national development.

4.2 The Methodology

The methodology as described in an earlier chapter, uses the integrated modeling framework. The integrated use of models does help to take advantages from each model adopted separately but the critical consideration is to ensure that the model specifications are harmonized, if models are used in conjunction. Consistency can be ensured through soft linkage whereby the scenario specifications across the models are harmonized. While this does not ensure the consistency in theory, in practice the results from different models can be made consistent through meticulous scenario specifications and cross checks.

This study uses an integrated modeling framework for energy and emissions future analysis using bottom-up and top-down energy and economy models viz. MARKAL, AIM along with a few other specific models viz. Demand forecasting, Power sector LP model, ERB and SGM. Here the soft-linked framework allows a very detailed assessment of specific sectoral policies, while at the same time allowing integration within the energy system forming a part of the overall economy, thus mirroring reality.

The top-down models, the bottom-up models and other models are soft-linked through various parameters. For example, the top-down models provide GDP and energy price projections that are used as inputs to the bottom-up models. The bottom-up models, on their part, provide future energy balance that is used for tuning the top-down models. Such multiple feedbacks ensure that the results from both the modules are in congruence.

Similarly the bottom-up models provide detailed technology and sector level emission projections that are also used for health impact assessment. These projections along with future scenario assumptions also provide inputs to the GIS based energy and emissions mapping for the country. The other models provide health costs to the economy and these help in analyzing local pollution control policies through the bottom-up models. The objective, outputs and policy issue addressed by each model is indicated in Appendix 1. Figure 4.1 shows the integration of the "bottom up" and the "other model" modules.

