ANALYSIS OF LONG-TERM ENERGY AND CARBON EMISSION SCENARIOS FOR INDIA

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Abstract. In the coming years India faces great challenges in energy and environment. The path of development chosen by India, upon which lies the future growth of energy and emission trajectories, would be greatly influenced by technological developments both within and outside the country, economic cooperation between countries, and global cooperation in limiting greenhouse gas emissions. This paper discusses the integrated modeling system used for developing and analyzing the long-term trajectories and presents results for the scenarios developed. In the context of ongoing market reforms two scenarios – accelerated and decelerated reforms – are developed depicting fast and slow progress in energy sector reforms compared to expectations in the baseline scenario. Accelerated market reforms would spur improvements in technological efficiencies. Reforms would lower investment risks in India, thereby stimulating increased levels of foreign direct investment. On the other hand in decelerated reform scenario economic growth is lower than that in the base case, there is low access to capital, and technological improvements lag behind those in the base case. In another scenario we assume specific policy interventions for penetration of renewable technologies over the baseline scenario, for promotion and accelerated deployment of renewable energy technologies over and above the baseline assumptions. A scenario with carbon (C) constraints has also been developed and the results discussed.

Keywords: carbon-constrained scenario, integrated energy emissions modelling, long-term modelling, market reforms, regional energy markets, renewable energy

1. Introduction

The demand for hydrocarbon resources during the last century came largely from industrialized nations in the West. However over the last decade, Asian region led by China and India has emerged as their new growing consumer. These two regions, along with Japan, are likely to emerge as world's largest energy markets. Electricity consumption in India has more than doubled in the last decade, outpacing economic growth. Coal remains the mainstay of power generation providing about three-fifths of the country's power. With 243.3 million tons of carbon (C) released from the consumption and flaring of fossil fuels in 1999, India ranked fifth in the world. India's energy-related c emissions have grown nine-fold over the past four decades and its contribution to world C emissions is expected to increase in the coming years (EIA 2002).

In the coming years India faces great challenges in energy and environment. With rapidly increasing population and economic development the demand for electricity generation and vehicular usage is expected to go up. The path of development chosen by India will greatly dictate the country's future energy and emission trajectories. This path would be greatly influenced by technological developments both within and outside the country, economic reforms, economic cooperation between countries, and global cooperation in limiting greenhouse gas emissions. This paper analyses the long-term scenarios of energy market reforms and accelerated development of renewable technologies in India using an integrated modelling system.

2. Integrated Energy Emissions Modelling System

For the energy, economy and emissions mitigation analysis, an integrated modelling framework comprising three modules – the top-down models, the bottom-up models and local models – has been used. These three modules are soft-linked through various parameters. The top-down models provide Gross Domestic Product (GDP) and energy price projection outputs that are used as exogenous inputs to the bottom-up models. The bottom-up models, on their part, provide future energy balance output that is used for tuning inputs of the top-down models. Similarly the bottom-up models provide detailed technology and sector level emission projections that provide inputs to the Geographic Information System (GIS) based energy and emissions mapping for the country.

The framework depicted in Figure 1 is an update of previous work (Garg et al. 2001). It has three basic modules; the top-down models, the bottom-up models, and local models. Each module consists of multiple individual models. In the top-down module we have a global model, Edmonds-Reilly-Barnes model (ERB) (Edmonds and Reilly 1983; Reilly et al. 1987; Edmonds and Barns 1992), a regional model, AIM/Trend (Fujino et al. 2002) and three country models namely, Second-Generation Model (SGM) (Edmonds et al. 1993), AIM/Material (Masui et al. 2002) and GEMA (Jung and Moon 2000; Jung et al. 2001) which are all Computable General Equilibrium (CGE) models. The analysis of India's long-term energy and emissions profiles is done using the ERB model (Rana and Shukla 2002) in conjunction with other top-down models (Rana and Shukla 2001).

The bottom-up module integrates three individual models:

