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Energy Use and Climate Change: A Policy Analysis for India

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Abstract

In the coming years South Asia 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 the region, upon which lies the future growth of energy and emission trajectories, would be greatly influenced by technological developments, economic cooperation between countries, and global cooperation in limiting greenhouse gas emissions. Among the most important anthropogenic causes for climate change is energy use, which is dominated by fossil fuels. In the background of existing energy system in the region and the vulnerability of major natural and social systems in South Asia to climate change, this paper analyses the long-term energy and emission trajectories for India under various scenarios using an integrated modeling framework. 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. In another scenario we assume specific policy interventions for penetration of renewable technologies over the baseline scenario by placing an additional thrust for promotion and accelerated deployment of renewable energy technologies over and above the baseline assumptions. Scenarios with regional energy cooperation and constraints on carbon emissions (650 ppmv and 550 ppmv) are also discussed.

The main results show that in the baseline scenario the Indian power generation capacity increases about nine times with coal as its mainstay. In the long run, penetration of renewables will largely depend on increasing competitiveness of wind technology. Accelerated market reform scenario shows higher technological progress. However concerted policy initiatives need to be taken for penetration of renewables. In the accelerated renewable technology development scenario the share of renewables increases but does not contribute substantially to carbon mitigation. The carbon stabilization scenarios lead to changes in technology choices within the energy system. Carbon mitigation happens during the latter half of the century. Regional cooperation in energy among the South Asian countries also results in environmental benefits due to reduced emissions from power generation.

Energy Use and Climate Change: A Policy Analysis for India

The demand for hydrocarbon resources during the last century came largely from the industrialized nations in the West. However over the last decade the Asian region led by China and South Asia has emerged as their new growing consumer. These two regions along with Japan are likely to emerge as the world's largest energy markets. South Asia in this paper refers to the member countries of the South Asian Association for Regional Cooperation.

In the coming years South Asia faces great challenges in energy and environment. The South Asian region is characterized by diversity in geography, energy sources and in political and economic structures. In an area comprising 3% of the world total, the region holds about a quarter of the world's population. The geographical diversity in the region has not only given rise to diverse climatic conditions but has also resulted in the availability of diverse energy resources leading to a diverse energy mix in the region. South Asia's commercial energy mix was 43% coal, 35% petroleum, 13% natural gas, 8% hydroelectricity, and 1% nuclear in 1999 (EIA, US DoE 2001). Given the diversity in primary energy resources, governments in the region are pursuing steps to further cooperation in the energy sector.

With in this region the Indian energy system occupies a dominant position. The country's share in the total commercial energy consumption in 2001 was 85%. Also her shares in the total installed electricity generation capacity and carbon emissions were 82% and 86% respectively (EIA, US DoE 2001). The path of development chosen by India will greatly influence not only the country's energy and emission trajectories but also that of the region.

This paper first discusses in brief the existing energy system in the region and the vulnerability of major natural and social systems in South Asia to changes in climate. *Vulnerability can be defined as the extent to which a system is susceptible to climate change.* Using an integrated modelling framework the paper then analyses the long-term energy and emission trajectories for India and presents results for the scenarios developed. A similar framework is also used to develop a short-term regional cooperation scenario. This scenario would elaborate benefits that would accrue to the region as a result of cooperation among the South Asian countries in the energy sector.

The Energy Scenario in South Asia

South Asia's primary energy consumption (from commercial energy sources), increased by around 50% between 1990 and 1999. In 1999, South Asia accounted for approximately 3.8% of world commercial energy consumption, up from 2.4% in 1987. Despite rapid growth in energy demand, South Asia continues to average amongst the lowest levels of per capita energy consumption in the world, but among the highest in terms of energy consumption per unit of GDP (EIA, US DoE 2001).

The Regional Picture

South Asia's commercial energy mix was 43% coal, 35% petroleum, 13% natural gas, 8% hydroelectricity, and 1% nuclear in 1999. There are significant variations within the region. Bangladesh’s energy mix, for instance, is dominated by natural gas (71% in 1999), while India relies heavily (51%) on coal. Sri Lanka is overwhelmingly dependent on petroleum (75% in 1999), while Pakistan relies on oil (42% in 1999), natural gas (40%), and hydroelectricity (13%), and the Maldives is 100% dependent on petroleum. The Himalayan countries of Nepal and Bhutan have high shares of hydroelectric power in their energy consumption mix. In recent years, natural gas has been growing in importance as a source of energy in South Asia, especially for use in power generation, fertilizer and petrochemical production.

South Asia contains reserves of only 5.0 billion barrels of oil, around 0.5% of the world total. In 1999, the region consumed around 2.4 million barrels per day (bbl/d) of oil, and produced 0.81 million bbl/d, making South Asia a net oil importer of around 1.6 million bbl/d. Growing demand for transportation fuels and increased industrial power demand have been major factors for growth in South Asian oil consumption in recent years.

