Future GHG and Local Emissions for India: Policy Links and Disjoints

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Abstract

This paper estimates the future GHG and local pollutant emissions for India under various scenarios. The reference scenario assumes continuation of the current official policies of the Indian government and forecasts of macro-economic, demographic and energy sector indicators. Other scenarios analyzed are the economic growth scenarios (high and low), carbon mitigation scenario, sulfur mitigation scenario and frozen (development) scenario. The main insight is that GHG and local pollutant emissions from India, although connected, do not move in sync in future and have a disjoint under various scenarios. GHG emissions continue to rise while local pollutant emissions decrease after some years. GHG emission mitigation therefore has to be pursued for its own sake in India. National energy security concerns also favor this conclusion. The analysis of contributing factors to this disjoint indicates that sulfur reduction in petroleum oil products and penetration of flue gas desulfurization technologies are the two main contributors for SO_2 mitigation. The particulate emission mitigation is mainly due to enforcing electro-static precipitator efficiency norms in industrial units, with cleaner fuels and vehicles also contributing substantially. These policy changes are already taking place in India and would only strengthen in future. Another insight is that high economic growth is better than lower growth to mitigate local pollution as lack of investible resources limits investments in cleaner environmental measures. Our analysis also validates the environmental Kuznets' curve for India as SO_2 emissions peak around per capita GDP of US$ 5,300-5,400 (PPP basis) under various economic growth scenarios.

Keywords: Disjoint, future emissions, Kuznets' curve, mitigation, scenario analysis.

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1 Introduction

Expanding industrialization, increasing incomes, rapidly rising transport and modernizing agriculture have led to rapidly rising energy consumption in India over the past decade. The Indian GDP has grown at 5.7 percent per annum during the eighties and above 6 percent during the nineties (GOI 2000). Indian energy use has grown faster than GDP for the last twenty years now (GOI 2000; CMIE 1999). Carbon emissions have almost grown parallel to energy use. Sulfur emissions have a slower growth rate since biomass emissions also contribute to them (Garg et al. 2001a, b). While the impacts of climate change from greenhouse gas (GHG) emissions are felt over a long duration, local pollution causes immediate impacts on health and ecology. Mitigation of local pollutant emissions therefore is a more urgent concern, accentuated by fast deteriorating air quality in many Indian cities (CPCB 1991, 1996; Biswas 1999).

Large fossil fuel use by major energy intensive sectors, like power generation, steel, cement, chemical and fertilizer, transport etc, contributes to high GHG and local pollutant emissions. Thus high growth of these sectors has resulted in a high growth rate of emissions at above 5 percent per annum during 1990-95 (Garg et al. 2001a, b). However, methane emissions have grown slower at 1.8 percent due to agriculture sector dominance. Although nitrous oxide emissions also have agriculture dominance, their growth rate has been higher due to faster growth of the main contributing factor namely use of synthetic fertilizer. Efficient use of energy in various sectors results in reduced emission growth rates. Therefore the future dynamics of energy consumption and technology selection in various sectors will play an important role in long-term emission trajectories. This paper estimates these future GHG and local pollutant emission trends under alternate scenarios. The study indicates that the trajectories of two prominent local pollutants, namely SO_2 and particulate, decline in later years under reference scenario itself while those of greenhouse gases continue rising. Thus local pollution and GHG

mitigation policies in India, although connected, have a disjoint in future. Therefore, GHG mitigation policies will have to be followed for their own sake in India.

2 Methodology and scenario description

The future carbon and local pollutant emission trends under various policy scenarios from India would mainly depend upon macro-economic structure, economic growth, improvements in energy use efficiency, global energy prices, and specific policy paradigms. The technology dependence of emissions necessitates disaggregated study of energy demand and supply projections, environmental performance of various technologies, and detailed assessment of technological progress and energy transitions in future. We, therefore, adopt a bottom-up methodology, which can be used to examine in detail the economic and environmental implications of different energy policies and vice-versa (figure 1). This integrates an energy system optimization model (MARKAL), fifteen end-use sector models (AIM/ENDUSE), and a demand projection model that separately projects demands for forty-two end-use services (Garg et al. 2001c).

2.1 Reference scenario

The 'reference scenario' for future emission projections captures continuation of present government policies, and forecasts of various macro-economic, demographic and energy sector indicators. The Indian GDP is assumed to grow by about six folds during 2000-2035 at an annual average of 5.2 percent based on past 30-year trends and government projections. The population will touch 1.44 billion in 2035 (World Bank 1995) indicating a four-fold increase in per capita income during 2000-2035. On the fuel side, power plants using low ash imported coal (and even low sulfur in some cases like Ahmedabad Power Plant), and mandatory washing of coal that is used 700 Km away from the mine mouth, will alter the all India weighted average ash and sulfur percentages for coal. Similarly, the recent policy initiatives to reduce sulfur contents in the diesel for the transport sector, use of compressed natural gas for public transport in Delhi, emission

limiting performance standards for passenger vehicles, and stricter enforcement of existing environmental laws would bring down the related emissions (Mashelkar et al. 2002). However, the Delhi experience is unlikely to be repeated in other cities due to its cost (Chandler et al. 2002).

2.2 Alternate policy scenarios

The reference scenario provides a platform for analyzing the emission mitigation implications of alternate policy paradigms. The scenarios analyzed here are the economic growth scenarios (high and low), sulfur mitigation scenario, carbon mitigation scenario, and frozen (development) scenario.

The 'high growth scenario' assumes 6.1% average annual GDP growth rate over 2000-2035, synchronized in the short term with the latest government targets of 8% GDP growth during the next five years (GOI 2001). Fast technological progress, liberalized trade markets, improved infrastructure facilities, government as a facilitator, and rising income levels bring in this scenario. 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. However high income levels encourage comfortable and convenient lifestyles, therefore increasing energy consumption in commercial and residential sectors as well as penetration of cleaner fuels like LPG and electricity.

In the 'low growth scenario', on the other hand, low productivity growth rates result in lower per capita incomes. The macro-economic structural shift away from agriculture is also slower than the reference case. There are slower improvements in autonomous energy efficiency of supply and end-use technologies. Transfer and penetration of new technologies is also slow.

In 'sulfur mitigation scenario', 6 Tg SO_2 emission cap is applied for the Indian emissions with an intention that the emissions in the long run are lower than the present levels (Garg et al.