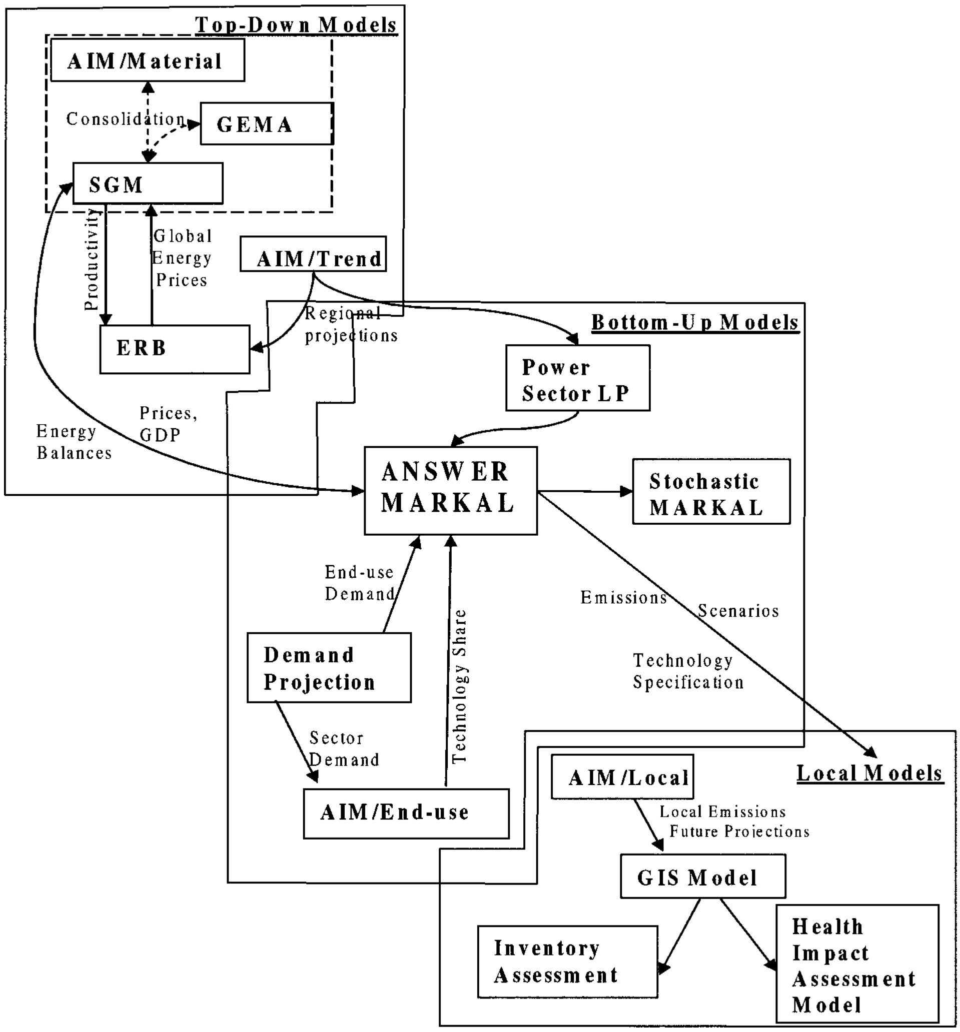

Figure 1. Soft-linked integrated modelling framework for energy and carbon emission analyses in India.

- ANSWER MARKAL – an energy systems optimisation model (Berger et al. 1987; Fishbone and Abilock 1981; Shukla 1996), which is used for overall energy system analysis.
- AIM/ENDUSE model (Morita et al. 1994; Morita et al. 1996; Kainuma et al. 1997), which is a sectoral optimisation model, used to model fourteen end-use sectors.
- A demand model which projects demands for each of the thirty-seven end use services.

Each of these models addresses specific questions and compliments others for a comprehensive analysis of energy and environmental concerns. The demand projection model, for example, provides end-use demands to the ANSWER MARKAL and AIM/ENDUSE models that are demand driven. The integration of demand and supply within a bottom-up framework is achieved through a soft linkage of ANSWER MARKAL with the AIM/ENDUSE model whereby the output of each end-use modelling exercise is exogenously passed to the ANSWER MARKAL model as an input.

The present paper lays emphasis on results from ANSWER MARKAL. It is a multi-period, long-term model of the integrated energy system. ANSWER MARKAL selects the technology mix (in 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 it 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). The present Indian ANSWER MARKAL has been set up for the 105-year period spanning years 1995–2100 in 15-year step. Researchers have emphasised the importance of using long time horizons for global change mitigation calculations (Fearnside 2002).

Utilizing the integrated framework of models, the baseline scenario follows in the footsteps of Special Report on Emission Scenarios (SRES) of Intergovernmental Panel on Climate Change (IPCC) (Nakicenovic et al. 2000). The assumptions for baseline scenario for India are made keeping in mind SRES B2 storyline. B2 storyline and scenario family describes a world in which emphasis is on local solutions to economic, social and environmental sustainability. It is a world with a continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in B1 and A1 storylines. Similarly in our baseline, population for India continuously increases to 1.65 billion by 2100. GDP projection is assumed to increase by 5.5% per annum on an average during 2000–2025, by about 5% during 2025–2050, by 4.5% during 2050–2075, 3.5% during 2075–2085 and stabilizing at 2% by year 2100. This represents the intermediate level of economic development.

3. Scenario Description

The important exogenous model specifications for the scenarios include the electricity demand trajectory, investment constraints, energy supply limitations, energy prices, technology costs and technology performance parameters. The *baseline scenario* presumes continuation of the current energy and economic dynamics and provides a reference for comparing the impacts of policies for alternate futures. The *accelerated reform scenario* assumes accelerated progress in the ongoing market reforms in the energy sector compared to expectations in the baseline scenario. In the context of economic globalization and liberalization, accelerated market reforms would spur improvements in technological efficiencies. Reforms lower the

TABLE I
Key scenario drivers and model parameter for energy and carbon emissions modeling in India.

