NATCOM Emission scenarios and Carbon Emissions projections for India

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Abstract

Scenarios are alternative images of future and are useful tools for learning about complex environmental systems behaviour. The objective of this study is to generate future socio-economic cum emissions scenarios and projections for carbon emissions in each scenario for the time period up to 2030. There are not many studies available in India on scenario construction though different government organisations have developed scenarios for short-term to long-term future to aid policymaking. This study generates four scenarios of the future state of Indian economy in the next 30 years as combinations of market integration of economy and centralized v/s decentralized nature of governance. The scenarios capture the essence of the internationally accepted UN IPCC SRES future scenarios. and are termed as IA1, IA2, IB1 and IB2. The key driving forces are economic growth, population, emphasis on heterogeneity and self-reliance in regions, speed of introduction of new and efficient technologies, extent of cultural and social interactions. While the scenarios are being developed for the emission projections at the national-level, these could also be extended to include local energy-environment concerns. Storylines of the four scenarios differ in how demographic structure changes with socio-economic conditions, how does technological developments and market integration with global economy drive the economic growth, how decentralized economic development activities evolve, how protection of local and regional environments is implemented etc.. The scenario characteristics have been quantified into parameters like fuel supply and price, technology cost, efficiency parameters, transmission and distribution losses, Investment capacity, Technology choices, discount rate which have then been analysed in an integrated energy-emissions modelling framework using the MARKAL and AIM-Enduse, and demand projection models. The results of modelling analysis show that energy consumption grows more than 1.6 to 2.6 times and the carbon emissions grow by 2.1 to 3.2 times across the four scenarios. Coal in power sector continues to dominate the Indian energy as well as carbon emissions sector. The per capita carbon emissions show an increasing trend dampened only by a simultaneous rise in population.

Key words: Scenarios, Key driving forces, Energy-Environment modeling, Future emissions: Carbon

Introduction

Scenarios are useful tools for scientific assessments, for learning about complex systems behaviour and for policy making. Each scenario is one alternative image of how the future can unfold; they are neither predictions nor forecasts. Scenarios need to describe the relationships between important drivers of resource availability, productivity and technological change. They are based on internally consistent and reproducible set of assumptions about the key relationships and driving forces of change, which are derived from an understanding of both history and current situation.

Studies on future emissions scenarios are necessary to support study of potential anthropogenic impacts on the climate system, to serve as the basis for further analysis, as well as estimating the consequences of an event and defining better strategies for adaptation. They provide inputs to climate models and also assist in assessing the relative importance of greenhouse gases in changing atmospheric composition and hence climate. Scenarios also have an important role to play as baselines for comparison with stabilisation scenarios in order to calculate the required mitigation effort. They have been useful for a multitude of purposes by governments, industry, and social organizations.

We strive here to construct alternate socio-economic scenarios for India and identify key drivers for these scenarios for the time period up to 2030. The scenarios would capture the current global understanding on future scenarios as represented in the Intergovernmental Panel on Climate Change

(IPCC) Special Report on Emission Scenarios (SRES). Each scenario storyline is a description of possible future development of a combination of key scenario characteristics explaining the state of economic, technical, social and policy development.

Emission scenario construction efforts in India

Long term modelling of energy emissions in India is a recent phenomenon. Shukla and Rana, while using the Edmonds-Reilly-Barnes model (ERB) model in 1998, worked with one reference scenario and a few mitigation scenarios wherein imposition of carbon taxes at various levels were varied and its impact on future carbon emission was studied. The PEW Center on Global Climate Change has developed six scenarios in its study of the electric power sector of India (Chandler et al, 1999). Another set of scenarios analysed in one of the emissions studies using the Asia-Pacific Integrated (AIM) Enduse and Market Allocation (MARKAL) model (Garg et al., 2003) are the economic growth scenarios (high and low), environmental scenarios (Climate Change Policy, Sulfur Control Policy and Clean Air Policy), some sensitivity scenarios (Gas price and Discount rate) and some specific sectoral switch policy scenarios (road versus rail and metals versus plastics).

The environmental scenarios represent conscious policy interventions linking environment and energy sectors. Another study (Ghosh, 2000) explores the implications of specific intervention scenarios on the long-term technology strategy for power sector and related carbon emissions. The scenarios considered are local and global environmental interventions, demand side management for electricity and grid integration & regional co-operation.

Different ministries in India have also developed scenarios for future, which have been used in policymaking, both short-term and long-term policies. For instance,

- A Group constituted by the Government of India for the India Hydrocarbon Vision- 2025 developed different scenarios for the demand and supply projections of petroleum products. These scenarios are based on assumptions of GDP growth rates.
- The Planning Commission adopts alternative growth scenarios while formulating its plans. For instance, in the Approach Paper to the Tenth Five Year Plan, the commission has considered two alternative growth paths - the base scenario achieving 6.5% growth in GDP during the plan period and the target scenario achieving 8% growth (PC, 2001).
- Technology Information Forecasting & Assessment Council (TIFAC) of Government of India is putting efforts in delivering a Technology Vision for India for 2020 to provide directions for national initiatives in Science & Technology, make a policy framework for investment as well as development of an integrated science and technology policy both at the state(s) and national levels. Seventeen sectors have been identified for Technology Vision 2020 under the broad categories of Technologies with socio-economic implications, Major infrastructures and advanced technologies.
- The Ministry of Power, in its 16th Electric Power Survey, has provided forecasts of power requirements in India till 2004-05.
- The Ministry of Railways is deliberating on a pipeline project named "Railways vision for 2050"
- The National Highways plan is working in the direction of the need of 10,000 km long Expressway network by the year 2015. A broad assessment of investment requirement for the development and expansion of the main road network in India has been done till 2005-6.
- The Mashelkar Committee, in its report on the Auto Fuel Policy (GOI 2002) has developed a roadmap, which extends to 2010, for the implementation of proposed emission norms for new vehicles.
- Nuclear Power Corporation Ltd. (NPCIL), a public sector company which owns, constructs and operates nuclear power plants in India is spearheading the nuclear power programme in India plans to put up a total installed nuclear power capacity of 20,000 MWe by the year 2020.
- At a localized level, the Ministry of Environment and Forests and the Government of the National Capital Territory of Delhi (Planning Department) have brought out a report on "Delhi 2021", which presents a course of action to be taken to make Delhi environmentally sustainable by 2021 (Delhi 2021).