2001b). Replacement and retrofitting of existing sulfur intensive technologies by cleaner technologies in initial periods, however, generate a momentum where the SO_2 emissions in later period go down below the sulfur cap. SO_2 emission mitigation is achieved through a combination of command & control and market based instruments. The policy decisions, as those mentioned above, provide the initial thrust to SO_2 mitigation. Later, market pull mechanisms like sulfur mitigation through efficiency improvements, cleaner fuels, fuel switching etc take over, as cleaner technologies and fuel become the market norm. Deeper and faster sulfur mitigation policy may however force a faster meshing of these two instruments duly complementing each other in an emissions cap-and-trade approach.

In 'carbon mitigation scenario', 7% cumulative carbon mitigation is envisaged over the reference case carbon emissions from India during 2000-2035, almost similar to the original Kyoto targets for Annex-I countries. The cumulative carbon mitigation is spread across years and sectors in a cost-effective manner by MARKAL. Carbon mitigation commitments would impact future technology fuel mix and therefore the investment decisions. Efficiency improvement measures, low and carbon free technologies and cleaner fuels will penetrate faster and infrastructure to facilitate these has to be built. Societies with strong mitigation commitments would therefore have to start thinking differently.

3 Reference scenario results

Under the reference scenario, the four-fold growth in per capita GDP during 2000-2035 drives per capita energy consumption growth by 2.4 times, electricity by 3.6 times, carbon emissions by twice and SO_2 emissions by 0.9 times. For the economic growth trajectory up to 2020, the overall energy consumption grows at a higher rate than the GDP. However operational efficiency improvements in technologies and technological stock turnovers lead to declining energy intensities (energy consumed per unit of output) in later years. The per capita carbon emissions reach 0.51 tons in 2035, almost doubling during 35 years.

3.1 Emissions basket

The integrated energy environment analysis projects carbon and local pollutant emission trajectories up to 2035 (table 1). Methane and nitrous oxide emissions depend more on agriculture sector and therefore are not direct model outputs. Their emission projections depend on growth of rice paddy cultivation, livestock population, biomass consumption, waste decomposition (solid and water) and use of nitrogen fertilizer. We have used secondary data sources and some MARKAL input/outputs to estimate these growths and then used inventory framework (Garg et al. 2001a) to project methane and N_2O emissions for the reference case.

While the carbon emissions almost triple over 2000-2035, those for local pollutants in general grow much less. Methane emissions grow along agriculture sector rate while N_2O trajectories have a close correlation with nitrogen fertilizer use (Romanovskaya et al. 2002). The emission growth rates follow a decreasing trend for almost all the gases. Carbon and SO_2 emission trajectories are moving in closer bands up to 2010, but in later years SO_2 emissions decline much faster than carbon emissions. Particulate emissions are also declining. This indicates that Indian GHG and local pollutant emissions have a disjoint in future. The main thrust in local pollution mitigation is provided by improved fuel quality resulting in lower ash and sulfur contents, stricter enforcement of emission regulations, deeper penetration of flue gas desulfurisation (FGD) technology, and energy efficiency improvements. These policy developments are already visible in India as mentioned in earlier sections, and are likely to be strengthened in future. CO_2 equivalent GHG emissions increase by 2.8 times in 35 years. CO_2 share grows to 76 percent from the present 62 percent, mainly at the expense of methane. Nitrous oxide emission share stagnates around 6 to 7 percent. Since methane and N_2O emissions are much more regionally dispersed and CO_2 emissions are dominated by large point sources (LPS), the growing dominance of latter provides an opportunity for effective GHG mitigation measures in future.

LPS emissions are growing at a rate much faster than the national average. Future emission analysis using AIM/Local model suggests that LPS would continue to contribute a major share to national emissions, with industrial centers and large cities growing into major hotspots of emissions (table 2). The largest 50 LPS contribute almost 50% of all India emissions in 2000, which decreases to 41% in 2030 as the emissions from smaller LPS increase. The CO_2 and SO_2 emissions from LPS and area sources over the years for reference case are illustrated in figures 2 and 3 respectively (Kapshe et al. 2002). These indicate the regional spread of future GHG and local emission disjoints.

At sectoral level, power sector carbon emissions increase around 3.5 times during 2000-2035 as coal continues to be the mainstay of the Indian power sector. However its use becomes cleaner over the years. The industrial emissions increase by 2.75 times while its overall share reduces as industrial energy efficiency improves. The apparent slow down in industrial emissions is due to increased use of power in many industries. Since emissions from electricity are counted against power sector emissions for primary energy consumption, industrial emissions appear to grow slowly. Transport sector emissions increase above four-folds during 2000-2035 with their overall share in national emissions increasing to 21 percent. Road contributes 92 percent to transport sector emissions in 2035 as compared to 87 percent in 2000. Therefore increasing rail's share at national level is a favored policy option for not only improving overall fuel efficiency of the transport system in the long run, but also to mitigate carbon emissions.

The other two GHG emissions have agriculture sector domination. Methane emissions from paddy cultivation stagnate around 4 Tg per year as better harvesting practices and water management offset cultivation growth. Livestock related emissions grow by 37 percent during forty years, while biomass emissions mostly stagnate around 3 Tg per year. The share of municipal solid waste (MSW) in methane emissions increases gradually to over one-fifth in 2035. This indicates growing size of urban population, and improved collection and disposal of

MSW. This share is at par with the present MSW share in developed countries and offers substantial methane recovery possibilities from waste-dumps in urban centers.

The growth of NO_X emissions from transport sector slows down as cleaner and efficient technology stocks take over. NO_X control in power sector is a difficult proposition as it requires extremely fine temperature control of coal combustion process and also post-combustion NO_X control is quite expensive (Guha 1999).

Particulate emission growth from the transport sector slows down from 2005 and emissions start declining from 2010 onwards as cleaner and efficient technology stocks take over. However as Electro Static Precipitator (ESP) operations become more and more compliant to the existing pollution prevention acts, industrial and power sector particulate emissions decline much faster. Therefore transport sector share in overall particulate emissions increases even though their absolute values come down. Moreover the multiple and dispersed nature of transport sector sources makes implementing mitigation measures much more difficult than those for the large point sources in industry and power sectors.