Scenario	Key drivers	Implication on critical parameters
Market reform (Accelerated/Decelerated)	Economic growth rate, competition, access to global finance and technology	Technology cost (↓/↑), efficiency (↑/↓), investment capacity (↑/↓)
Accelerated development of renewable technologies	Technology R&D, technology transfer, and capacity building	Renewable technology costs (↓), efficiency (↑)

investment risks thereby stimulating increased levels of foreign direct investment. As a result the economy grows rapidly and the GDP reaches the level of year 2100 in base case ten years earlier i.e. in 2090 in this scenario. The *decelerated reform scenario* on the other hand assumes less progress in reforms compared to the base case. In this scenario economic growth is lower than that in the base case, there is low access to capital, technological improvements lag behind those in the base case, and consequently in this scenario, GDP reaches the level of year 2100 in base case fifteen years later in 2115.

The *accelerated development of renewable technologies scenario* assumes specific policy interventions for penetration of renewable technologies over the baseline scenario. Some of the interventions discussed here are built in the baseline scenario as per the ongoing policies and most likely future expectations. However, interventions in this scenario place a thrust for promotion and accelerated deployment of renewable energy technologies including decentralized and grid applications for electricity supply, additional to the baseline assumptions. This scenario presupposes interventions for substantial research and development investments in renewable energy technologies that facilitate cost reductions through scale economies, increases the commercialization possibilities of these technologies and leads to their higher penetration. Technological progress is accelerated, both in terms of autonomous efficiency improvements of existing technologies and earlier and higher penetration of advanced technologies as compared to baseline scenario. Table I gives the key scenario drivers and implications on the key model parameters.

4. Analysis of Results

In baseline the Indian power generation capacity increases about nine times from 96 Gigawatt (GW) to 912 GW between 1995–2100 (Figure 2). The share of coal in total generation capacity drops from a little over sixty percent in 1995 to about fifty percent by the end of the century but remains the mainstay of power generation.

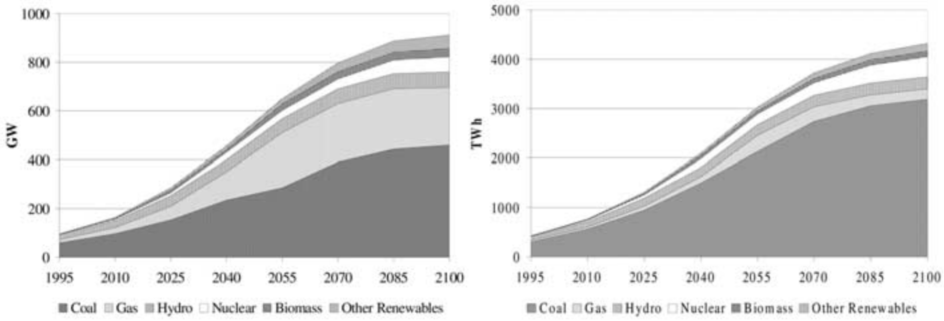

Figure 2. Base case power capacity and generation mix in India.

The share of oil and gas increases steadily from 12% in 1995 to about 25% in the year 2100. A notable feature of technology trajectory is substantial increase in gas-based capacity, which reaches about 235GW in 2100. The growing attractiveness for natural gas is due to relatively low investment costs of gas technologies as compared to coal, high operating efficiencies, and suitability for meeting peak load. Hydropower capacity increases to about 63 GW in 2100 but its share decreases from about 22 percent in 1995 to seven percent of the total generation capacity by 2100. The slow growth in capacity is due to barriers of high investment requirements and long gestation periods. A number of socio-environmental issues are related to dam construction, flooding of areas, damages to the ecology and resettlement and rehabilitation of the population. Renewable energy technologies include small hydropower, wind, cogeneration and biomass technologies, solar and geothermal. The share of renewables other than biomass increases from an insignificant 0.7% in 1995 to about six percent by the end of the century. Biomass share also steadily increases to four percent by the end of the century. The total renewables based generation capacity reaches 90 GW in 2100 in the baseline. The nuclear share increases from two percent to nearly seven percent by 2100. The entire nuclear share is nuclear fission. Geothermal has a negligible share in the total renewables capacity.

The electricity generation increases from 422 Terrawatt (TWh) in 1995 to 4325 TWh in 2100 (Figure 2). Domination by coal-based generation continues. The generation mix indicates a ten-fold increase in coal based power generation during 1995–2100. Gas based power generation increases till 2040 and then declines as a result of limited availability of low cost gas. Given that natural gas fired power generation virtually eliminates sulphur dioxide, halves C emissions compared to coal, expanding the supply of natural gas becomes a critical variable in India's future energy equation.

