7. Methodology for Exploring Co-benefits of CO_2 and SO_2 Mitigation Policies in India using AIM/Enduse model

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Summary. This study illustrates a methodology to explore co-benefits of CO_2 and SO_2 mitigation objectives, along with initial results for India, using AIM/Enduse model. It is assumed for India that use of low-sulfur fuels in transport sector, rapid penetration of sulfur removal technologies in power sector and large industry boilers will enable early decoupling of the two emissions under the business-as-usual scenario. Two additional sets of scenarios – one for carbon taxes and the other for corresponding SO_2 constraints – were set up to analyze co-benefits. Initial results suggest that under the application of carbon tax there is a strong overlap among the economic options for reduction of CO_2 and SO_2 emissions over the business-as-usual level. However, under pure SO_2 mitigation targets over business-as-usual, the economic options for SO_2 mitigation and CO_2 mitigation are likely to get decoupled. AIM/Enduse, being rich in representation of technological processes, is an effective vehicle to analyze these effects.

7.1 Introduction

The Indian energy system, dominated by coal, accounted for over 250 million tons of carbon emissions from the country in 2000. Despite a decade old process of economic reforms and accompanied introduction of efficient technologies and practices in certain sectors like process industries, manufacturing, and transportation, carbon emissions continue to rise at an alarming rate. This is mainly because of three reasons: i) The Indian economy continues to grow at a high rate; ii) Cumulative shift away from coal remains insignificant, particularly in the electricity generation and industrial sectors, and iii) Inefficient technologies and practices still thrive in significant parts of the economy including several small and medium industries and services, agriculture, and the traditional sector. Although India does not have GHG emissions mitigation commitment under Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), it would be interesting to analyze the effect of future carbon mitigation commitment on Indian economy, energy, and emissions.

An important concern of policy makers in developing countries like India will be how to achieve a synergy between domestic environmental policy priorities and

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GHG mitigation objectives to accrue the co-benefits. Concerns of controlling local pollution deservedly figure high on the list of domestic policy priorities. Since developing countries have scarce financial resources, it is essential for them to design policies that are aimed toward domestic priorities and simultaneously contribute to GHG mitigation objectives.

In this paper we present a methodology for analyzing above-mentioned synergy using AIM/Enduse model, with initial results for India. We analyze two sets of policies – (i) CO_2 emissions mitigation (ii) SO_2 emissions mitigation – and the extent to which the latter can contribute to the former and vice versa. Focus of our analysis is on technology and energy options available within different sectors of Indian economy to achieve these objectives. For this purpose we set up the AIM/Enduse model for India by treating entire country as a single area, in contrast to chapter 6 of this book which analyzes Indian area and large point source emission using AIM/Local model with spatial disaggregation.

7.2 Bottom-up Modeling Framework

Depending on the way a model captures interactions between energy and economy, it is classified as bottom-up or top-down. Zhang and Folmer (1998) have discussed different bottom-up and top-down economic modelling approaches used in the context of carbon dioxide emissions mitigation. Pandey (2002) has discussed this classification from the viewpoint of energy policy modeling and research concerns for developing countries. Bottom-up models contain detailed representation of the energy resources, technologies, and end-uses. They are better suited than top-down models to analyze sector and technology level policy options. Although top-down models have better characterization of impacts on economic growth, price feedback, and trade (Hourcade 1993), they are weak in representation of technology and energy details.

AIM/Enduse (Morita *et al.* 1996; Kainuma *et al.* 1999, 2000), MARKAL (Fishbone and Abilock 1981; Berger *et al.* 1987), and EFOM (Finon 1974) are examples of bottom-up models. AIM/Enduse scores over several other bottom-up models with respect to its representation of technological detail. On one hand, it permits modeling of technological processes as complex networks of devices through which energy and materials flow. On the other hand, it enables representation of SO_2 and NO_x pollution removal processes as attachments to regular industrial technologies. Refer to ‘A Guide to AIM/Enduse model’ in this book for further details.

Setting up country-level AIM/Enduse model for India comprised four steps: (i) Selection of sectors, services, technologies, reference year and discount rate, (ii) Estimation of data for services and technologies in the reference year, and (iii) Projection of service demands, technology shares, and technology improvements over 37 year time horizon, and (iv) Design of business-as-usual (BAU) and other scenarios for policy analysis. We summarize the salient features of AIM-India in Table 1.