3.2 Mitigation policy analysis

The reference scenario incorporates many improvements and policy changes covering existing technology efficiencies, cleaner technology penetration, cleaner fuel penetration, and stricter enforcement of pollution norms among others, as already explained. In their absence, future emissions trajectories would traverse much higher levels than those discussed so far. The present analysis is aimed at assessing these much higher levels, identifying relative contributions of these measures on overall emission mitigation, and therefore assists in emphasizing the relative importance of various policies in the reference scenario. These will also indicate alternate emission baselines in case certain policy packages, as envisaged in the reference scenario, are not implemented.

Figure 4 indicates the result of this simulation for carbon emission mitigation. The lowest line on the graph represents the reference case estimates for carbon emissions. The second line from the bottom represents emissions when no autonomous energy efficiency improvements (AEEI) were incorporated over 2000-2035 in the reference scenario for all supply and demand technologies. The difference between the bottom-most two line therefore represents the carbon mitigation contributed by AEEI. Power, steel and cement sectors play prominent role here. Power and cement sector potential for carbon mitigation has been indicated in other developed countries as well (Soares and Tolmasquim 2000; Schaeffer et al. 2001). The next line represents estimate values for incremental emission volumes when no new technologies are permitted to penetrate on both supply and demand sides, therefore freezing the existing technological know-how levels. The highest line represents estimate values for incremental emission volumes when no macro-economic structural changes are expected to occur in future and the existing macro-economic structure continues with a reliance on heavy industries. There is a 46 percent increase in carbon emissions over the reference case if the existing technological and macro-economic structures are frozen. Supply technologies contribute almost 17 percent of this increase while demand technologies 12 percent as latter consume considerable electric power. The supply side increases are mainly due to an increase of 65 percent in coal based power generation, while demand side changes are mostly due to steel and cement sectors.

Figure 5 indicates similar results for SO_2 emission reduction. The bottom line gives the reference case emissions. The next line represents estimate values for incremental emission volumes when fuel sulfur content reductions are not executed and these are frozen at present levels. The next trajectory estimates emissions in absence of investments in FGD technology. The next three trajectories represent similar simulation results as those for carbon emissions above. Holding back reduction of sulfur contents in petroleum products alone accounts for 62 percent increase in SO_2 emission volumes in 2035 with almost three fourths coming from the

transport sector. These increases are gradual and well spread over in time. In fact as cleaner diesel has been made available in the four metro cities from 1st April 2000, the second line has already started moving towards the reference case emission estimates. Similarly removing FGD installations alone increases the emissions by 56 percent over the reference case in 2035. However these increases are more towards later years as more FGD penetration occurs. Freezing the autonomous energy efficiency improvement increase the emissions only marginally as compared to the above two measures. Supply and demand side technologies contribute almost equally to these. In comparison, freezing the existing technological know-how levels has a higher impact on emission levels, which increase by 30 percent in 2035 over the previous line. Supply side accounts for three fourths of these since futuristic clean coal technologies and gas based power generation emit much less sulfur than the existing sub-critical pulverized coal technology. Lastly the increased emission estimates due to frozen macro-economic structure are mainly due to power sector where the increasing demand in heavy industries is met by coal-based power that is sulfur intensive.

Had absolutely no sulfur dioxide emissions control measures been assumed in the reference case, it is estimated that emission volumes would have increased rapidly to more than thrice the reference case in 2035. Some of these sulfur mitigation measures are already visible in recent policy guidelines of the power, oil and natural gas, and environment and forest ministries of the government of India and have been discussed in earlier sections. Moreover the latest scenario descriptions (IPCC 2000) also acknowledges these reducing trends in global sulfur emissions. Japan's experience in the battle against air pollution (Sawa 1997) illustrates a similar story between 1960 and 1996 where actual SO_2 emissions reduced due to similar measures adopted in Japan.

The factors contributing to particulate matter emission reductions (figure 6) have two predominant contributors. The first is due to holding back ESP performance improvements, thus

continuing them at the present operational levels around 95 percent. These increase the particulate matter emissions by more than three-folds and are concentrated in power and cement sectors. The second factor is due to freezing of autonomous energy efficiency improvements. Transport sector is the major contributor here as Euro-II norms and further technological progresses in this industry are assumed to evade India. These double the transport sector particulate emission loads over those in the last line. The high particulate emissions from existing diesel driven two-wheelers, cars and buses continue and these increasing loads pollute the urban air environment. Following the high growth rate in transportation of hotspot districts and state capital cities in India (Garg et al. 2001a and b), these cities will become gas chambers under this scenario due to cumulative effects of local pollutants.

4 Scenario results

4.1 Comparative emissions

The carbon emissions continuously rise although the growth retards in later years under all scenarios (figure 7). The cumulative emissions would touch 25 billion tons under the frozen scenario and represent a sort of upper bound on Indian carbon emissions in the long run. The comparative sulfur emissions offer some interesting insights (figure 8). The foremost being that for mitigating local pollution, high economic growth is better than low growth. This is reflected in earlier bending of the SO_2 emission curves under high economic growth scenarios. The sulfur emissions start reducing after 2020 for the high growth case, after 2025 under the reference case and after 2035 under the low growth case. This is against the conventional wisdom that high growth brings in more industries that in turn increase pollution levels. This may be true in a short time horizon. However as the economy matures, the market realizes the economic benefits of cleaner and more efficient production. High economic growth also provides more resources to invest in cleaner technologies and processes. Gradually the environmental push policies in the initial periods are replaced by market driven pull policies for cleaner and more efficient

production in the long run. The results of synergy between environmental consciousness, energy efficiency and economic growth are felt at a macro level.

The second insight is that the magnitudes of mutual ancillary benefits for sulfur mitigation policy and carbon mitigation policy vary drastically. The emission elasticity of local pollutants due to carbon mitigation policy (around 1.2) and carbon elasticity due to sulfur mitigation policy (around 0.1) corroborate this. For equal mitigation of SO_2 emissions, carbon emission mitigation is much more in following carbon mitigation policy. However additional investment requirements and increased dependence on imported gas make it an unattractive national policy especially when India does not has any GHG reduction commitments. Cleaning the local air appears to be well within our reach with a little efforts and policy re-orientation. Under the sulfur mitigation scenario, coal use continues to a large extent although with cleaner technologies and FGD penetration, as compared to substantial penetration of gas based and carbon free technologies in the carbon mitigation scenario. Coal is the abundant national resource while most of the gas has to be imported. It indicates that national energy security concerns would be better addressed under sulfur mitigation policy scenario if mitigating local pollutant emissions is the primary concern.