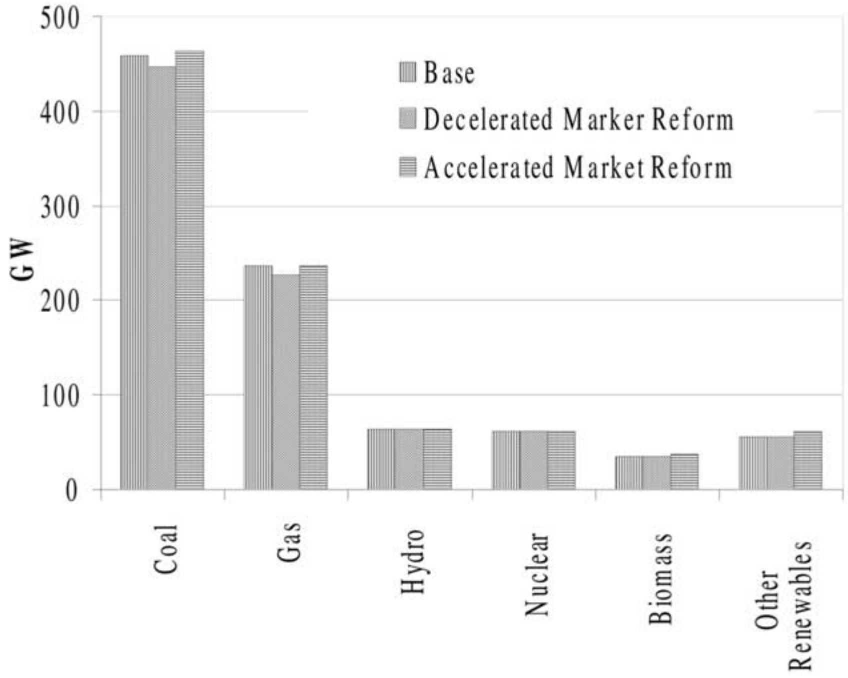

Figure 3. India electricity capacity requirement in 2100 (GW).

4.1. Market reform scenario

In the accelerated market reform scenario the total generation capacity reaches 925 GW by 2100 as compared to 912 GW in the baseline. Coal based technologies remain predominant with a share of fifty percent as in the base case. The share of oil and gas increases steadily from twelve percent in 1995 to about 25 percent in the year 2100. Shares of large hydro and nuclear power remain at about 7% each. The installed capacity of renewables in 2100 is 10 GW higher than in the base case (Figure 3).

In the decelerated market reform scenario the total generation capacity reaches 890 GW in 2100. Here too coal dominates with a share of fifty percent. The share of gas is 25%, large hydro and nuclear power is 7% each, while that of renewables is about 10%.

Given the cost structure for fusion power, it cannot compete with alternate base-load power options in either of the scenarios. Coal continues to dominate the power generation mix in both the accelerated (73%) and the decelerated (72%) market reform scenarios (Figure 4) largely due to reliance on domestic resources for energy supply.

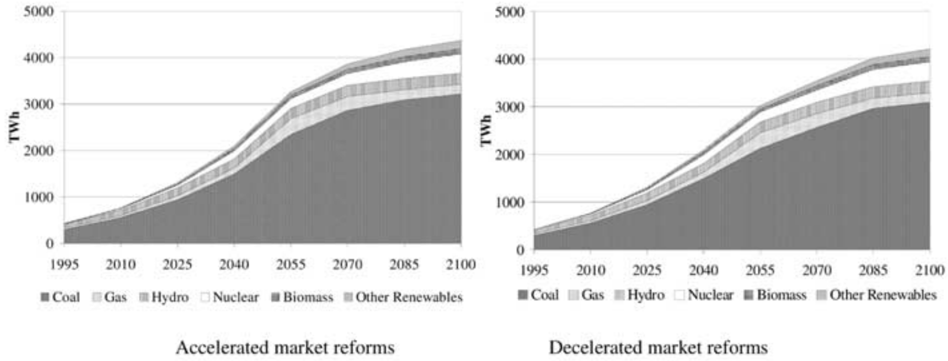

Figure 4. India power generation mix for electricity reform scenarios.