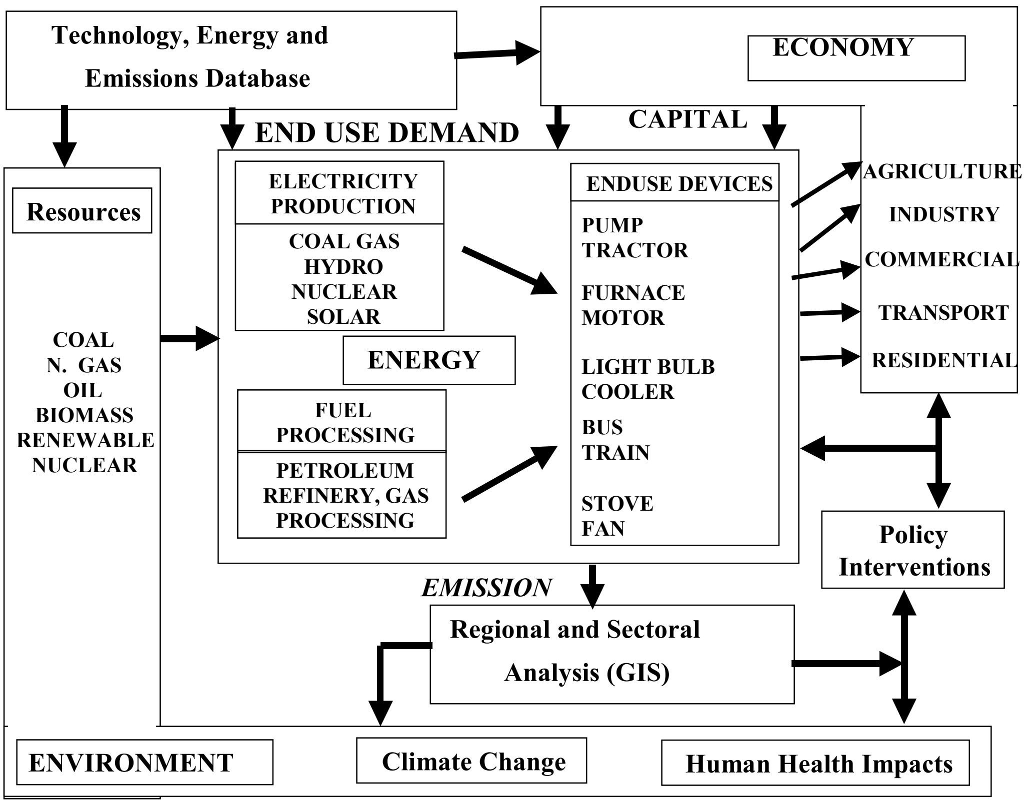

Figure 4.1: Integrating the "bottom-up" and "other model" modules

Bottom-up models follow the optimistic "engineering paradigm" in that they presume the existence of an efficiency gap. Top-down models reflect the pessimism of the "economic paradigm" which originates from the assumption that the present technology mix is the result of an efficiently functioning market. They are appropriate tools to endogenously derive the macro-economic indicators for a reference future and aggregate behaviours of economic agents based on prices and substitution elasticities.

The bottom-up module integrates five individual models:

i) MARKAL - an energy systems optimization model (Berger et al, 1987, Fishbone and Abilock, 1981, Shukla, 1996) which is used for overall energy system analysis,

ii) AIM/ENDUSE model (Morita et al, 1994, Morita et al, 1996, Kainuma et al, 1997) 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.

4.2.1 Model inputs

MARKAL model requires specification of various exogenous parameters. These parameters can be classified into the following categories:

- End use energy demands: Population and GDP growth are the major driving forces, which determine energy demands in the economy. India has charted out a future with high economic growth rate, which translates into a high rate of growth in demand for infrastructural assets and services. This further translates into greater demand for commodities from industries like steel, cement, aluminium and services like in the transport and commercial sector. The experience of developed countries shows that as the process of development stabilizes, the growth rates of infrastructural goods and services decrease. This increasing growth followed by a saturating trend is best represented by a logistic curve.
- Demands in the Indian energy system have been considered across 5 major end-use sectors and various demand sub-categories in residential, commercial, industrial, transport and agricultural sectors. The consistency of the end use projections with the macro economy is achieved through macroeconomic parameters such as the 'sectoral

GDP' as independent variables for demand projections. Expert judgment is relied upon wherever past data alone is not enough to make future projections considering the fact that the Indian economy is going through a period of transition fuelled by economic liberalization.

- Technology representation is fairly detailed. It is specified for demand as well as supply side. Cost of a technology and fuels vary across locations due to natural causes like the quality of mines or wind regime, logistics costs and economic condition external to the model like the cost of capital or labour. Thus fuels and technologies are modeled using different grades, each grade representing different cost composition. Demand technologies are specified in terms of energy inputs, specific energy consumption, and efficiencies.
- Reserves of primary energy and their costs: The delivered cost of energy from different primary energy sources depends on factors such as quality of the fuel (heat value, sulfur and ash content), extraction process employed and mode of transportation. For this reason, different energy sources appear competitive at different geographical locations. These dynamics have been represented in the model by incorporating various levels of energy source prices.
- Emission coefficients: Relevant emission coefficients as per Indian conditions have been used for various fuels and electricity generating technologies. Wherever, Indian data were not available, appropriate IPCC default emission factors have been applied.
- Transmission and distribution losses are assumed to decreases from the current level of 21% to about 12% by 2030.
- GDP projections are derived from a macroeconomic model for various scenarios (refer Table 4.2) Current trends indicate that the contribution of commercial sector (which includes service sector) to GDP has been growing at the expense of GDP contribution of agriculture and to some extent, even industry and this trend is likely to continue in the reference period till 2030.