The relative costs of mitigating local pollutants either through carbon mitigation or through direct local pollutant mitigation policies also favor the latter. SO_2 emissions may be mitigated at around US$ 120 per ton of SO_2 in the sulfur mitigation scenario. Particulate mitigation mainly requires stricter enforcement of existing norms in India. On the other hand, if we mitigate SO_2 and particulate emissions as ancillary benefits of carbon mitigation measures like fuel switching from coal to gas, the investment requirements per ton SO_2 mitigation are more than double due to relatively higher infrastructure investment requirements and higher average fuel prices (gas imports). Even the 10th annual SO_2 allowance auction at the Chicago Exchange conducted in March 2002 indicated 51% price differential between the spot and seven-

year advance auctions (Bologna 2002). Cost effectiveness requires equal marginal mitigation cost across various mitigation options. It may therefore be concluded that in a developing country perspective, where resources are competing for allocation, if mitigating local pollutants (and not GHG mitigation) is the national priority, then it is better to follow the direct local pollutants mitigation route rather than going through the indirect GHG mitigation route. GHG emission mitigation therefore has to be pursued for its own sake in India.

The analysis also indicates the excessive local pollutant emissions under the frozen scenario compared to all other scenarios. This implies that the present policy thrust to mitigate local pollution levels should continue; otherwise there may be a serious local pollution problem.

4.2 Mitigation potential

The future emission analysis under reference and alternate scenarios suggests a hierarchy of carbon mitigation options in India. These include energy demand and supply side efficiency improvements, fuel switching from coal to gas, residential biogas digesters, enhanced penetration of renewable, and nuclear power. It is estimated that India could reduce projected carbon emissions over the next decade by nearly 120 Tg for less than $25 per ton of carbon equivalent, with a substantial portion available at a very low cost (table 3). Demand- and supply-side energy efficiency measures alone could avoid 45 Tg of emissions. During the short term, the demand sectors show more flexibility than the supply side by contributing more to carbon mitigation, since end-use technological stock turnover is faster due to their relatively shorter lifetimes. A case in point is the up gradation of India's vehicle stock over the past decade fuelled by economic reforms-induced rapid penetration of domestically produced foreign brands, and rising concerns about local air quality (CMIE 2002; Mashelkar et al. 2002). Energy efficiency improvements in industry comprise a major portion of these low hanging fruits and include a switch to electric arc and gas based sponge iron processes in steel, improved dry process in cement,

cogeneration in sugar, waste recycling in paper, membrane process in caustic soda, and vertical shaft in brick kilns.

In later periods, beyond 2015, supply side contribution increases gradually reaching almost three-fourths of total carbon mitigation in 2035. These include mitigation due to lower power requirements as demand side energy efficiencies improve. The supply side mitigation options are primarily associated with fuel switching from coal to natural gas, and penetration of carbon-free technologies like nuclear and renewable.

The cost of these measures depends on the extent to which they would be applied, which in turn depends in part on the stringency of GHG mitigation policies. India could in the midterm help finance these mitigation measures by selling emission reduction credits, either through the Clean Development Mechanism established under the Kyoto Protocol, or in a futures market based on expectations that future global policies will impose more stringent GHG restrictions, provided that credits could be banked and sold.

4.3 Emissions -Environmental Kuznets' Analysis

US economist Simon Kuznets (1955) proposed that income inequality generally rises as development proceeds, falling only after the rewards of growth accumulate. Similarly some researchers have claimed to identify an environmental Kuznets curve, in which pollution from industry, transport and households increases until development generates enough wealth to promote significant pollution control (World Bank 1994). The specific claim has been that increase in per capita income is initially encountered by worsening environmental conditions up to a certain point, which is then followed by improvement in environmental quality – relationship that is graphically portrayed by an “inverted U”. This suggests that a country has to attain a certain standard of living before it starts to respond to its concern for environmental quality. Whether the turning point occurs when countries reach per capita incomes of $5000 or $15000 per year has never been clear. Environmental Kuznets curve provides snapshots of a

dynamic relationship between pollution and development that is evolving in response to experience. World Bank data reveal that pollution intensity falls by 90% as per capita income rises from US$500 to $20000 (World Bank 1994). Most important, the fastest decline occurs before countries reach middle-income status. There have been some recent criticism of the environmental Kuznets curve as well, indicating that the inverted U curve has been found only for a few pollutants, mainly those that have local health effects and can be dealt with without great expense (Hettige et al. 1997).

SO_2 is a major local pollutant having profound health impacts. Future SO_2 emissions are influenced by level and structure of energy supply, end-use demands, levels of industrial output and process mix, and extent of SO_2-control policy interventions (IPCC 2000). Grubler (1993) has reviewed literature and empirical evidence, and showed that these driving forces are linked to the level of economic development. With increasing affluence, energy use per capita rises and its structure changes away from traditional solid fuels (coal, lignite, peat, fuelwood) toward cleaner fuels (gas or electricity) at the point of end-use. This structural shift combined with the greater emphasis on urban air quality that accompanies rising incomes results in a roughly inverted U (IU) pattern of SO_2 emissions and/or concentrations. Emissions rise initially (with growing per capita energy use), pass through a maximum, and decline at higher income levels due to structural change in the end-use fuel mix and control measures for large point sources.

Our analysis indicates that SO_2 emissions peak around per capita GDP of US$ 5300-5400 for India on purchasing power parity (PPP; one US$ = 9 Indian Rupees) basis. In the low growth scenario this per capita GDP is reached around the year 2035, whereas in high growth scenario this is reached around the year 2020 (figure 9).

5 Conclusions

Our study demonstrates that there is an overlap between economic options for CO_2 and SO_2 mitigation. However, this is mainly because energy substitution from coal to natural gas and

renewables offers an economic way of sharing costs to achieve both CO_2 and SO_2 mitigation. This may be because some gas-based technologies are proving to be economically viable (compared to coal based technologies) in electricity generation and a few other industries worldwide (Pandey 2002). For a CO_2 mitigation policy SO_2 mitigation will be correlated, however, the two trajectories get decoupled under a SO_2 mitigation policy regime. Thus the carbon limitation has much greater residual impact on SO_2 trajectory whereas SO_2 limitation has milder residual effect on carbon trajectory (Pandey and Shukla 2002).