Table 1. Salient features of AIM-India

Feature	Description
Time horizon	37 year horizon, from 1995 to 2032
Demand sectors*	18 sectors comprising agriculture, commercial, residential, road transport, rail transport, air transport, water transport, iron & steel, aluminium, cement, brick, nitrogenous fertilizer, pulp & paper, caustic soda, soda ash, cotton textiles, sugar, and other industries
Energy conversion and supply sectors	3 energy conversion and supply sectors comprising electricity, oil refining, and natural gas (refer to Sec. 4 of 'A Guide to AIM/Enduse model')
Services	Over 70 services including 33 final (or external) services
Energy	Over 20 energy kinds including 10 primary (or external) energy kinds
Technologies*	Over 190 devices in demand sectors, and over 25 devices in energy conversion sectors (refer to Appendices J and K of 'A Guide to AIM/Enduse model')
Sulfur removal processes	Pollution removal processes like coal washing, limestone injection, conventional and advanced flue gas desulfurization in electricity generation and process industries
Data estimation for reference year	Bottom-up methodology for estimation of data in reference year based partly on published sources and partly on standard assumptions (refer to Sec. 4 of 'A Guide to AIM/Enduse model')
Projection of service demands	Projection of service demands until 2032 based on a top-down methodology comprising projection of drivers using logistic regression (refer to Sec. 4 of 'A Guide to AIM/Enduse model')

* Technological processes in small and medium industries have not yet been modeled in the current version of AIM-India.

7.3 Design of Scenarios

7.3.1 BAU scenario

No GHG policy intervention was assumed in BAU over the 37 year horizon. Service demands were projected assuming GDP growth with compounded annual growth rate of 5% in 1995-2032, decreasing from 5.7% in 1995-2010 to 4.0% in 2020-2032. Annual discount rate was fixed at of 6%.

BAU scenario assumes SO_2 control measures that are already envisaged (for the near-term implementation) and others that can be anticipated (in the long-term) for a rapidly growing developing economy with low per capita present income. Mitigating SO_2 pollution in urban India is a domestic concern that has recently attracted attention of policy makers. Electricity generation, Iron & Steel industry, Road transport, and Biomass combustion comprised over 65% of India's SO_2 emissions in 1995 (Garg and Shukla 2002). Recent steps taken by policy makers include regulation targeted at reducing sulfur content of diesel in large cities accompanied with an elaborate vehicle inspection and certification system. Such measures have already led to a reduction of SO_2 concentration in traffic intersection areas in Delhi by over 50% from 1995 to 2000 (Sengupta 2001). Additionally, regulations for adoption of pollution removal technologies like coal washing and flue gas desulfurization in thermal power plants have been reasonably successful. In BAU, we assumed continuation of these trends.

7.3.2 Policy scenarios

Carbon tax scenarios

Carbon tax is one of the instruments for mitigating global CO_2 emissions that is widely discussed in international forums on climate change. Main economic advantage of emissions tax is that it limits the cost of reduction programme by allowing emission to rise if costs are unexpectedly high (IPCC 2001). Since we wanted to study the linkage between SO_2 mitigation and CO_2 mitigation objectives using AIM/Enduse, we first chose three levels of carbon tax and then set corresponding SO_2 mitigation targets for defining SO_2 constraint scenarios. AIM/Enduse permits application of sectorwise and energywise application of tax or constraints on each gaseous emission. In each scenario, a constant level of carbon tax was applied from 2010 onwards (no tax was applied before 2010). These levels are based on the likely ranges of tax indicated by results for 550 ppmv carbon mitigation target through 2100 from AIM/CGE global model (see Chapters 4 and 10 of this book). However, it must be noted that at this stage these tax levels are for illustrating the methodology. Following tax scenarios were assumed.

- C-Tax (US$50/t-C): Constant tax of US$ 50/t-C from 2010 onwards
- C-Tax (US$100/t-C): Constant tax of US$ 100/t-C from 2010 onwards
- C-Tax (US$200/t-C): Constant tax of US$ 200/t-C from 2010 onwards

SO_2 constraint scenarios

To analyze the co-benefits, we constructed three SO_2 constraint scenarios having SO_2 limitation equivalent to the SO_2 emissions trajectory for each of the three carbon tax scenarios. Table 2 shows the SO_2 emissions constraints for the three scenarios. The scenarios, named SO_2 Constraint1, SO_2 Constraint2, and SO_2 Constraint3, correspond to SO_2 emissions in C-Tax (US$50/t-C), C-Tax (US$100/t-C), and C-Tax (US$200/t-C) scenarios respectively.

The effect of a SO_2 constraint is different from the effect of a carbon tax even if the level of SO_2 emissions is the same in the two scenarios. While a carbon tax increases the price of an energy-kind in proportion to its carbon content, a SO_2 constraint imposes a hard limit on the total quantity of SO_2 emissions in a year. While the former is an example of a market-based intervention, the latter is that of a command-and-control regulation. Imposing an upper limit on SO_2 emission quantity will induce different players to chose technologies and fuels that are lesse sulfur intensive, independent of their carbon emission performance.