Although, these studies have not been used for emission projections, they provide useful information on some key driving forces useful for the present study.

Scenario construction methodology

The methodology chosen for the development of Indian scenarios and analysis draws mainly from the IPCC SRES methodology. The IPCC SRES scenarios explain the world economy and emissions in two dimensions viz. relative orientation toward economic or environmental concerns and global and regional development patterns. The key driving forces are economic growth, population, emphasis on heterogeneity and self-reliance in regions, speed of introduction of new and efficient technologies, extent of cultural and social interactions. This study aims to report future emission scenarios as reflected by following integrated energy and environmental policies, technological response strategies and implementation measures in India. The Indian case is discussed under following heads:

- Developing a storyline, which is a narration of the scenario characteristics and describe developments in the economic, technical, environmental and social dimensions
- Analyzing key drivers which might push India along different development paths

While the scenarios are being developed for the emission projections at the national-level, these could also be extended to include local energy-environment concerns.

India, a developing country, is committed to economic reforms and the process is underway as the economy moves closer to integration with the world economy. It has signed the World Trade Organisation (WTO) agreement and is committed to all the clauses and speed up the opening up of economy. Foreign exchange reserves are shoring up and there is a steady flow of Foreign Direct Investment in the economy. The tariff barriers are coming down. On the demand side, the continuously high growth rate of around 5-6 percent in the last decade has created wealth and higher per capita incomes. The population growth rate has slowed down in the latest census but is still more than 1% per year and coupled with higher economic activity is resulting into higher demand for goods and services. The high-energy intensity converts this general demand into higher energy demand and hence the pressure on the environmental front. Meanwhile political developments have led to creation of smaller states. These newly formed states are demanding their pie of development and given the wide inter-regional disparities, it is an important factor to reckon with.

Keeping in mind the socio-economic conditions as indicated above, the future state of Indian economy in the next 30 years can broadly visualized under four scenarios proposed as combinations of market integration (extent of liberalization, globalisation and integration with the world markets) and nature of governance (centralization v/s decentralization) to depict the future Indian economy in the period from 2000-2030. The market integration can be high on globalisation and fragmented to make it more inward looking. Governance could be centralised or with more emphasis on decentralised development. The scenarios are termed as IA1, IA2, IB1 and IB2.

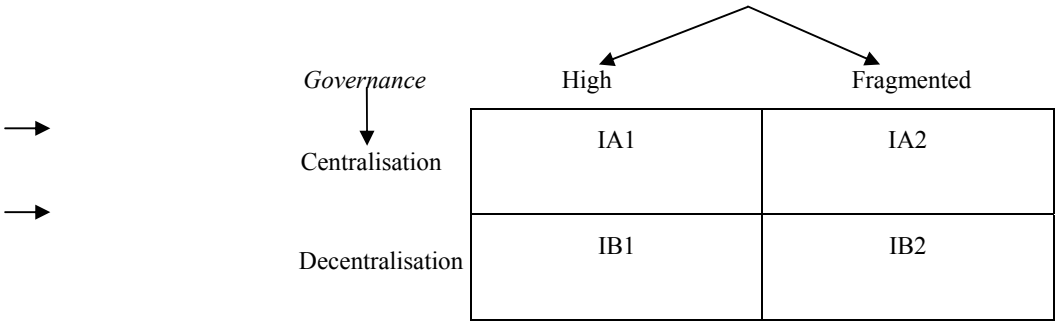

Figure 1: Matrix of scenarios

The four scenarios can be best understood as taking a position in a combination of locus points on the two continuums; extent of market integration and nature of governance. There would be several other scenarios, which are also likely but not talked about here, and only the most likely representative sets are visualized here. Amongst these four, IA2 scenario reflects close to how the Indian socio-economy would evolve if the present policies were followed in future.

The key forces driving each of the scenarios would be economic growth, population growth, vision of various energy and infrastructure industries for technical change, speed of globalization, emphasis on decentralized and distributed development, sustainable development pressure. No climate change mitigation policy is assumed in these scenarios. They specifically exclude the effect of new policies that may be adopted in order to meet the commitments given under Kyoto Protocol. The ensuing section will detail the scenario descriptions and describe the key driving forces.

NATCOM emission Scenarios

Scenario Storylines

Scenarios are important to develop a clearer understanding of the interplay between the driving forces within each and across alternative scenarios. The basic idea of the scenarios (refer Figure 2) has been borrowed from SRES 2000 (Nakicenovic et al 2000), with changes suiting to the specific socio-economic environment of India.