In future the LPS would continue to be responsible for considerable part of the Indian carbon emissions. Analysis of LPS emissions highlights sectors and plants where mitigation efforts should be targeted for cost-effectiveness. Power sector is the predominant emission source for CO_2 and SO_2. Power generation and industry would contribute almost 75% of CO_2 emissions. Since these sectors have a natural dominance of LPS, mitigating emissions from LPS would become even more important in future. Operational improvements (like heat rate reduction, excess air control etc.), better maintenance, reducing transmission and distribution losses in the power sector would go a long way in emissions mitigation. Energy efficiency improvement measures in other sectors like steel, cement, caustic soda, sugar, brick making and fertilizer would improve productivity while reducing overall emissions.

The emission trajectories of two prominent local pollutants, namely SO_2 and particulate, come down in later years under reference scenario itself while those of greenhouse gases continue rising. The analysis of contributing factors to these future trends indicated that sulfur reduction in petroleum oil products and penetration of FGD technologies are the two main contributors for SO_2 mitigation while particulate emission mitigation is mainly due to enforcing electro-static precipitator (ESP) efficiency norms in industrial units. These policy changes are already taking place in India and would only strengthen in future.

These results have implication for sequencing of mitigation options over a long term planning period. Facilitating rapid penetration of conventional sulfur removal technologies for coal washing, limestone injection, and flue gas desulfurization, is an immediate domestic policy imperative, independent of GHG mitigation objective. The GHG mitigation policies for India therefore may have to be crafted for its own sake, in accordance with the global GHG mitigation dynamics.

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Table 1: Emission inventory projections for India (Tg)

Emissions (Tg)	**2000**	**2005**	**2015**	**2025**	**2035**	**CAGR***
Carbon	253	329	488	645	738	3.1
Methane	19.5	20.5	22.2	24.5	25.7	0.8
N_2O	0.31	0.41	0.61	0.78	0.88	3.0
CO_2 equivalent GHG	1433	1764	2445	3121	3519	2.6
SO_2	5.47	5.54	7.32	8.39	7.24	0.8
Particulate	5.16	4.71	4.42	4.03	3.1	-1.4

* Percentage Compounded Annual Growth Rate over 2000-2035

Table 2: Share of LPS emission in all India emissions

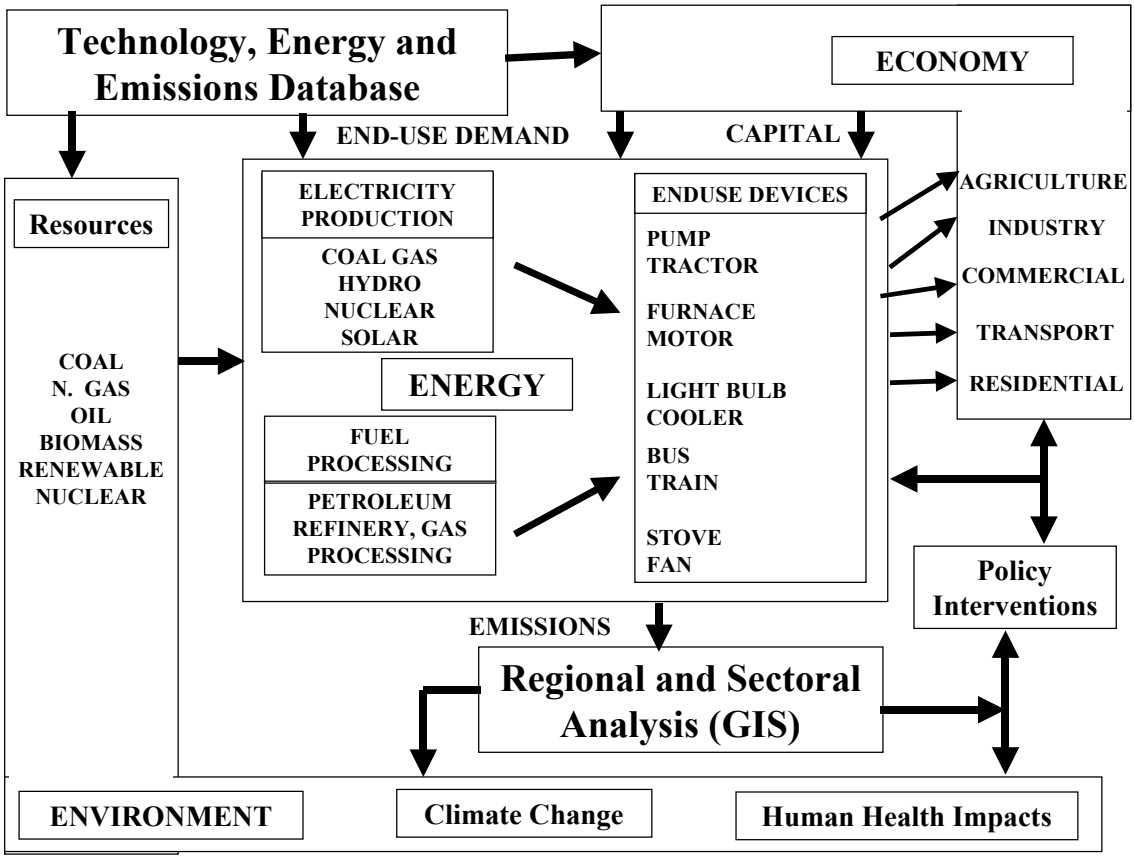
Emission details		**2000**	**2010**	**2020**	**2030**
CO_2	Number of LPS	303	374	435	495
	LPS emissions (Tg)	630	989	1418	1912
	All India emissions (Tg)	983	1556	2189	2945
	LPS/Total (%)	64	64	65	65
SO_2	Number of LPS	368	437	499	559
	LPS emissions (Tg)	3.12	3.96	4.35	3.83
	All India emissions (Tg)	5.02	5.87	6.25	5.77
	LPS/Total (%)	62	67	70	66