Table 4.2: GDP Growth rates CARG (%)

Scenario	2000-2010	2010-2020	2020-2030
IA1	9%	8.5%	8%
IA2	6%	5.5%	5%
IB1	7%	6.5%	6%
IB2	5%	4.5%	4%

- The population figures follow our projections based on the Census and World Bank data. The Planning Commission of India projects the population at 1.37 billion by 2031 Census.
- Discount rate: The high capital costs of energy projects and their long life times often make the setting of the discount rate a determining factor in the choice between energy options. There are two major approaches used to determine the appropriate discount rate: social rate of time preference (2-3 %) and opportunity cost approach (10%). Most international modeling studies take the middle path with an intermediate discount rate of 4-7%. Considering the fact that India is a developing country and energy sector investments are still considered risky, a discount rate of 8% is assumed in the base case. However, in a scenario where market reforms are assumed to be successful thereby lowering risk perception, a lower discount rate of 6% is assumed.

4.2.2 Technology specification in the models

The Indian MARKAL model used in this study for projections has around 280 present and future technologies represented in the model (refer Table 4.3). Demand technologies are identical to those in the AIM end-use sector model. Supply technologies fall under two categories: electricity generation technologies and oil refineries. There are 22 different types of electricity generating technologies (pulverised coal, gas turbine, large hydro, nuclear fission etc) and two refinery technologies representing different fuel mix and cost structure.

Table 4.3 Technology specification in the models

Sectors	Sub-Sectors	Technologies	Grades
Industrial	11	152	
Residential	2	46	
Agricultural	1	14	
Transport	8	25	
Commercial	1	9	
Power Sector	1	22	78
Oil Refinery	1	1	2
Total	25	280	

In a large country like India, the cost of a technology or fuel varies across regions due to natural causes like the quality of mines or wind regime, location specific factors like logistics costs, and economic conditions external to the model like the cost of capital or labor. These regional variations indicate an underlying non-linear cost distribution of technology and fuel combinations with respect to its national availability. This non-linear distribution is modeled using step-wise linear approximation, resulting in multiple grades of technologies/fuels, each grade representing different cost composition. This allows realistic competition among technologies and fuels. The future technological progress is assumed to consist of three factors: autonomous energy efficiency improvement (AEEI), improvements in present technologies and investments in new technologies. Bounds on penetration of demand technologies are set around the optimal technology mix trajectories obtained from the AIM/ENDUSE model (Pandey, 1998).

4.2.3 End-use Demand Projections

Indian economy is presently on a rapid development path, growth rates in the demands for most goods in the end-use sectors are high. These rates have further picked up in the post liberalization years. The experience of developed countries shows that these saturate in long run as an economy modernizes. Hence, logistic curve regression is used for projecting the end-use demands over long run. In order to ensure macroeconomic consistency, first the long-term projections for GDP are made. The GDP projections are then disaggregated into the Gross Value Added (GVA) contributions from Industry, Transport, Commercial, and Agriculture sectors. Logistic regression based on past data, government projections, industry reports and expert estimates are used at each stage. Intensities of final end-uses with respect to the sectoral GVA are projected in the similar manner. Finally, the projections of sectoral GVAs and end-use intensities are used to arrive at the end-use demand projections. Some important end use demand projections for the Indian scenarios are presented in Appendix 2.

4.2.4 Integcrated analysis using MARKAL Model

MARKAL is a multi-period, long-term model of the integrated energy system of a geographic or political entity, which encompasses the procurement as well as the transformation and the end-use of a good range of mix of energy forms (Manne and Wene, 1992). Various energy extraction, conversion, and consumption activities are quantified in the model through individual technologies that play a role in the energy system.

The model is dynamic and a technology is linked not only with other technologies through energy flows, but also with itself across successive time periods. Another important characteristic of MARKAL is that it is driven by a set of demands for energy services, e.g. passenger travel, household cooking, steel production etc.. MARKAL selects the technology mix (both supply and demand sectors) that minimizes the discounted cost of energy system, which includes capital and variable costs. This optimizing feature of the model ensures that MARKAL computes a partial economic equilibrium of the energy system, i.e. a set of quantities and prices of all energy forms and materials, such that supply equals demand at each time period (Loulou et al, 1997).