Creation of multiple scenarios serves the primary purpose of exploring the uncertainties behind potential trends in political, economic and social and technological developments and the related environmental developments particularly GHG emissions in India. Such trends will be associated and influenced by the happenings in the related areas at global levels. The individual scenario storylines will help the policy makers and scientists think more coherently about the complex interplay between scenario driving forces within and across alternative scenarios and to enhance the consistency in assumptions for different parameters. A narrative description or in other words, the storyline behind such scenarios makes it all the more easy to explain it to various user communities like policy makers, researchers, and environmentalists.

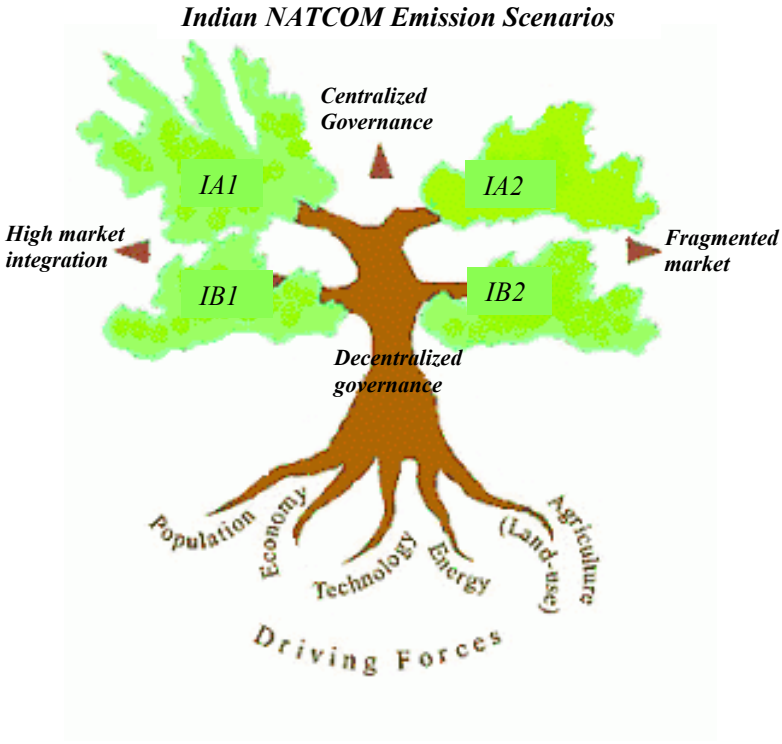

Figure 2: Indian emission scenario families

The four scenario families presented in this study are representatives of a broad range of possibilities of combinations of key drivers on the continuum of extent of market integration and the levels of decentralization in governance. The storyline of each scenario has been developed on the basis of the general knowledge of the scenario literature and on the basis of viewpoints of experts based on their

personal experiences. The description of storylines is qualitative as it covers a wide range of possibilities and can hold true within a range of values assigned to depict the effect of the driving forces. They include type of governance, political, social and economic and technological conditions.

The storylines differ in how demographic structure changes with socio-economic conditions, how does technological developments and market integration with global economy drive the economic growth, how decentralized economic development activities evolve, how protection of local and regional environments is implemented etc. Most of such dynamic forces often cannot be defined in strictly quantitative terms. They, however, participate in complex "cause–effect" relationships with quantitative emission drivers (e.g., economic activities and growth, population levels, energy consumption). The qualitative description of scenarios gives credibility to the scenarios, which could be amenable to some suitable numeric combination of quantitative parameters.

There is always a danger of little differentiation in the scenarios but each storyline has been so articulated such that they take a different direction of future developments so that they differ in an increasingly irreversible way over a longer period of time. The main characteristics of future developments that take distinct development paths in the four storylines are:

- Extent to which economic liberalization, globalization and increased economic interactions continue over the next three decades.
- Rates of National and State-level economic developments and trade patterns in relation to the other characteristics of the storyline.
- Nature of the National and regional level demographic developments in relation to other characteristics of the storyline.
- Rates and direction of global and Indian technological change, especially in relation to the economic development prospects.
- Extent to which national and local environmental concerns shape the direction of future development and environmental controls.
- Balance of economic, social, technological, or environmental objectives in the choices made by consumers, governments, enterprises, and other stakeholders.

The IA2 scenario for future emission projections captures continuation of present government policies, and forecasts of various macro-economic, demographic and energy sector indicators. It provides a platform for analyzing the emission mitigation implications of alternate policy paradigms reflected in the other scenarios. The three other alternate policy scenarios analysed here are possible variable combinations on the continuum of extent of market integration and nature of governance and are referred to as IA1, IB1 and IB2 scenarios (Figure 1). The storyline behind each of these scenarios follows:

IA1 Scenario

This scenario follows policies in the direction of high globalisation and high economic growth. It assumes 9% average annual GDP growth rate over 2000-2030. This is in line with the Planning Commission's Vision 2020 unveiled in January 2003 (Planning Commission, 2003). The vision to increase the per capita incomes by 4 times over 20 years from 2000 till 2020 means a more than 9% growth rate (including 8% plan and more than 1% population growth) for 20 years which may continue for another 10 years till 2030, if the impetus is strong. China as a big country is already experiencing a good run of 10% plus growth rates for a long time now.

Technological progress is expected to be faster due to rising incomes owing to high economic growth and more transfer and sharing of information and material in an era of liberalized trade markets. The improved infrastructure facilitated by a proactive role of the government as a facilitator would spur economic growth and scientific temper. The rising income levels due to high growth would ensure that there is a demand for further investment opportunities and growth in the technical and economic infrastructures. There is greater and easier access to global knowledge, technology and capital. There is increased macro-economic structural shift away from agriculture sector towards knowledge based industries, commercial and services sectors which provide growth impetus to the economy.