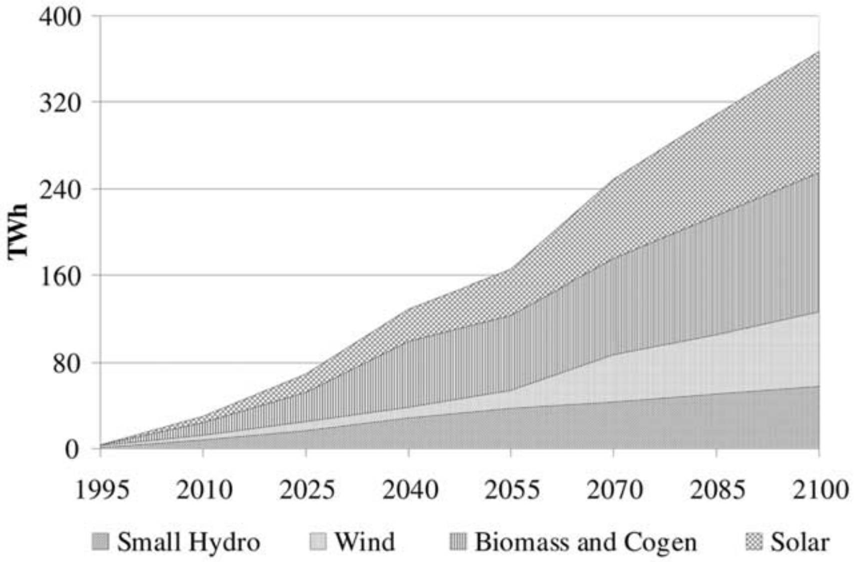

Figure 5. Electricity generation by renewables energy in India.

4.2. Accelerated development of renewable technologies scenario

In the accelerated development of renewable energy technologies scenario the Indian power generation capacity reaches about 940 GW by 2100. The most important observation here is that share of renewables increases from 0.9% in 1995 to 14% percent by 2100. This is an increase of 4% over the base case scenario replacing some amount of coal as well as gas-based capacity.

Renewable technologies include small hydropower, wind, cogeneration and biomass technologies, solar and geothermal. Wind power capacity doubles to reach

TABLE II
Cumulative carbon dioxyde emissions based on scenario B2-AIM world (Nakicenovic et al. 2000).

1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Cumulative CO_2 Emissions (PgC)											
7	82	169	269	381	507	650	801	951	1100	1246	1388

30 GW by 2100. Its share in generation is about 23 percent among renewable energy technologies (Figure 5). In the long run, penetration of wind power is driven by development of indigenous manufacturing capabilities and increasing competitiveness of wind technology. There is a substantial increase in biomass and cogeneration technology capacities, with their combined capacities reaching around 54 GW. Expectations about the development of a biomass supply market, technological advancements and increasing commercialisation of the technologies lead to increasing deployment of biomass conversion technologies for centralised electricity generation as well as decentralised applications. Small hydropower capacity reaches around 12 GW and that of solar about 40 GW, which is 30% of total renewable capacity. Penetration of solar energy technologies will depend largely on their costs coming down internationally, lowering of their capital intensity and establishing institutions for co-operative R&D and technology transfers. Geothermal energy has a low share of less than 1 percent in the total renewables capacity.

The total electricity generation increases ten times during the period from 422 TWh in 1995 to 4325 TWh in 2100. The share of renewables in the total power generation in the year 2100 is around 9% as opposed to 6.5% in the base case. However domination by coal-based generation continues. Biomass has the highest share of about 35% in electricity generated through renewables.

4.3. Carbon reduction policy scenario

In the above-described scenarios no C reduction policies were assumed. However during the next century several policy targets with respect to reduction of greenhouse gas emissions could be implemented. With a constraint on C emissions there would be changes in technology choices within the energy system. In the model, reduction in C emissions is achieved through constraint on the cumulative C emission. Emission budgets for India have been calculated for global C stabilization levels of 550 and 650 ppmv. The calculation of emission budgets for India from global emission budgets requires allocation of budgets between world regions. The cumulative C emission calculation for India for the period 1990–2100 from present study shows it to be around 104 Petagrams C.

TABLE III

World CO_2 emissions for different stabilization scenarios.

Global stabilization level	[ppm]	450	500	550	650	750
Cumulative CO_2 emissions	[Petagram CO_2]	2520	3050	3510	4270	4850

Source: Lako et al. 1998.

TABLE IV

Carbon emission budgets for India for different stabilization scenarios.

Global Stabilisation Level	[ppm]	550	650
Cumulative CO_2 emissions	(Pg C)	73	87
	(Pg CO_2)	264	319

Since the base case assumptions of the present study are made according to the SRES B2 storyline, the world cumulative C emission according to the B2 scenario of AIM have been used for the calculating the emission budgets. The world cumulative C emission according to the B2 scenario of AIM is given in Table II. The Indian cumulative c emission for the period 1990–2100 is about 7.5% of the world cumulative emissions.

Table III next provides the world CO_2emissions for the different stabilization scenarios. Adopting a 7.5% share for calculating emission budgets for India, Table IV gives the emission budgets for the 650 ppmv and the 550 ppmv cases. These budgets are used as cumulative c constraints in the model. The budgets corresponding to the two stabilization levels are 73 and 87 GtC respectively.