South Asia contains around 55 trillion cubic feet (Tcf) of proven natural gas reserves, or about 1% of the world total, with potentially larger resources suspected but unproven. The region consumes and produces around 1.85 Tcf of gas. Long-term projections of rapidly increased gas demand for South Asia will require significant increases in production, imports, or most likely both. Gas imports to the region will require construction of infrastructure - either pipelines or liquefied natural gas (LNG) facilities.

South Asia contains 86 billion short tons of coal, or around 15% of the world total. Currently, coal accounts for 43% of South Asia's energy consumption. Nearly all of this is produced and consumed by India, the only South Asian country with significant coal reserves. Power generation accounts for about 70% of India's total coal consumption, followed by steel and other industries.

As is the case in many developing countries and regions, South Asia continues to rely heavily on biomass (i.e., animal waste, wood, etc.) for its energy needs. As of 1995, biomass accounted for 56% of the region's final energy consumption, and 46% of its primary energy use. Also around 20%-30% of South Asia's biomass use is animal waste, with another 20%-30% made up of agricultural residues, and only small amounts of charcoal. Biomass generally is burnt directly using traditional, low-efficiency equipment. Biomass is consumed mainly in rural areas of South Asia.

In 1999, South Asia generated 538 terawatthours of electricity. Of this, around 60% was generated from coal, 21% from hydroelectric plants, 10% from natural gas, 6% from oil, and 2% from nuclear, and less than 1% for "other renewables" (like wind and solar). Also in 1999, India accounted for the vast majority (82%) of regional electric generation capacity, followed by Pakistan (13%), Bangladesh (3%), Sri Lanka (1%), Nepal, Bhutan, and the Maldives (1% total) (EIA, US DoE 2001). The high proportion of coal-based generation has resulted in an increasing trend in carbon emissions in the region. Carbon emissions have increased from 185 million tonnes in 1991 to about 294 million tonnes in 2000. The South Asian region is also home to several of the most polluted cities in the world. These include Calcutta, Delhi, Mumbai, Karachi, and Dhaka. Although the total emissions in the region are only a small part (3%) of the global total, the major concern is regarding the high annual growth rates in this region. Carbon dioxide a major green house gas contributes to global warming and climate change. Climate change defined as, " *a change of climate that is attributed directly or indirectly to human activity that alters the composition of global atmosphere and which is in addition to natural climate variability observed over comparable time periods*," (Article 1, UNFCCC) impacts human health, major sectors like Agriculture, Industry, Power, Forestry, and low lying coastal areas.

Impacts of Climate Change

From Pakistan in the north to Sri Lanka in the south, the region is characterized by climate as diverse as those found in the Sahara desert and the equatorial tropics. The region's climate is predominantly tropical monsoon though half the region lies north of the Tropic of Cancer. The great Himalayas act as a barrier for the mid-latitude influences of Central Asia and play an important role in shaping the regional climate. In South Asia, the amount and the seasonal distribution of rainfall rather than temperature are the major factors responsible for delineating the climate of one region from the other. Temperatures range from -50° C in the Himalayas during winters to + 50° C in the west. The region is characterized by striking contrasts in the amount of rainfall received. Further the warm waters of the Indian Ocean, an

area of organized convection and cyclonic activity leading to cyclones make the climate of the region complex. Changes in such varied climatic conditions can have the following impacts.

Health

Human health is affected by changes in weather such as high temperature, high humidity and stillness of air during summers. Increasing temperatures lead to heat load and heat stress. Heat stress can cause damages to physiological functions, metabolic processes, and the body's immune system. Several deaths due to heat waves have been reported in recent years in North India, Pakistan and Nepal. Vector borne disease like Malaria is an important disease in the tropical regions of India, Bangladesh and Sri Lanka. Increasing temperatures would expand these vectors in the tropical areas (Reeves et al., 1994) of this region. Further, warmer sea surface temperatures along South Asian coastlines would support higher phytoplankton blooms. These are excellent habitats for survival and spread of infectious bacterial diseases.

Agriculture

The agricultural sector in South Asia is highly dependent on the monsoons. The agricultural yields are highly correlated to the monsoons. Yields are higher in years of excess rainfall and dip in the years of deficient rainfall. Change in temperature and UV-B levels have adverse effects on agricultural yields. The productivity of wheat, rice and other crop species declines markedly at high temperatures. The situation is similar for sorghum, and pearl millet, which are exposed to high temperatures in Rajasthan, India (Mitra *et al.*, 2002).

Industry

Agro industries such as food, tobacco, beverages, natural fibre textiles, leather, wood, paper and rubber, depend on forests, agriculture or fishery products for raw materials. Climate change would adversely affect agricultural, forestry and fishery production. Since a large part of the industrial sector in the region depends on primary commodities, changes in climate would adversely affect these sectors.