An important assumption in this scenario is the continuing government support for accelerated socio-economic reforms especially in the ongoing market reforms in the energy sector compared to

expectations in the baseline scenario. In the context of economic globalisation and liberalization, accelerated market reforms would spur improvements in technological efficiencies. Reforms would lower the investment risks and reforms commitment would reduce country risks thereby stimulating increased levels of foreign direct investment.

Higher growth would necessarily depend on speed of globalisation. Increased trade and liberalization would lead to higher trade based incomes and better investment flows, foreign and local both, would further lead to filling the investment gap. Free Convertibility of currency will help higher globalisation. Regional business blocks like European Union and ASEAN provide opportunities for further trade on good foreign relations. Increased trade and business investment would also accrue given the successful realization of SAARC goals. The world would realize the importance of economics and peace and increased peace would benefit trade. Higher economic globalisation would lead to higher growth in participating countries. Good neighbour relations lead to stability and increased favourable environment for business, trade and investment.

Higher growth would lead to that would facilitate business and help further growth. Increased business and trade would further spur higher demand for the infrastructure services thus creating necessary impetus for more investment in infrastructure services. Higher transportation service demand would lead to a growth in all the allied sectors of airports, ports, railway lines and roadways development and the vehicle manufacturers. Successful reforms would bring about efficiency improvements through private participation and efficient management practices. Regulation that places an incentive on efficiency such as price cap regulation and tariff reforms that make electricity markets profitable and attractive for investment would increase efficiency improvements.

Globalisation and integration with market economy would lead to higher economic opportunities and exposure to western culture, which is also associated with development. This would lead to a tendency to keep families of shorter size. High centralization in governance would lead to stricter and uniform implementation of family planning and population control policies. This would lead to more population control and simultaneous with high economic growth, would lead to higher levels of urbanization and more opportunities in rural areas with shifting of work-force. This would lead to a population growth in a low growth range and eventually stabilize before 2030. More resources would lead to higher commitment of funds to education and health infrastructure.

Energy and mineral resources are abundant in this scenario because of rapid technical progress, which both reduces the resources needed to produce a given level of output and increases the economically recoverable reserves. Final energy intensity decreases over time. The development of energy sources and conversion technologies would follow a more carbon-intensive energy path consistent with the current development strategy with abundant domestic coal resources giving way in the longer run to oil and natural-gas resources. Environmental amenities are valued and rapid technological progress “frees” natural resources currently devoted to provision of human needs for other purposes. The concept of environmental quality changes in this storyline from the current emphasis on “conservation” of nature to active “management” of natural and environmental services.

IA2 Scenario

This scenario is reflective of the continuance of the present Government policies. The growth rate assumed for this period are between 5% to 6% per annum from 2000 to 2030. This growth rate assumption is based on the actual experiences with the way Indian economy has been performing in the last two decades.

Comparing with SRES, the SRES-A2 scenario family represents a differentiated world compared to the A1 storyline. On similar lines, IA2 scenario is characterized by lower trade flows and relatively slower technological change. It depicts a case of low globalisation and liberalization restrained by the democratic political forces in the country. Political disturbances would lead to more regionalism and hence would put pressure against globalisation. The problems of mass unemployment with inadequate job opportunities coupled with the unpredictable business environment and policies, restrain wholesale globalisation and interplay of market forces. Self-reliance in terms of resources and less emphasis on economic, social, and cultural interactions between countries are characteristic for this future. Economic growth is uneven and the income gaps keep rising even in relation with the newly industrializing countries.

Decreased international trade and investment flows slow down the technology diffusion process. Technological change is also more heterogeneous as it is expected to be more rapid than average in

some regions and slower in others, as industry adjusts to local resource endowments, culture, and education levels. In the absence of significant imports and technology availability, areas poor in resource innovate to improve resource efficiency and make use of substitute inputs. Other endowed regions with abundant energy and mineral resources evolve more resource-intensive industry, which also places a high priority on minimizing import dependence through technological innovation.

With economic development, the share of commercial energy increases, partly due to a switch from traditional energy to commercial energy, and partly due to a change in the composition of GDP towards more energy-intensive output and an increase in the availability of commercial energy. There is a strong preference for commercial energy because it is more convenient to use, it has higher efficiency than traditional energy and its availability is increasing, whereas the supply of traditional energy is limited. In this stage, commercial energy intensity increases with growth in GDP and per capita income levels.

With the emphasis on family and community life in absence of major international influences, fertility rates decline relatively slowly and despite centralized family planning programme, the population is on the higher side. The population may cross 1.4 billion by 2030. The environmental concerns are relatively weak.

IB1 Scenario

High level of environmental and social consciousness exists in this scenario which emphasizes on sustainable development policies. There is an increased emphasis on environment damage prevention and long-term sustainability of socio-economic developmental actions on the part of government, businesses, media, and the public. Heightened environmental consciousness shows itself in the positive impacts on natural resource use, such as deforestation, soil depletion, over-fishing, and global and regional pollution, which pose a serious threat to the continuation of human life on Earth. Technological change plays an important role.