4.3 Future Projections

4.3.1 Aggregate Energy Consumption

There is a significant growth in energy consumption of more than 2.6 times in the IA1 scenario. Energy consumption increases from about 500 mtoe in 2000 to about 1300 mtoe in 2030. Energy consumption in the base case IA2 is close to 1100 mtoe. Energy consumption in the IB1 and IB2 scenarios are lower than in the base case scenarios. Consumption in the IB2 scenario increases by about 1.6 times and reaches about 800 mtoe by 2030 (figure 4.2). Figure 4.3 gives the percapita energy consumption across the three scenarios.

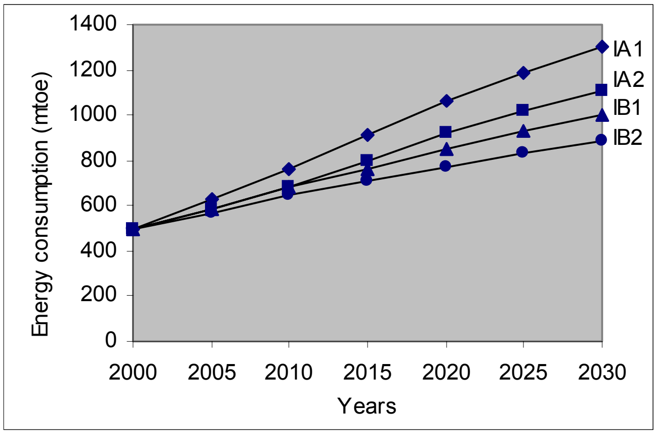

Figure 4.2 Energy consumption across scenarios

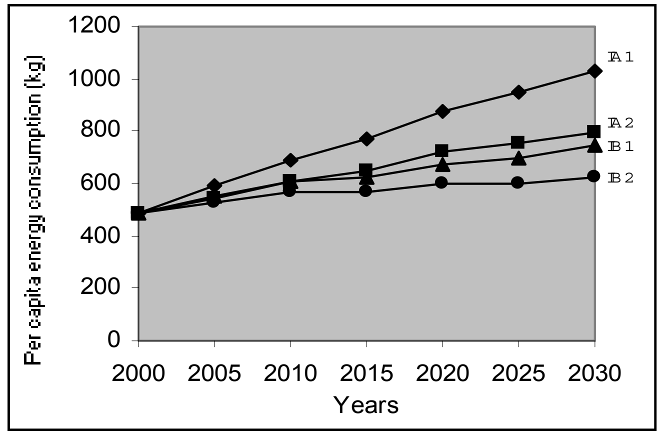

Figure 4.3 Per capita energy consumption

4.3.2 Projections for consumption of Coal, Gas, Oil, Renewable Energy

Despite higher economic growth rates in IB1 as compared to IA2 scenario, coal grows slowly in IB1 due to adoption of sustainable development policies in which coal is gradually replaced by non-polluting or less polluting fuels. Coal continues to dominate the energy mix and shows growth rates between 2.3 times to three times in the 30-year period (figure 4.4). Natural gas shows tremendous growth of more than four times even in the low growth scenario IB2. Gas also shows remarkable higher growth in sustainable development IB1 scenario because of growing infrastructure and improvement in cost economics of natural gas as a fuel (figure 4.5).

Oil consumption increase ranges between 2.7 to 3.6 across the scenarios for the 30-year period (figure 4.6). Renewable power increases by about 15 times in IB1 scenario due to greater emphasis and investments in renewable energy infrastructure as part of sustainable development policies (figure 4.7).