Coastal areas, Mountain regions and Forests

Low lying coastal areas would be submerged with rise in sea levels brought about by global warming. The potential impact of sea level rise would include inundation of low lying deltas and estuaries, retreat of shore lines, salination of ground water, and changes in the water table. The Ganges-Brahmaputra is the important low-lying river delta in the region. The island nation of Maldives and parts of other nations in the region with long coastlines would be adversely affected by a rise in sea levels. A growing

number of extremely large cities are located in coastal areas, which means that large amounts of infrastructure may be affected. Although annual protection costs for many nations are relatively modest, about 0.1 per cent of gross domestic product (GDP), the average annual costs to many small island states, total several percent of GDP.

Substantial elevation shifts of ecosystems in the mountains and uplands of Tropical Asia are projected. At high elevation, weedy species can be expected to displace tree species, though the rates of vegetation change could be slow compared to the rate of climate change and constrained by increased erosion in the Greater Himalayas.

The Himalayas have a critical role in the provision of water to continental monsoon Asia. Increased temperatures and increased seasonal variability in precipitation are expected to result in increased recession of glaciers and increasing danger from glacial floods.

Changes in the distribution and health of rainforest and drier monsoon forest will be complex. In Sri Lanka, a significant increase in dry forest and a decrease in wet forest could occur. Projected increases in evapotranspiration and rainfall variability are likely to have a negative impact on the viability of freshwater wetlands, resulting in shrinkage and desiccation.

Impact on Energy demand

As a result of a rise in the temperatures there would be an increased demand for cooling purposes. In agriculture more electricity would be needed for irrigation pumping during warmer weather, as the soil would become drier. The region already faces a severe demand supply gap in the power sector and a rise in temperature would only worsen the situation.

As defined in Article 2 of the UNFCCC, we need to focus on the anthropogenic causes for climate change since the climate systems have inherent variations and uncertainties. Among the most important anthropogenic causes is the energy use, which is dominated by fossil fuels worldwide and particularly in this region, as noted earlier. Electric power production, industry and transport are the sectors contributing substantially to GHG emissions.

Using an integrated modelling approach, explained below, we analyse the long-term energy emissions scenarios for India. In addition, we briefly discuss the development of regional energy markets and the benefits that would accrue as a result of cooperation in energy among the South Asian countries.

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 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 GIS based energy and emissions mapping for the country. The framework depicted in Figure 1 is an update of a previous work (see Garg et al., 2001) and is described in detail in Shukla et al. (2001).