Table 2. SO_2 constraint scenarios

Scenario	1995	2005	2010	2020	2032
SO_2 Constraint1	4.93	5.44	5.87	6.06	4.74
SO_2 Constraint2	4.93	5.44	5.87	4.61	3.08
SO_2 Constraint3	4.93	5.44	5.79	3.98	2.30

Note: Units are in Million ton SO_2; These figures denote the upper bounds on quantity of SO_2 emission; Data between specified years are linearly interpolated.

7.4 Results and Analysis

Discussion of BAU scenario for India has been covered under ‘reference scenario’ in Chapter 6 of this book. We will confine our discussion to analysis of policy scenarios. Since the results are from the initial stage of our study, our discussion in this section is meant to illustrate the richness of analyses that is possible with AIM/Enduse model, rather than provide specific numbers for policy recommendation.

Figures 1 and 2 show the CO_2 and SO_2 emissions in BAU and carbon tax scenarios. In comparison to BAU, CO_2 emissions in 2032 under carbon tax scenarios of US$ 50, US$ 100, and US$ 200 decline by 9%, 28%, and 35% respectively. Marginal reduction in CO_2 decreases with increasing carbon tax, indicating a corresponding increase in the marginal cost of carbon reduction.

Carbon taxes aimed at reducing CO_2 also induce significant SO_2 reduction. Explanation for this close association can be found in primary energy substitution as shown in Fig. 3. Under carbon tax scenario of US$ 200, coal reduces by 286 Million tons oil equivalent (Mtoe), whereas natural gas increases by 91 Mtoe and renewables and nuclear energy (excluding biomass) increase by 32 Mtoe, in 2032, as compared to BAU. Most of the energy substitution occurs in electricity generation (higher penetration of natural gas and renewables), iron & steel production (higher penetration of electric arc furnace and direct reduction process), pulp & paper production (higher penetration of waste paper based process), sugar industry (greater use of cogeneration), and residential sector (greater use of fluorescent lamps). There is little change in supply of crude oil due to little switch in road transport sector.

Additionally, there is an increase in efficiency of technologies in various sectors leading to a decline in total primary energy supply during the period 1995-2032 from 29.0 Btoe in BAU to 27.6 Btoe in carbon tax US$ 200 scenario. Substitution of coal primarily by natural gas and renewables, and increase in efficiency, result in a close association between reductions in CO_2 and SO_2. This phenomenon is also observed in case of other carbon tax scenarios.