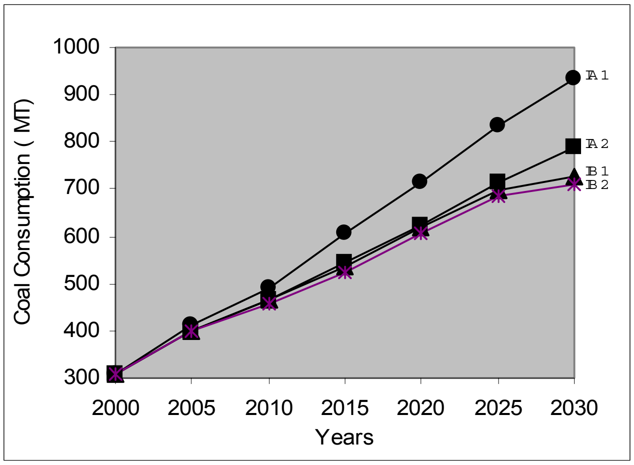

Figure 4.4 Growth in coal consumption

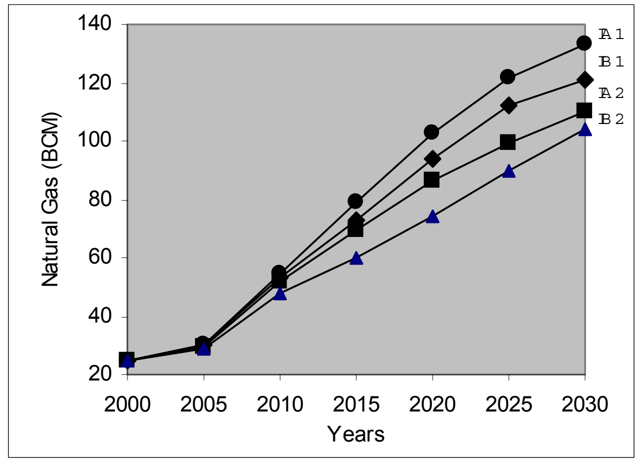

Figure 4.5 Growth in gas consumption

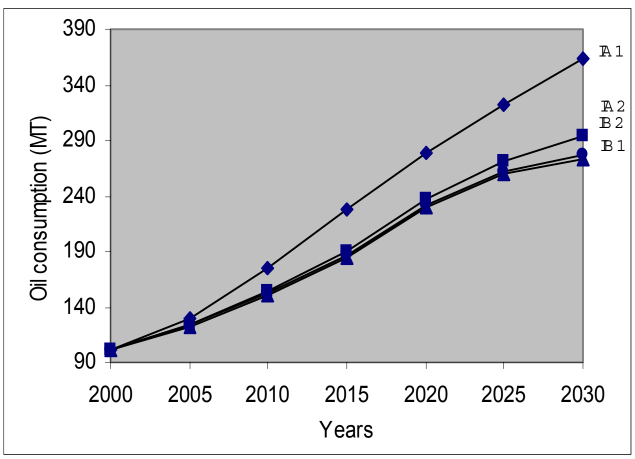

Figure 4.6 Growth in oil consumption

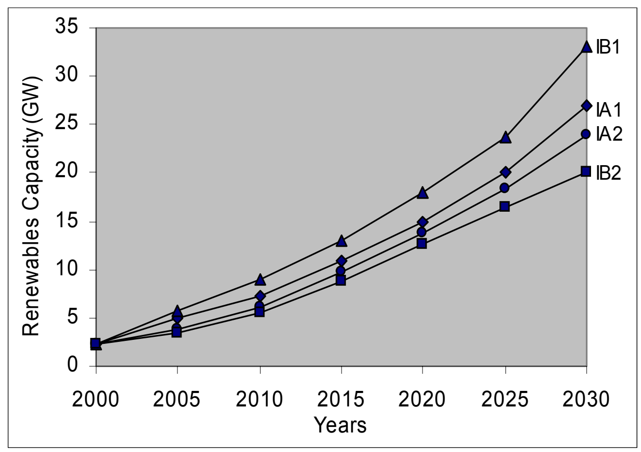

Figure 4.7 Growth in renewable capacity

4.3.3 Total Electricity capacity and generation

The increase in required electric generation capacity in the year 2030 over year 2000 capacity ranges between 2.5 to 3.7 times across the four scenarios (figure 4.8). The installed capacity in 2000 was about 97 GW and an increase of 2.5 times means that even in the low growth IB2 scenario, India will have to add upto 5000 MW per annum in order to satisfy the growing power demand. The electricity production projections indicate growth range of 2.2 to 3.5 times which is relatively lesser than the capacity installation growth rates (figure 4.9). This anomaly is caused by combined effect of demand patterns, cost of production, load distribution and plant load factor.