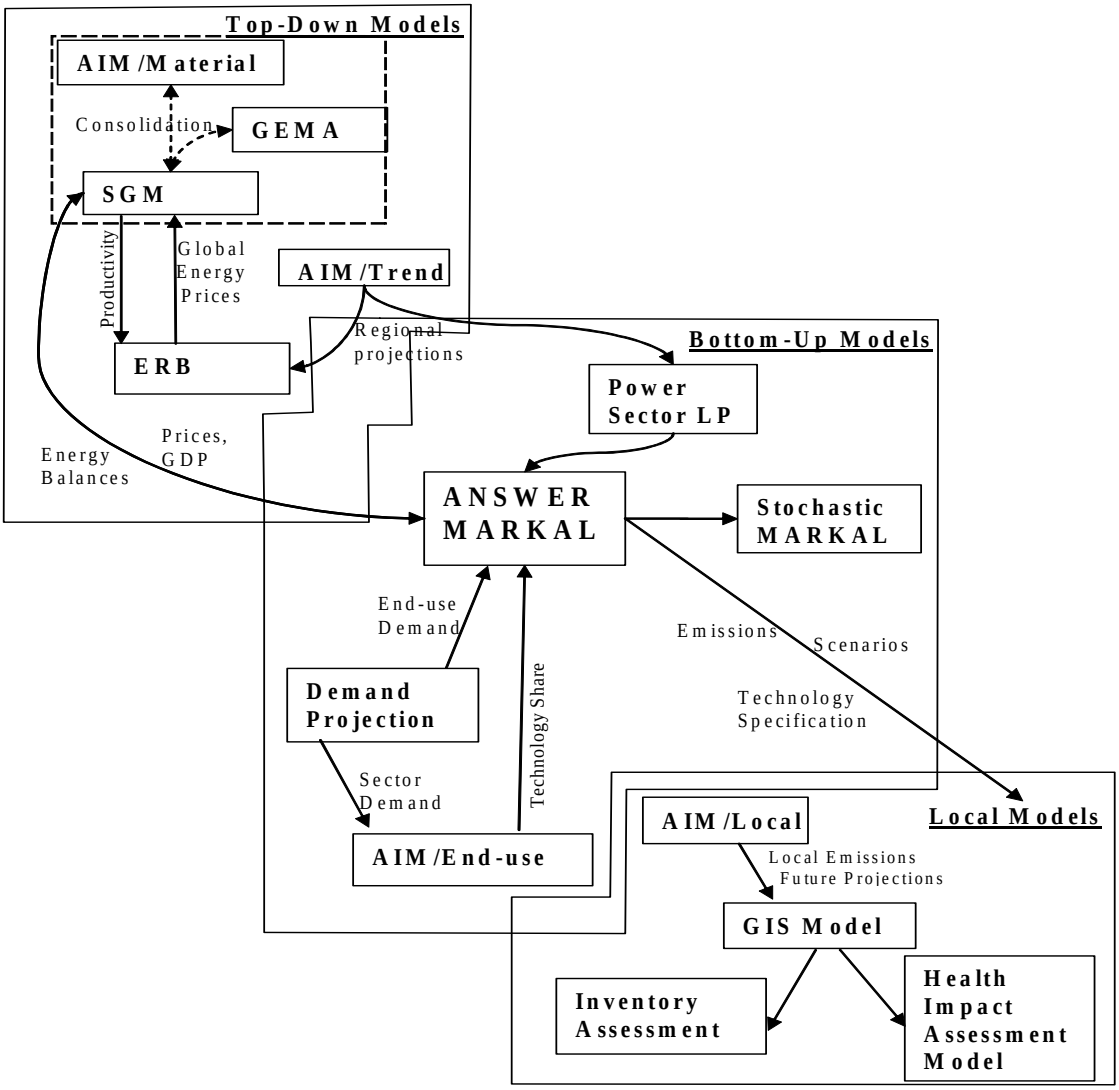


Figure 1: Soft-linked Integrated Modelling Framework

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.

Utilizing the integrated framework of models, the baseline scenario follows in the footsteps of Special Report on Emission Scenarios (SRES) of 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.

Scenario description and analysis of results

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 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 R&D 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 1 gives the key scenario drivers and implications on the key model parameters.

Table 1: Key Scenario Drivers and Model Parameter

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 (↑)

Power capacity and generation

In the *base case* the Indian power generation capacity increases about nine times from 96 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. 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. Hydro 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 technologies include small hydro, 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 total electricity generation increases from 422 TWh in 1995 to 4325 TWh in 2100 (Figure 2).

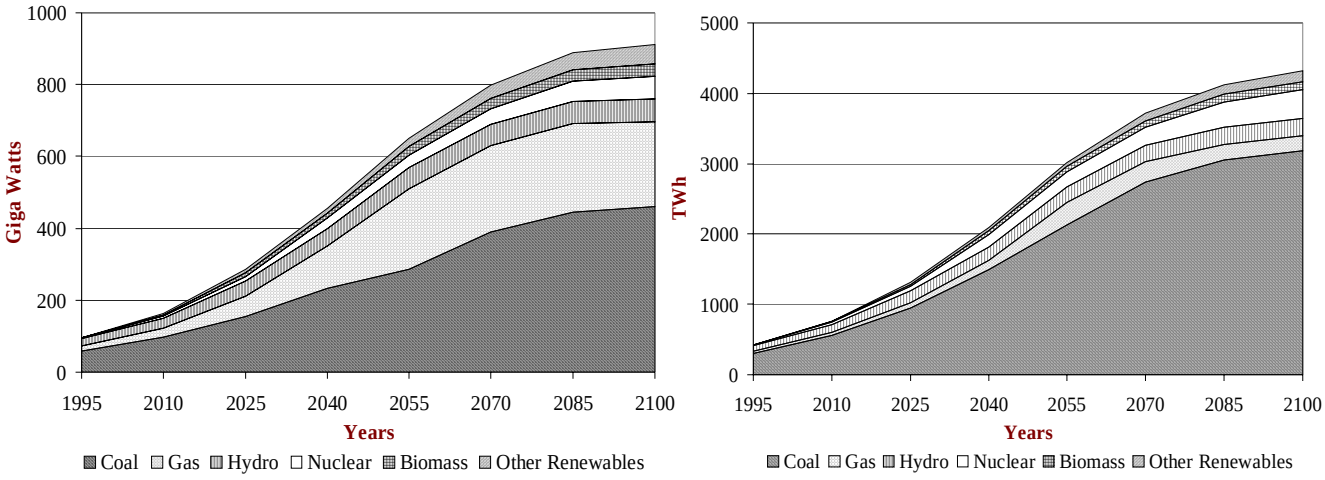


Figure 2: Base Case Power Capacity and Generation Mix

Domination by coal-based generation continues. The generation mix indicates a ten-fold increase in coal based power generation over 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 carbon emissions compared to coal, expanding the supply of natural gas becomes a critical variable in India's future energy equation.