In the year 2100, the share of renewables in the total power capacity increases from about 9% in the base case to 21% and 19% respectively for 550 and 650 ppmv stabilization levels. The share in power generation for the same year increases from approximately 6.5% in the base case to 17% and 16% respectively for the two stabilization levels. Figure 6 shows the electricity generated from renewable technologies across different scenarios.

Carbon emissions increase by about eight times over the model horizon from 206 TgC in 1995 to about 1.66 Pg in 2100 in the base case (Figure 7). Share of the power sector C emissions is highest around 45%. This is because of the continued dominance of coal in power generation. This dominance by large point sources provides an opportunity for C mitigation. Industry and transport are the next major contributors to C emissions, sharing about 50% between them.

The continued dominance of coal results in C emissions in both the accelerated and decelerated market reforms scenarios being close to the base case level. For

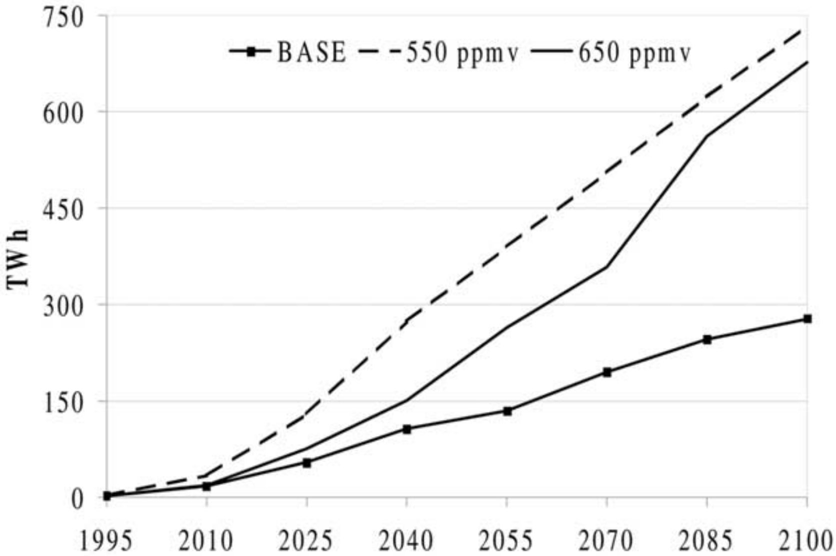

Figure 6. Electricity generation by renewable energy in India under three scenarios.

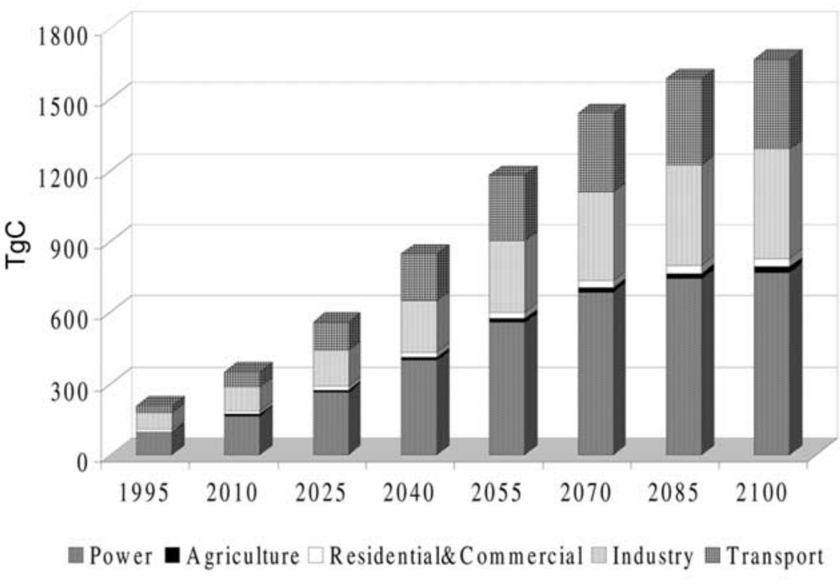

Figure 7. Current and Future carbon emissions for 5 economic sectors in India.