Economic development in IB1 is balanced, and efforts to achieve equitable income distribution are effective. As in IA1, the IB1 storyline describes a more globalised and integrated Indian economy with trade and investment flows aiding economic growth. In some sense, but the priorities differ wherein the IA1 scenario invests its gains from increased productivity and know-how primarily in further economic growth, the IB1 scenario invests a large part of its gains in improved efficiency of resource use, equity, social institutions, and environmental protection.

Efficiency improvement measures, low and carbon free technologies and cleaner fuels will penetrate faster and infrastructure to facilitate these has to be built. This will drive the carbon emissions below the IA2 scenario. Technological progress is accelerated, both in terms of autonomous efficiency improvements of existing technologies and earlier and higher penetration of advanced clean technologies as compared to IA2 scenario. Incentive systems, combined with advances in R&D and field institutions, permit the rapid diffusion of cleaner technology. The R&D efforts in the direction of education and capacity building for clean and equitable development will be enhanced. Organizational measures are adopted to reduce material wastage by maximizing reuse and recycling. The combination of technical and organizational change yields high levels of material and energy saving, as well as reductions in pollution. Labour productivity also improves as a by-product of these efforts.

This scenario assumes more emphasis on development of renewable technologies as conventional cleaner oil and gas resources decline. Since we are not considering any specific policy interventions, the impetus for deployment of cleaner technologies comes from increased international trade and technology and financial investments in clean technologies. Under an enabling international environmental consciousness, there would be increased R&D investments, both from abroad as well as at local level, in renewable energy technologies that facilitate cost reductions through scale economies, increases the commercialisation possibilities of these technologies and leads to their higher penetration. There will be extensive use of conventional and unconventional gas as the cleanest fossil resource during the intervening period but there will be a continued push toward post-fossil technologies, driven in large part by environmental concerns.

Social and environmental concerns guide the next 30 year's Indian demographic transition in this scenario. Mortality and fertility rates would be lower and akin to the IA1 scenario leading to medium to low level population growth. The high to medium economic growth with higher market integration would lead to higher incomes and reduced income inequality. This would be a scenario visible today in the state of Kerala where higher incomes and social infrastructure has led to stabilization of population

and sex ratio. We visualize Kerala's policies to be replicated to a large extent in most states. In some northern states like Bihar, Orissa, U.P., M.P. and Rajasthan, replication of Kerala would take a higher time because of persistent economic backwardness and traditional social structure.

Services rather than on material goods would command a higher proportion of this income in this scenario because the emphasis on material goods is less and also resource prices are increased by environmental taxation to ensure sustainability. SRES describes such a scenario as one in which community values triumph over individualist ones and lead to resource-friendly lifestyles based on clean and light technologies. This scenario includes a voluntary embrace of cohesion, cooperation, and reduced consumption, backed by government legislation and even corporate policies (Wilkerson, 1995). The "Ecologically Driven" scenarios by IIASA–WEC with accelerated efficiency improvements in resource use, share several of the characteristics of this scenario in India.

IB2 Scenario

This is a 'low growth scenario' with increased decentralization in governance and insulation of economy, with higher emphasis on localization of resources and decentralized resource-sharing and economic development. This signifies a trend toward local self-reliance and stronger regional influences on national development priorities. A perceptible shift toward state and region level decision-making structures and institutions is there. This would lead to generally low levels of economic and productivity growth rates resulting in lower per capita incomes. The macro-economic structural shift away from agriculture is also slower than the IA2 case. There are slower improvements in autonomous energy efficiency of supply and end-use technologies. Transfer and penetration of new technologies is also slow.

Local level environmental concerns reign over the national and global environmental concerns. The governments have difficulty designing and implementing policies that combine national priorities of economic development and environmental protection, at the global level even when they could be associated with local economic benefits. Political disturbances could lead to more fissiparous tendencies and in turn to more regionalism and less globalisation. Some regions/states with higher economic development but limited natural resources, place particular emphasis on technology development at local levels. Technical innovation and change is therefore uneven and more heterogeneous. R&D investments show a declining trend and hence there is a predominance of conventional energy technology use for development.

Despite lower growth and incomes, local inequity is reduced through the development of stronger community-support networks. There could be development of strong regional markets with intra-regional and intra-state trade. The rate of urbanization is slow and agriculture retains its important status in the economy. Land-use management becomes better integrated at the local level. Energy systems also differ from state to state and across regions, depending on the availability of natural resources. The need to use energy and other resources more efficiently spurs the development of less carbon-intensive technology in some regions. Environment policy initiatives at local levels leads to success in the management of some local emission problems like acidification caused by sulfur dioxide (SO_2) and lower emissions of nitrogen oxides (NO_x) and volatile organic compounds (VOCs). This scenario assumes policies that are more inward looking, and emphasis is more on traditional values. Hence, there is no propensity to follow family planning policies and the population growth is on the higher side.

Quantification of Scenarios

The scenarios and their respective storylines would characterize the basic features of the socio-economic, technological and environmental developments in the future. They next have to be quantified in terms of parameters, which could be used as inputs for modelling exercises. The key driving forces for each of the four scenarios are quantified in terms of modelling parameters (Table 1).