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.

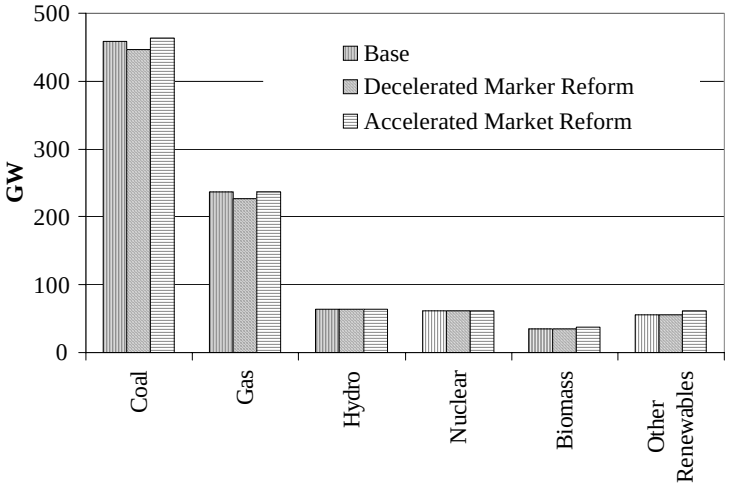


Figure 3: Electricity Capacity Requirement in 2100 (GW)

The shares of large hydro and nuclear remain at about 7% in this reform scenario. The installed capacity of renewables in 2100 is 10 GW higher than in the base case (Figure 3)**.**

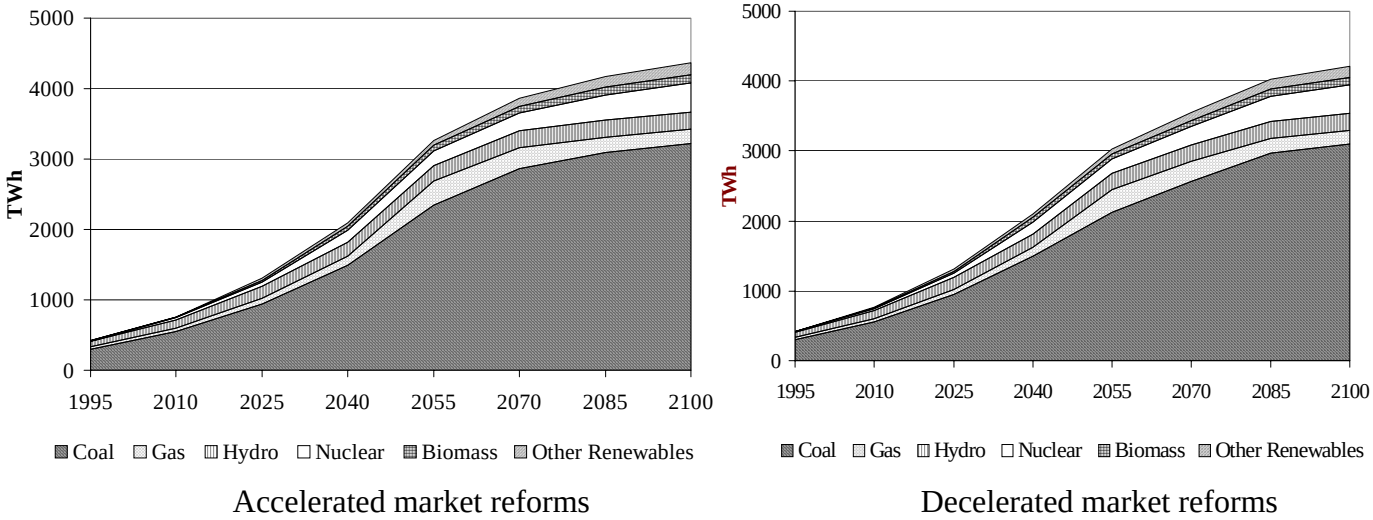


Figure 4: Power generation mix

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 is 7% each, while that of renewables is about 10%. 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.

In the *accelerated development of renewable technologies* scenario the Indian power generation capacity reaches about 940 GW by 2100.