Table 3: Carbon mitigation potential in India (Tg)

Mitigation options	**Mitigation potential during 2002-2012 (Tg)**	**Long-term marginal cost ($/tC)**
Demand side energy efficiency	45	0-15
Supply side energy efficiency	32	0-12
Electricity transmission and distribution	12	5-30
Renewable electricity technologies	23	3-15
Fuel switching (coal to gas)	8	5-20

Source: Based on present analysis and modeling exercises reported in Rana, A. and Shukla, P.R. (2001), Ghosh, D. et al. (2001), Garg, A. and Shukla, P.R. (2002), and Chandler, W. et al. (2002)

Figure 1: Integrated modeling framework



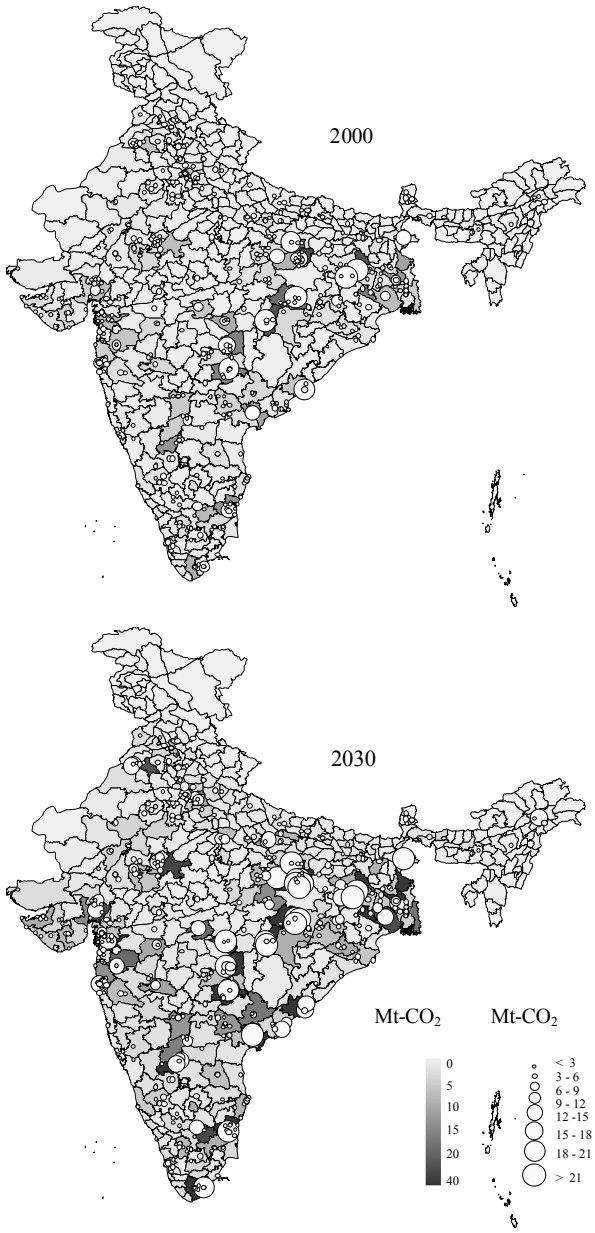


Figure 2: Regional distribution of CO_2 emissions in India 2000-2030 in Reference scenario
Note: Circles show emissions from large point sources

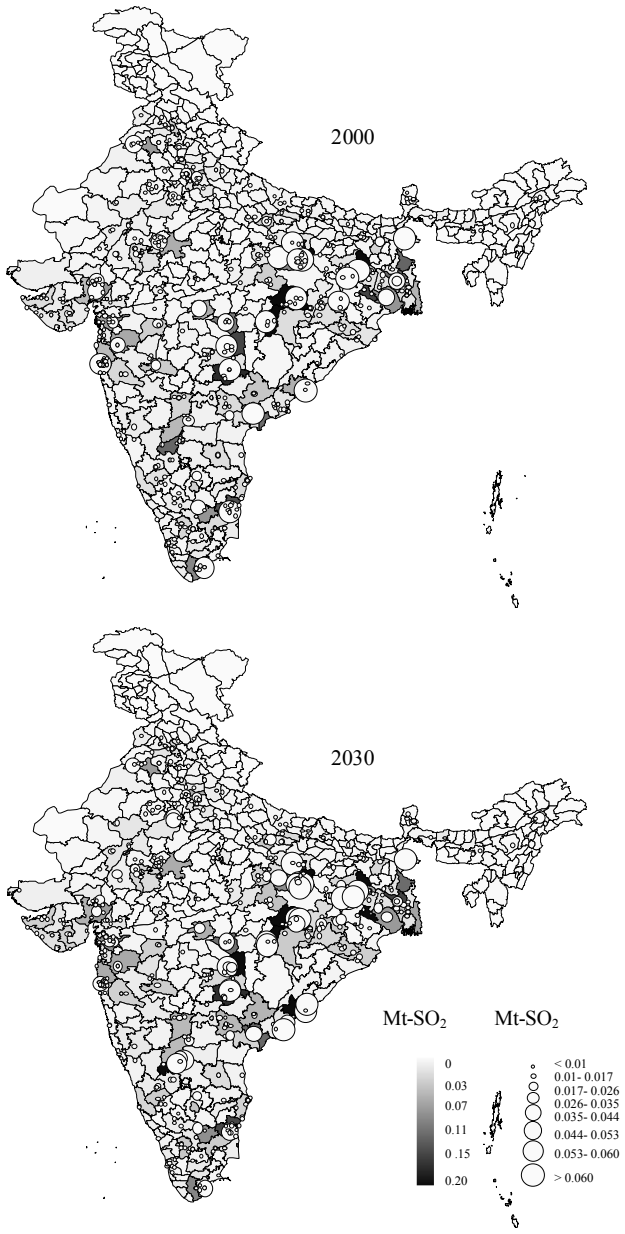


Figure 3: Regional distribution of SO_2 emissions in India 2000-2030 in Reference scenario
Note: Circles show emissions from large point sources

Figure 4: Contributing factors for carbon emission mitigation under reference scenario