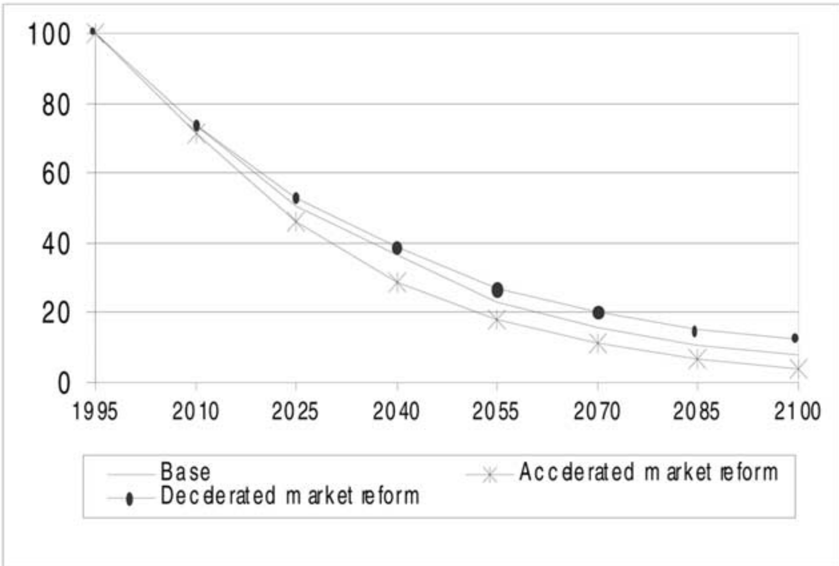

Figure 8. Current and future carbon intensity in India.

the accelerated reform scenario the carbon emission level in 2100 is 2.5% higher than the base case while in the decelerated market reform scenario its 3% lower. The C intensity trends (Carbon/GDP) for the two reform scenarios are compared with that of the base case in Figure 8.

In the accelerated renewable technology development scenario the emission are 1.65 PgC in 2100, about 20 Tg less than the base case. Increased penetration of renewables slightly impacts the C emission trajectory. While energy/fuel replacement by renewables is significant and amounts to 400 TWh in 2100, C replacement is insignificant. This result provides an important insight into the long-term competitive dynamics of energy technologies. The conventional belief that renewable technologies shall reduce equivalent C emissions does not hold. Under competitive dynamics as modelled, the enhanced penetration of renewable technologies happens by replacement of other non-C/low C technologies that are more expensive compared to fossil fuel technologies.

5. Development of Regional Energy Markets

Preceding analysis indicates a definite trend of increasing demand for clean and less expressive energy. Alternate supply options are needed to attain the objective of meeting these demands. While the above results are for India, the situation is akin in the whole South Asia region. South Asia’s consumption of oil and gas is expected to increase significantly. The region is heavily dependent on oil imports. The two largest economies of the region India and Pakistan, together import around US$ 15 Billion (Raza, H.A.: 2001, Potential and Prospects of Trade and Cooperation in Oil and Gas Sector between India and Pakistan. Presentation at the International Conference on India's Energy Security: The Oil and Gas Dimensions, organized by IDSA and ONGC, April 10–11, New Delhi) of oil annually. Some of the increasing dependence on external sources can be reduced by diversification to alternate sources of energy and through regional cooperation. Serious attention is required for a strategic policy to enhance cooperation in the region. The most compelling argument for cooperation lies in the fundamental energy dynamics in South Asia. India now relies on poor quality domestic coal and represents a large and expanding market for energy; Sri Lanka needs to import more fuel for power. Bangladesh and Nepal could realize significant economic benefits from the development and export of natural gas and hydroelectric power, and Pakistan's economy would benefit from both energy imports and exports.

Some limited exchange of electricity already exists between Nepal, Bhutan and India. Supporting and encouraging more robust trade in energy would have far reaching economic, development and energy security benefits. Nepal has an estimated hydropower capacity of 83,000 MW of which 42,000 MW are economically exploitable specially through harnessing perennial rivers. Bhutan also possesses a potential for generating about 20000 MW of energy of which 11000 MW is identified hydropower potential (Boquerat 2000). The excess electricity generated could be exported to neighboring countries. Exchange of electricity would also help the small nations set up larger plants and benefit from the economies of scale associated with such plants apart from earning valuable foreign exchange and improving their balance of trade position. Intensive exploration and production of natural gas and establishment of joint production facilities, with transfer of technology can be potential areas of cooperation. There is also scope for import of natural gas from several middle-east countries, which would benefit the region. The interest of the supplying country, which could be Iran or Central Asian Republics, would be to have a pipeline connection extending up to India.

Researchers have attempted to examine the policy, technology and economics of an overland pipeline supplying natural gas to Pakistan and India (Sen 2000). Such a pipeline provides a unique opportunity for cooperation. Such cooperation would benefit not only India but also Pakistan in terms of the transit fees it would receive. The papers argue that any overland gas pipeline does not depend solely on economic viability but on political acceptance as well. Studies have evaluated the status of several planned/proposed interregional gas transmission lines in Eurasia (Klaassen et al. 2001). Among these are the pipelines that have their source in Central Asia and destination in India. While the status of the Oman-India pipeline (length 1500 km, capacity 19 bcm/year) has been termed 'speculative,' the status of Iran-India pipeline (length 2000 km, capacity 19 bcm/year) has been termed 'possible.'

TABLE V

Implications of regional energy co-operation and trade in Southern Asia.