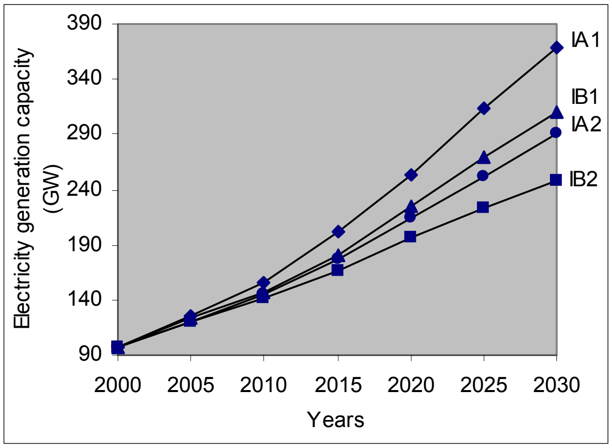

Figure 4.8 Growth in generation capacity

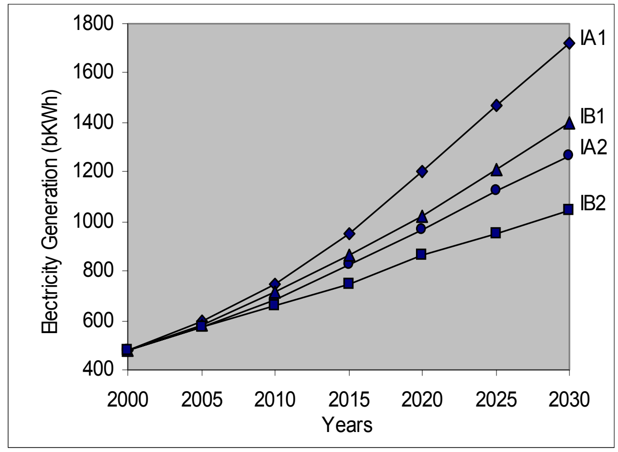

Figure 4.9 Growth in electricity generation

4.3.4 Aggregate and per capita carbon emissions (MT)

The carbon emissions grow from 261 MT in 2000 to 841 MT by 2030 in the IA1 scenario. The least emissions are in the IB1 scenario ie about 560 MT (figure 4.10). This is due to adoption of sustainable development policies.