Table 1: Scenarios, Key Drivers and Impact on Model Parameters

Scenario	Key Drivers	Implications on critical parameters of the scenarios and modeling analysis
IA1	Competition and private participation, Access to global finance and technology, technology R&D, transfer and capacity building Reduced risk perception	Fuel price (↑), technology cost (↓), efficiency (↑), Transmission and Distribution losses (↓), Investment capacity (↑), Technology choices (↑), Discount rate (↓), Earlier penetration of advanced technologies
IA2	GDP growth, Energy efficiency, Non-fossil fuels vs. fossil fuels, Oil consumption, Technological change, Movement on the fuel ladder	Sectoral demands (↑↓), investment limits (↑↓), fuel supply (↑↓), Range of Fossil fuel prices (↑↓), Relative fossil fuel price adjustments, Efficiencies of technologies using oil and gas
IB1	Strong environmental awareness and conservationist values, Environmental integrity, consumption changes, dematerialization, cooperation, Shift away from fossil fuels, Local capacity building, Rural energy and electricity development	Environmental constraints (↑), energy and materials content of goods/ services (↓), electricity consumption due to efficiency improvements (↓), Transmission and Distribution losses (↓), Penetration of clean and renewable technologies (↑), Fossil fuel prices (↑)
IB2	GDP growth, population, Local emissions, Productivity, Importance of Agriculture, Resource intensity, Self-reliance	Population growth (↑), Sectoral demand (↑↓), Investments (↓), Penetration of clean and renewable technologies (↑↓), Agriculture share high, Local resource intensive economy

The projections for GDP growth rates and population are provided in Figures 3 & 4.

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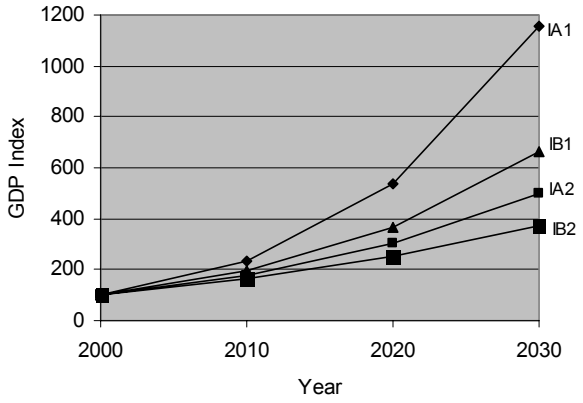


Figure 3: GDP projections for India

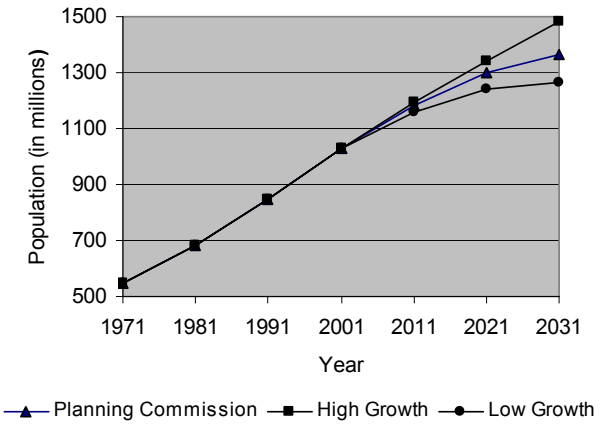


Figure 4: Population Projections for India

It would be necessary to qualify that it is very difficult to objectively assess the probability of a scenario's likelihood to exist in the future, although some of them would be more likely than others. The scenarios for India have been developed after extensive consultation with experts over possible socio-economic futures. Studies on future emissions scenarios face a hazard in terms of the validity of the assumptions about the socio-economic and political environment guiding the scenario at a future date. Each expert's understanding about the assumptions differ and hence it is all the more necessary to be careful in detailing coherent assumptions.

Carbon Emission Projections

Scenario based projections help identify alternate development paths that is crucial for policy analysis and formulation. It provides much more clarity to development planning in developing countries featuring socio-economies with limited resources and demands for the same from competing sources. 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.

In this section we attempt to project future Indian GHG emissions using appropriate models for the four Indian scenarios described earlier viz. IA2, IA1, IB1 and IB2 scenarios. An integrated bottom up modeling with ANSWER MARKAL described in here would generate results for the scenarios analysis that would essentially generate information required for policy analysis. The analysis presented covers the period 2000-2030 in steps of five years.

Methodology

We use an integrated modeling framework which helps to take advantages of different modeling paradigms. The framework for energy and emissions future analysis here uses 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, soft linked to each other through which the scenario specifications across the models are harmonized. The soft-linked framework allows a very detailed assessment of specific sectoral policies. At the same time, it also allows integration within the energy system forming a part of the overall economy, thus mirroring reality. While the soft linkage 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.

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 framework used in this paper integrates five individual models:

i) MARKAL - an energy systems optimization model (Berger et al, 1987, Fishbone and Abilock, 1981, Shukla, 1996). It 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).

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.

Model inputs

MARKAL model requires specification of various parameters including;

- GDP projections and structural composition of the economy.
- End-use demands across sectors and various demand sub-categories in residential, commercial, industrial, transport and agricultural sectors.
- Technology and fuel representation is fairly detailed for the above sectors. Non-linearity in cost is captured by multiple technology and fuel grade specification in the model.
- Emission coefficients for various fuels and technologies.