Technology/emissions	2005	2010	2015
Coal generation share (%)	67.3	63.5	58
Reduction over reference (%)	(–1.8)	(–2.7)	(–3.9)
Gas generation share (%)	11.7	13.9	16.2
Increase over reference (%)	(8)	(12)	(15)
Hydro generation share (%)	16.8	17	18.3
Increase over reference (%)	(7)	(11)	(14)
SO_2 Emissions (MT)	4.3	5.1	5.6
Reduction over reference (%)	(–2.1)	(–2.7)	(–4.2)
Carbon Emissions (MT)	142	180	212
Reduction over reference (%)	(–1.4)	(–1.6)	(–2.1)

Given the potential for cooperation in primary energy and electricity in the region, an attempt has been made to study its implications on the country's energy generation mix and emissions. The integrated model results which use ANSWER MARKAL, AIM/End-Use and AIM/Trend (used for future projections of economic indicators for South Asian countries) suggest that at a price of \$3 per GJ, there will be substantial demand for gas in India to absorb the proposed supply from Turkmenistan and Bangladesh. The demand for gas shall rise rapidly, if a strong carbon mitigation regime comes into existence. The ultimate success of these pipelines depends on the political will to overcome the barriers.

Within our integrated modeling framework, AIM-ENDUSE, ANSWER-MARKAL and AIM/Trend models together capture regional cooperation with the neighboring countries. The study time horizon was through year 2015. The cooperation scenario assumed 20 percent enhancement in hydropower potential and 15 percent increase in gas availability over the reference scenario. Regional cooperation with the neighboring countries caused changes in the generation mix. Coal based generation declined, which in turn is replaced by higher shares of gas and large hydro-based generation.

Regional co-operation also results in both local and global environmental benefits due to reduced emissions from power generation (Table 5). Most major cities in South Asia such as New Delhi, Calcutta and Dhaka are faced with the problems of local pollution. The AIM Local model (Kapshe et al. 2002), though beyond the scope of this paper would help analyze and ascertain the energy and emission trajectories for these cities. The model would provide optimal combination of technologies for local areas at minimum costs under constraints, which include demand, and environmental constraints. Projections of energy and emission trajectories using AIM Local for the above mentioned cities would be of interest for both researchers and policymakers.

6. Conclusion

In the baseline scenario the Indian power generation capacity increases about nine times from 96 GW to 912 GW between 1995–2100. Coal is expected to be the mainstay for power generation in the base scenario. A notable feature of the technology trajectory is the substantial increase in the share of natural gas. A technology push policy along with research and development thrust and learning innovations will enhance technology penetration in the short and medium run in renewables solar and wind energy. But in the long run, penetration will largely depend on increasing competitiveness of wind technology.

Base case analysis reveals that the per capita C emissions increase five times by the end of the century. However this is below the present per capita emissions of developed countries and still below the world average per capita emissions. Indian economy becomes C efficient. There is decoupling between GDP growth and C emissions and also between GDP growth and energy consumption. However there is no decoupling between C emissions and total energy consumption. This can be attributed to technology efficiency improvement and absence of change in fuel mix (continued dominance of fossil fuel technologies).

The absolute C emissions do not change much in the accelerated and decelerated market reform scenarios. The accelerated market reform scenario though contributes to technological progress, results in marginal increase in C emissions than the base case. Concerted policy initiatives need to be taken in order to encourage the development and penetration of renewables and exotic technologies such as nuclear fusion.

In the accelerated renewable energy technology development scenario the share of renewables in power generation capacity increases from an insignificant 0.9% in 1995 to 14% by the end of the century. This is an increase of 4% over the base case scenario. Increased penetration of renewables only slightly impacts the C emission trajectory and C replacement is insignificant. The conventional belief that renewable technologies shall reduce equivalent C emissions does not hold. This result also corroborates a recent paper (Rana 2003) in which an accelerated solar electricity scenario is studied using a top-down model for India.

Given the cost structure for fusion power, it could not compete with alternate base-load power options in the base case. However under constrained C scenarios nuclear fusion penetrates in the later half of the century.

Under the stabilization scenarios mitigation happens during the later half of the century. In case of 550 ppmv however, the utilization of existing coal plants declines even during the earlier periods. This indicates that under the stringent mitigation conditions the possibility of stranded asset problem arises in power sector and associated coal mining sector. In the present case, the stranded assets in power sector are of the order of 17% of present capacity. The nature of mitigation regime would actually determine the magnitude of this problem. If the regime remains uncertain till later years, the stranded assets problem may be more acute, than the case where the amount of mitigation that is required to be done becomes clear at an early stage. From a developing country perspective this would require special attention. Renewable energy technology penetration increases, as significant coal needs to be replaced in comparison to base case. In this context under a highly constrained regime renewable technologies not only replace the more expensive low/no C technologies but also fills into the market niche left by outgoing coal technologies. The accelerated penetration of renewable technologies, which reduces the technology costs, will have less impact on C emissions as discussed earlier, but a strong stabilization regime will enhance the renewable penetration. Also regional cooperation in energy markets could result in both local and global environmental benefits.

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