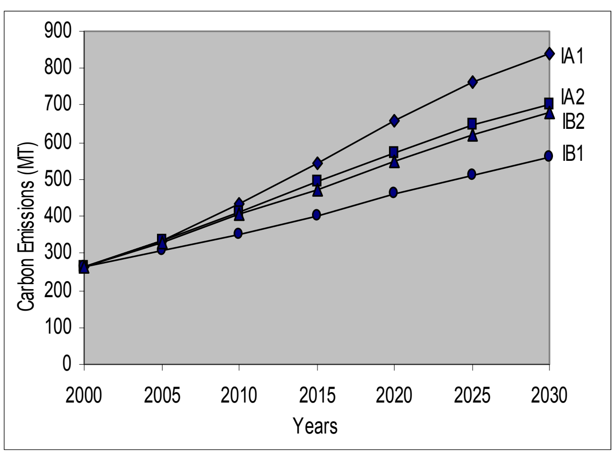

Figure 4.10 Growth in carbon emissions

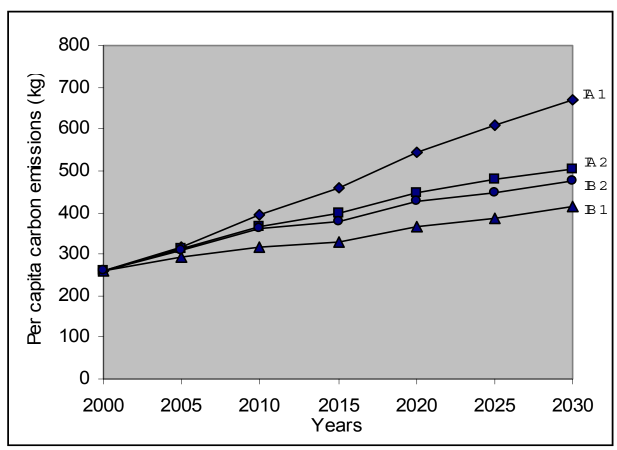

Figure 4.11 Growth in per capita carbon emissions

The per capita carbon emissions show an increasing trend with IB1 (figure 4.11) recording the least increase due combined effects of lower emissions and medium population growth.

4.4 Conclusion

This study builds upon the scenarios built for the socio-economic future of India (discussed in an earlier chapter) for the 30 years period from 2000 to 2030. The scenario assumptions reported in the earlier Indian scenario study have been used in an integrated energy emissions modeling framework to arrive at certain projection for emissions. These projections help in emission impact studies and policy formulations in the socio-economic and environmental areas. Towards this purpose, this study is an initial work that draws from the IPCC SRES and projection methodologies and thus requires further development and validation against actual developments over the currency of its duration in India.

This study should help identify broad economic directions that India should pursue in the long term. Any such long-term decision has a bearing on the present pattern of economic investments on technologies and infrastructure. With the present socio-economic conditions in India, the country can ill afford wastage of resources in long term unproductive investments, and hence the importance of such scenario based studies.

Appendix 1: Characteristics of models used in Integrated Modeling Framework

Model	Objective	Output	Policy Analysis
Bottom-Up Models			
End-Use Demand Projection	Demand Projections consistent with macroeconomic scenario	End-use Sector Demand Trajectory	Sectoral investment, technology and infrastructure policies
AIM/ENDUSE	Minimize discounted sectoral cost	Sectoral energy, and technology mix, investments and emissions	Sectoral technology, energy, investment and emissions control policies
MARKAL	Minimize discounted Energy system cost	National energy and technology mix, energy system investments, and emissions	Energy sector policies like energy taxes and subsidies; energy efficiency; emissions taxes and targets
Stochastic-MARKAL	Minimize expected value of discounted system cost	Energy and technology mix under uncertain future, Value of information	Hedging strategies for energy system investments; identify information needs
Top-Down Models			
SGM	Determine market clearing prices for economic sector outputs	GDP and consumption trajectories;, prices of sectoral outputs and energy; sectoral investment patterns	Macro-economic impacts of policy interventions such as energy tax / subsidies; emissions limitations
ERB	Determine Global / Regional Energy Prices and Energy Use	Long-term global and regional energy prices, energy mix and emissions	Implications of very long-term global energy resource, tech. expectations
Other Models			
Inventory Estimation Model	Estimate national emission inventory for various gases	National emission inventory	Regional and sectoral emission variability, bench-marking, emission hot-spot assessment
GIS Based Energy and Emission Model	Determine regional spread of energy and emissions	Regional maps	Linking energy and environment policies across time and space
Power Sector LP Model	Minimize discounted Power sector cost	Power plant capacity and generation mix, emissions profile, total costs	Power sector technology, energy, investment, emissions control policies
Health Impact Model	Estimate local pollutant emission impacts on human health	Impact of individual plants, per capita and total national human health impacts, sensitivity analysis	Plant location and stack height policies, emission norm analysis, enforcement policy assessment

Appendix 2: Sectoral Demand Projections Charts for the four Indian Scenarios