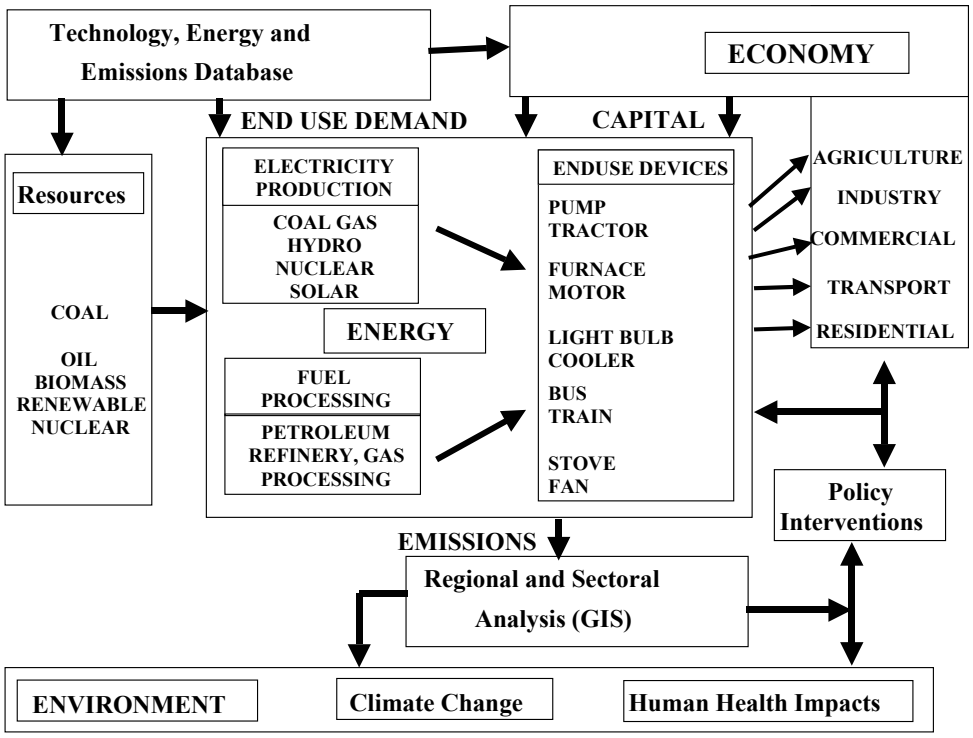


Figure 5: Future carbon emission projection framework

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. 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. 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 below in Figure 6.

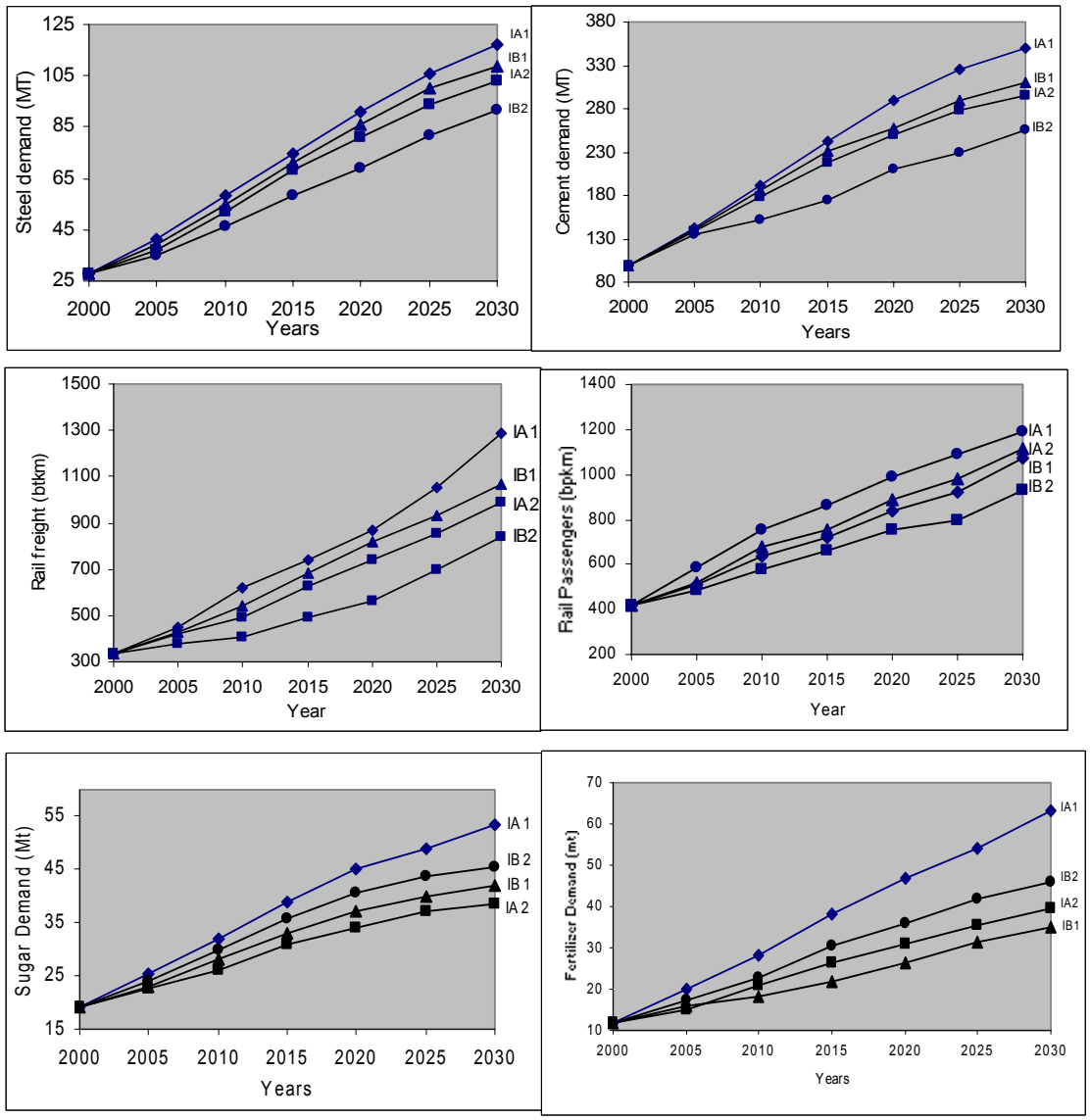


Figure 6: Sectoral Demand Projections Charts for the four Indian Scenarios

Future projections under various scenarios

Aggregate and per capita 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 7). Figure 8 gives the percapita energy consumption across the three scenarios.