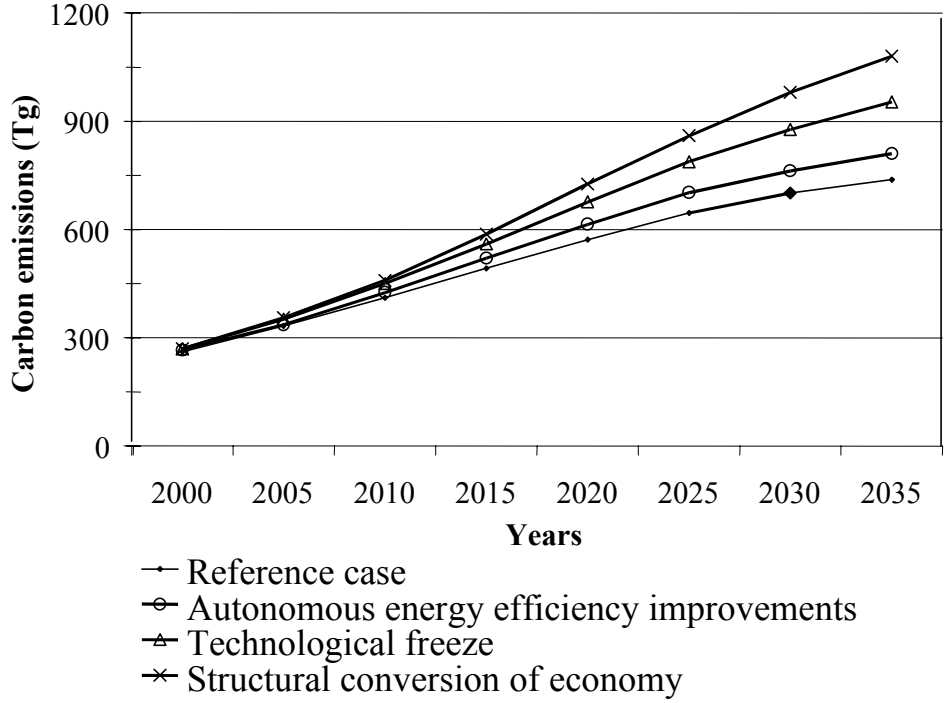


Figure 5: Contributing factors for SO_2 emission mitigation under reference scenario

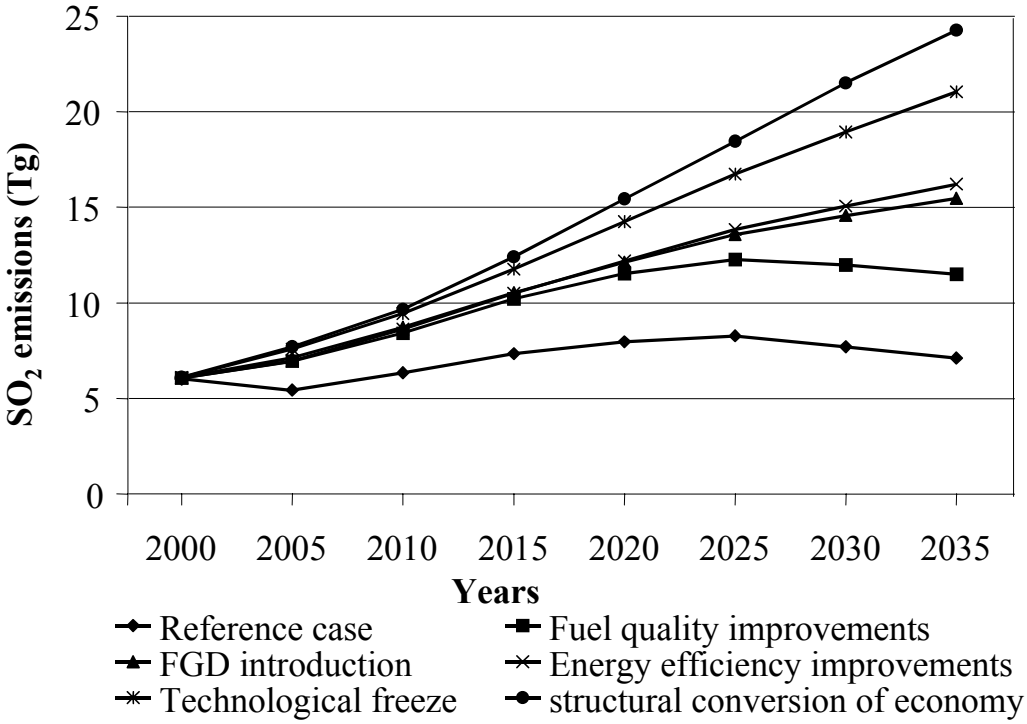


Figure 6: Contributing factors for particulate emission mitigation under reference scenario