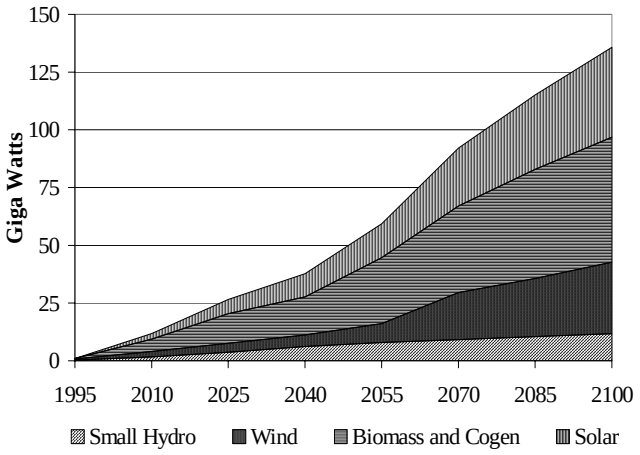


Figure 5: Electricity Capacity for Renewables

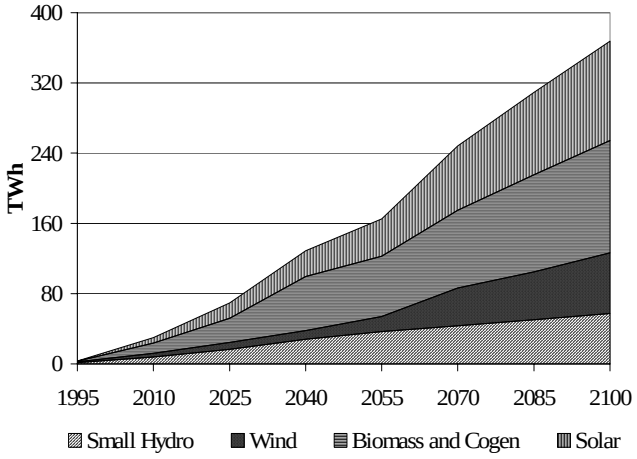


Figure 6: Electricity generation by renewables

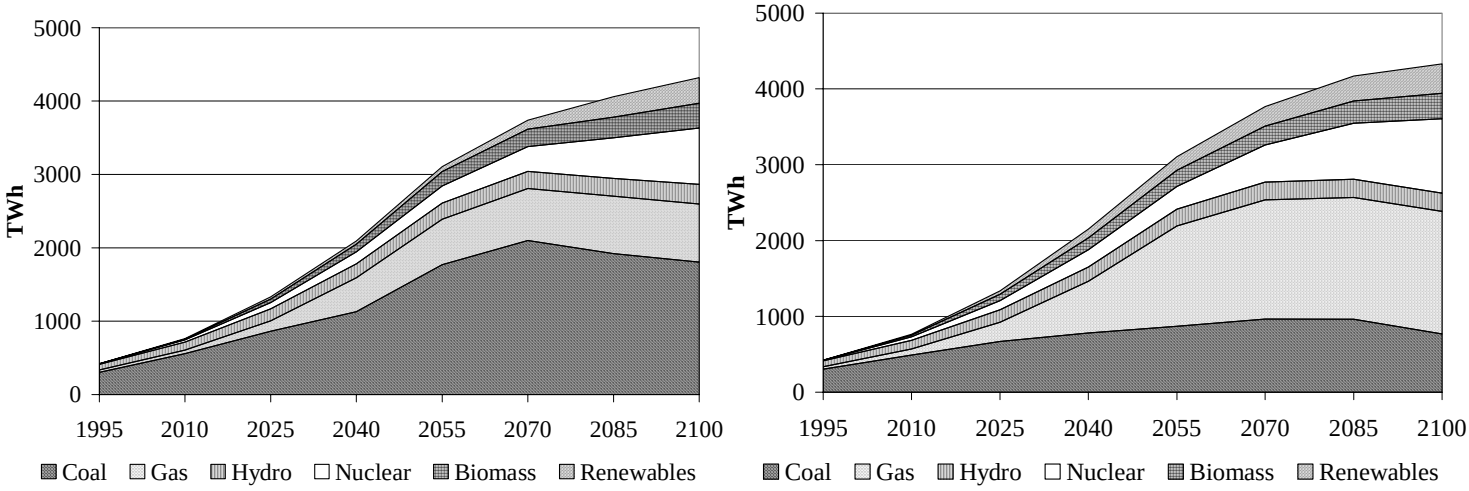
Renewable technologies include small hydro, wind, cogeneration and biomass technologies, solar and geothermal. Wind power capacity doubles to reach 30 GW by 2100 (Figure 5). Its share in generation is about 23 percent among renewable technologies (Figure 6). In the long run, penetration of wind power 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 hydro capacity reaches around 12 GW and that of solar about 40 GW, which is 30% of total renewable capacity. Penetration of solar 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 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.

In the above-described scenarios no carbon 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 carbon emissions there would be changes in technology choices within the energy system. In the model, reduction in carbon emissions is achieved through constraint on the cumulative carbon emission. The B2 scenario group is closest to the base case assumptions of the

present study. Hence the world cumulative carbon emissions according to the B2 scenario of AIM have been used for the calculating the emission budgets. Emission budgets for India have been calculated for global carbon stabilization levels of 550 and 650 ppmv (see Shukla *et al.,* 2001). The budgets corresponding to the two stabilization levels are 73 GtC and 87 GtC respectively. Figure 7 shows power generation mix for the two stabilization scenarios.