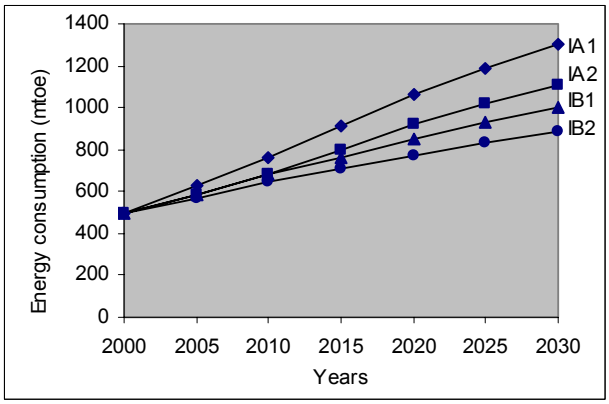


Figure 7: Energy consumption across scenarios

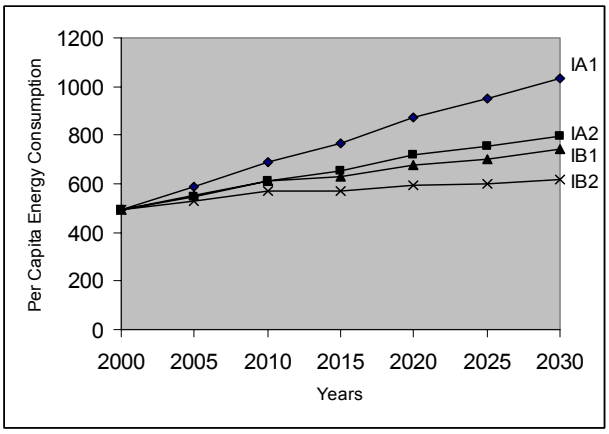
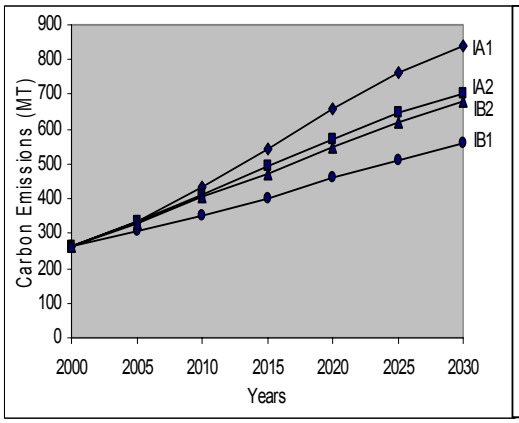


Figure 8: Per capita energy consumption

Aggregate and per capita carbon emissions

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 carbon emissions grow from 261 million tons (MT) in 2000 to 841 MT by 2030 in the IA1 scenario. The least emissions are in the IB1 scenario i.e. about 560 MT (Figure 9). This is due to adoption of sustainable development policies. The per capita carbon emissions show an increasing trend with IB1 (Figure 10) recording the least increase due combined effects of lower emissions and medium population growth.



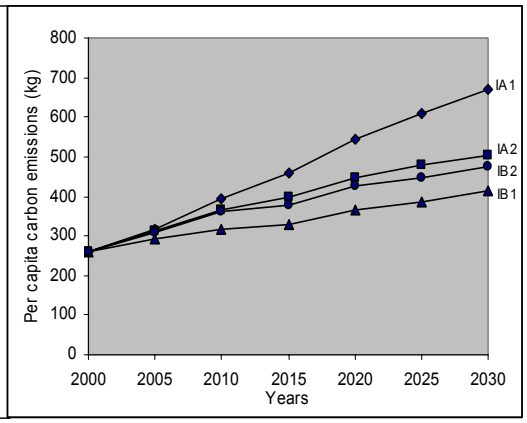


Figure 9: Growth in carbon emissions

Figure 10: Growth in per capita carbon emissions

While the carbon emissions in the IA2 case increases by around 2.7 times over the 30 year period from 2000-2030, the per capita carbon emissions increase modestly by around two times only over the same time period. 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.

Conclusion

We have presented the NATCOM emission scenarios for the 30 years period from 2000 to 2030 in this study. These scenarios have been used in an integrated energy emissions modeling framework to arrive at carbon emission projections. Towards this purpose, this study is an initial work that draws from the IPCC SRES and projection methodologies and thus requires further development, wider consultation and validation.

There is a huge cross country and regional variance in endowments as well as reach and success man-made endeavours across India. In this context while the 4 scenarios described in this study, present a spectrum of possible socio-economic states in which various political states/regions in India, each of these 4 scenarios is equally plausible for application on Pan-India basis. The most ambitious scenario IA1 itself is one which has manifested itself in some progressive states like Gujarat, Maharashtra or Punjab.

Due to path dependence of conventional technologies in power and industrial sector, the GHG emissions in India continue to increase and carbon emissions itself is slated to increase by two to three times the emissions in 2000 over the next 30 years. The per capita increases in energy consumption as well as emissions are dampened by a simultaneous rise in population.

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