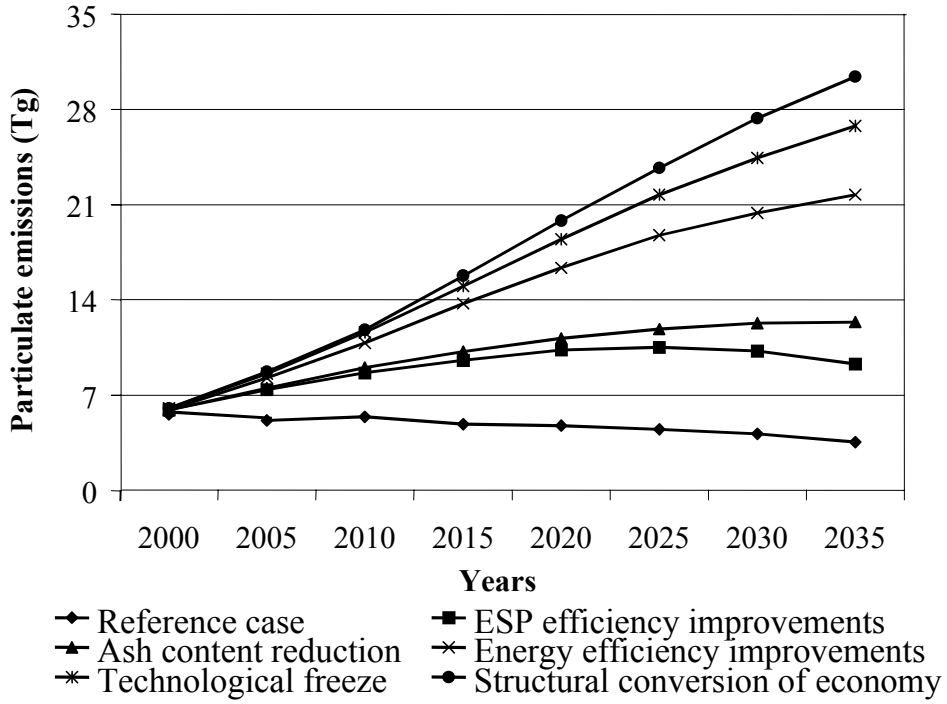


Figure 7: Comparative carbon emissions across scenarios

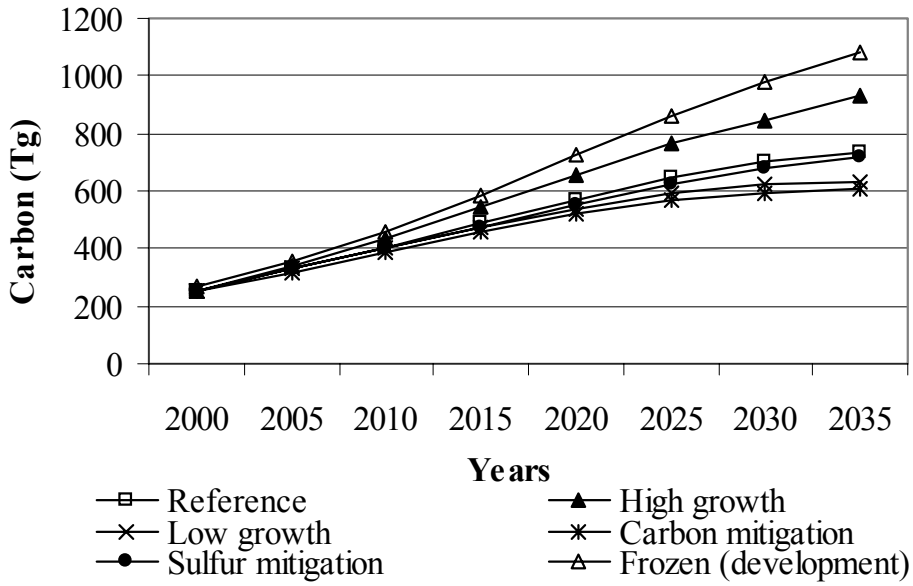


Figure 8: Comparative SO_2 emissions across scenarios

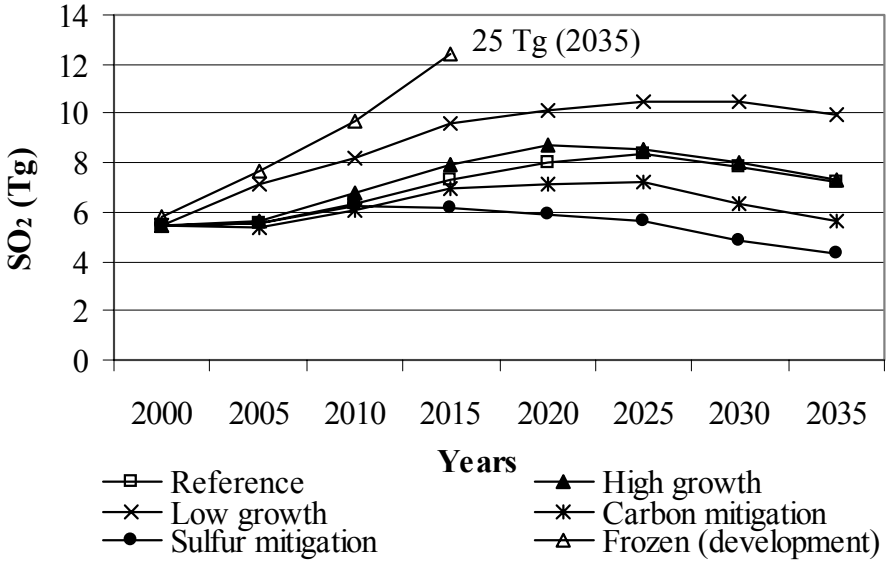
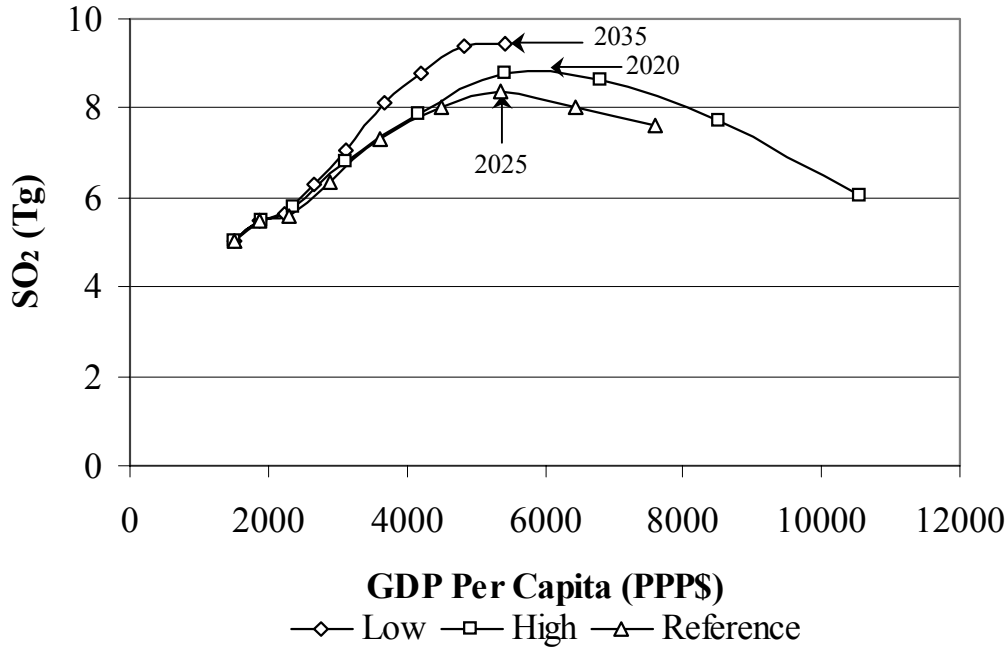



Figure 9: Environmental Kuznets' curve for SO_2 emissions