From figure 7 it is evident that the share of coal in total generation in the stabilization scenarios has reduced significantly over the base case.



650 ppmv 550 ppmv

Figure 7: Power Generation mix

Consequently the share of cleaner fuels like gas, nuclear, biomass and renewables has increased. The share of coal in total generation in the base case in 2100 is about 74%. This share reduces to 41% in the 650 ppmv scenario and to about 18 % in the 550ppmv scenario. In both the scenarios the share of coal is predominantly taken by gas. The share of gas in the 650 ppmv scenario in 2100 is about 18%. The share of gas further increases to about 35% in the 550 ppmv scenario. These increases are substantial considering the share of gas in the base case in 2100 was close to 5%. In this study it has been assumed that the commercial potential of large hydro is exhausted in the base case. Hence there is no change in generation from large hydro in the stabilization scenarios over the base case. The share of nuclear in 2100 in the 650 ppmv case is about 18% while that in the 550 ppmv case is 23%. The share of nuclear in 2100 in the base case was about 9%.

Under both the stabilization scenarios mitigation happens during the latter half of the century. While under both the scenarios coal power technologies decline in 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 a developing country perspective this would require special attention. The main competition arises from future expectations of development of low/no carbon technologies. In the stabilization scenarios renewable technology penetration also 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 carbon technologies but also fills into the market niche left by outgoing coal technologies.

Carbon Emissions

Carbon emissions increase by about eight times over the model horizon from 206 million tonnes of carbon in 1995 to about 1.66 billion tonnes in 2100 in the base case (Figure 8). Share of the power sector carbon 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 carbon mitigation.

Industry and transport are the next major contributors to carbon emissions, sharing about 50% between them. The continued dominance of coal results in carbon emissions in both the accelerated and decelerated market reforms scenarios being close to the base case level.

For 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 carbon intensity (Carbon/GDP) trends (Indexed 1995 = 100) for the two reform scenarios are compared with that of the base case in Figure 9.

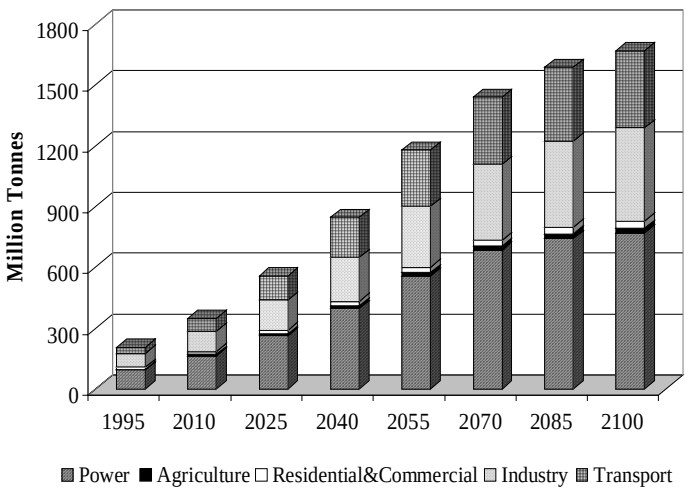


Figure 8: Sector wise carbon emissions for base case

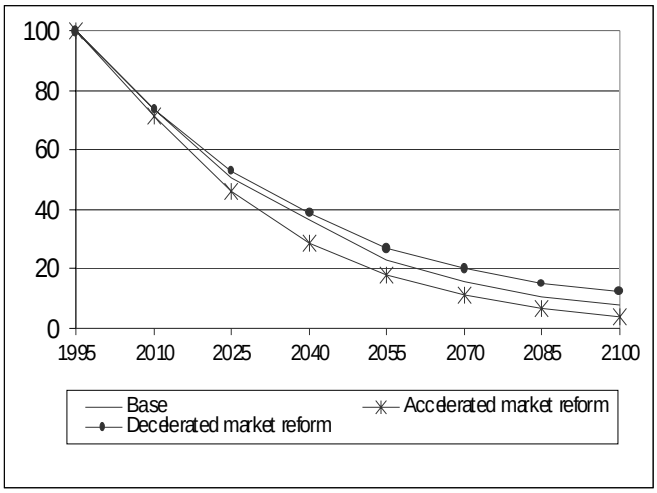


Figure 9: Carbon Intensity

In the accelerated renewable technology development scenario the emissions are 1.65 billion tonnes in 2100. Increased penetration of renewables slightly impacts the carbon emission trajectory. Carbon 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 carbon emissions does not hold. Under competitive dynamics as modelled, the enhanced penetration of renewable technologies happens by replacement of other non-carbon/low carbon technologies that are more expensive compared to fossil fuel technologies. Figure 10 compares the base case emission results with those of the carbon-constrained scenarios while figure 11 gives the carbon to total electricity generated ratio (Indexed 1995 = 100) for the three scenarios.

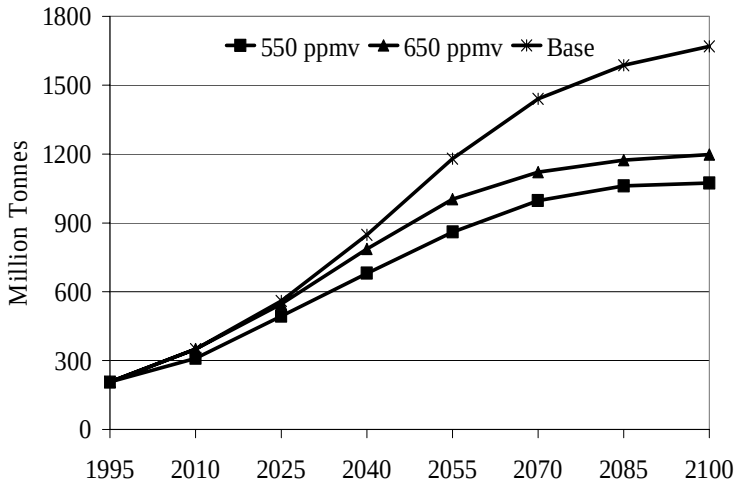


Figure 10: Carbon emission trajectories

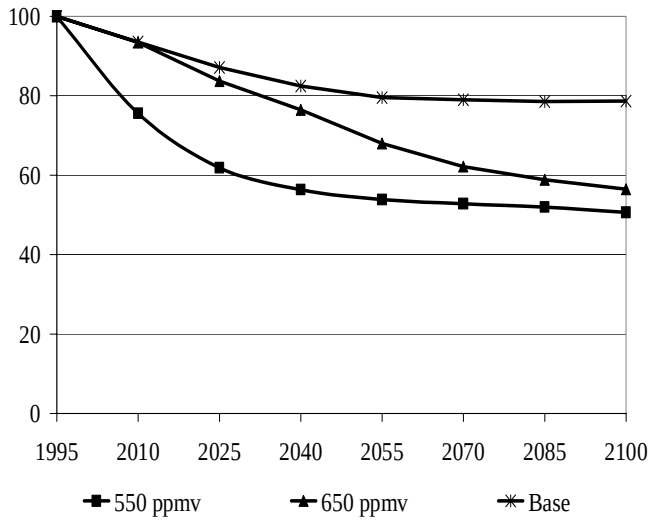


Figure: 11 Carbon/Total electricity generated

The figures shows that most of the mitigation happens during the later half of the 21st century. This is primarily due to inertia of the energy system in the initial periods to respond to policy initiatives. It is seen that in the 550 ppmv scenario, it becomes essential to take policy initiatives to mitigate carbon even in the early part of the present century.

Development of regional energy markets

Preceding analysis indicates a definite trend of increasing demand for clean and cheap 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, 2001) 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; Srilanka 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 capacity of 83000 MW of which 42000 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. 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 was till year 2015. The cooperation scenario assumed 20 percent enhancement in hydro 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 2).

Most major cities in South Asia like New Delhi, Calcutta and Dhaka are faced with the problems of local pollution. The AIM Local model (Yang, 2001) 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.

Table 2: Implications of Regional Co-operation

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

Projections of energy and emission trajectories using AIM Local for the above mentioned cities would be of interest for both researchers and policymakers.

Conclusions

- The South Asian region, which is in a period of transition, is fast emerging as a major contributor of green house gases. This problem is long term and needs to be addressed as one. This is primarily because from the developing country perspective there is inertia towards technological change in the short term.

- 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 technology push policy along with R&D thrust and learning innovations will enhance technology penetration in the short and medium run in renewables like Solar PV and Wind.
- Base case analysis shows that the per capita carbon 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 carbon efficient. There is decoupling between GDP growth and carbon emissions and also between GDP growth and energy consumption. However there is no decoupling between carbon 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 carbon 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 carbon emissions than the base case. Concerted policy initiatives need to be taken in order to encourage the development and penetration of renewables.
- In the accelerated renewable 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 carbon emission trajectory and carbon replacement is insignificant. The conventional belief that renewable technologies shall reduce equivalent carbon emissions does not hold.
- Under the stabilization scenarios mitigation happens during the later half of the century. In case of 550ppmv 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 a developing country perspective this would require special attention. Renewable 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 carbon 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 carbon emissions as discussed earlier, but a strong stabilization regime will enhance the renewable penetration. Therefore it is essential that the region should remain prepared for the development of renewable energy technologies.

- Though beyond the scope of this paper, there is also an immediate need to understand the transport sector and the new emerging technologies within it, given the rising share of this sector in carbon emissions.
- Regional co-operation in energy markets could result in both local and global environmental benefits.

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