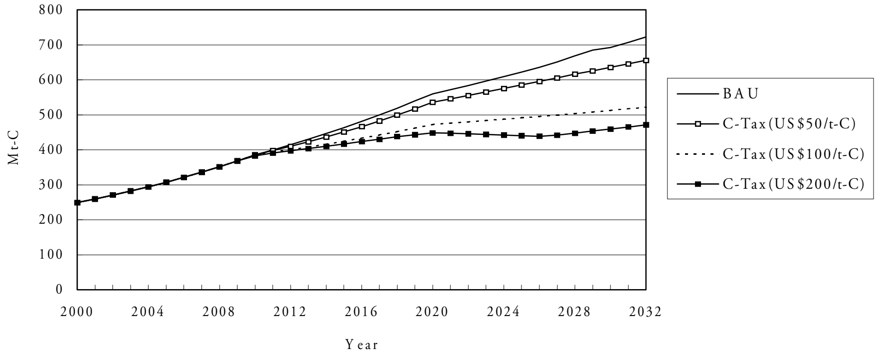

Fig. 1. CO_2 emissions in BAU and carbon tax scenarios

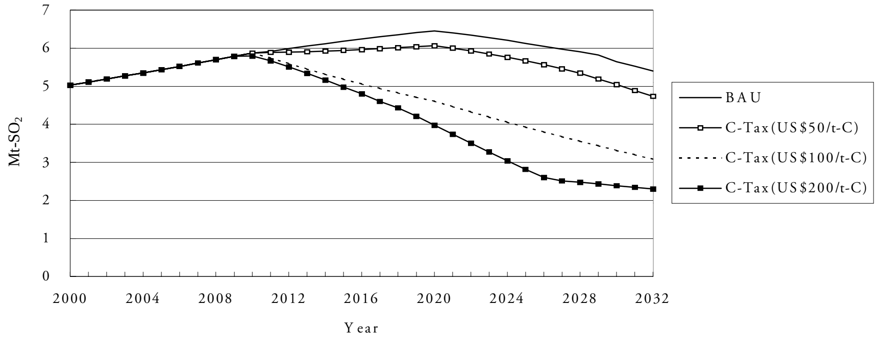

Fig. 2. SO_2 emissions in BAU and carbon tax scenarios

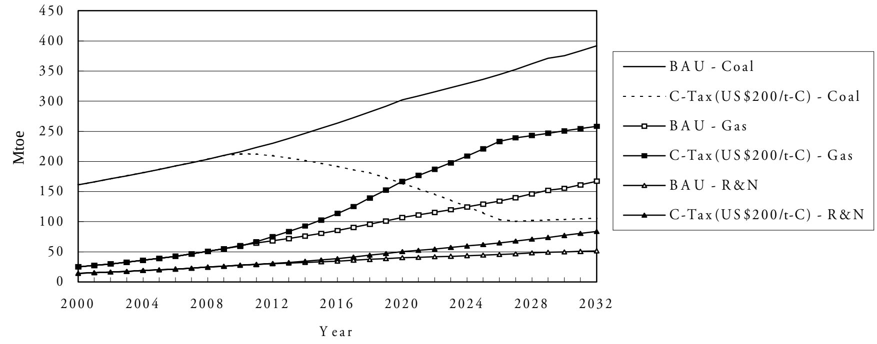

Fig. 3. Primary energy supply in BAU and carbon tax scenarios
Note: Coal includes coal and lignite; Gas includes natural gas; R&N includes renewables and nuclear energy excluding biomass.

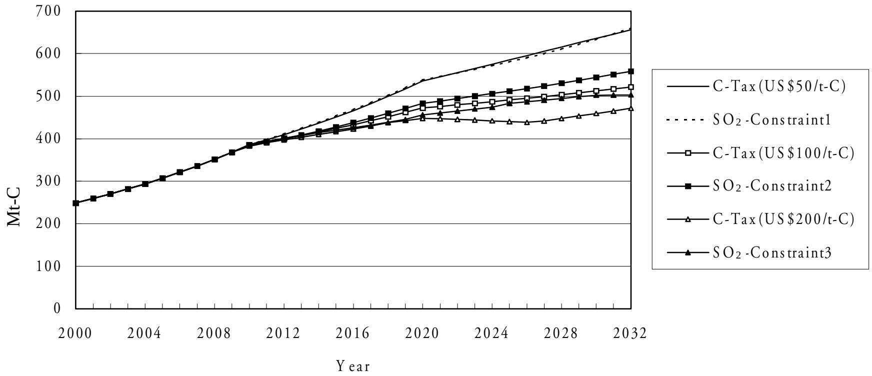

Fig. 4. Comparison of CO_2 emissions in carbon tax and SO_2 constraint scenarios

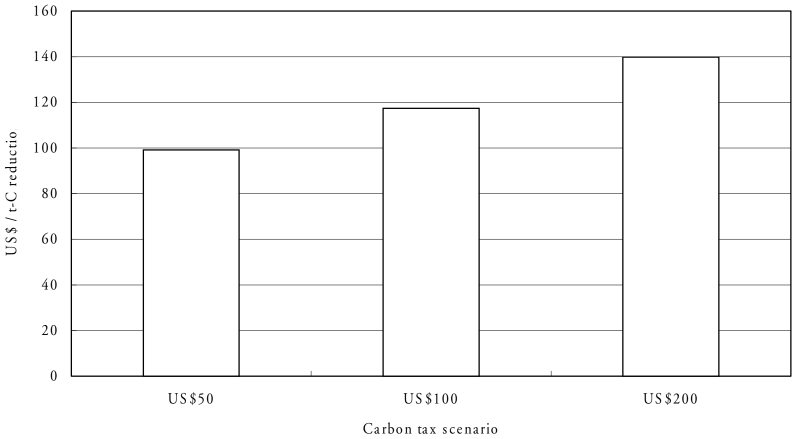

Fig. 5. Average undiscounted system cost over 2000-2032 period of CO_2 reduction under different levels of carbon tax
Note: The cost includes only initial investment cost in plant and machinery and energy costs; it does not include cost of land and building, wages and overhead costs, cost of carbon tax, and cost of implementing regulatory measures.

Figure 4 shows CO_2 emissions under carbon tax and corresponding SO_2 constraint scenarios. Figure 5 compares the average cost of CO_2 reduction over 2000-2032 under carbon tax scenarios. These figures are based on initial results, and in future they may change as we intend to consider more sulfur removal options especially in small and medium industries, and effect of on-going reforms in the power sector. Nevertheless, with the existing results, we can make the following observations.

- For the same trajectory of SO_2 reduction under both policies, carbon emissions are lower under carbon mitigation policy as compare to sulfur mitigation policy.
- Overall, a domestic regulation for reducing SO_2 emissions beyond the BAU is likely to result in some reduction in CO_2 emissions as well. This is because the majority of options exclusively for SO_2 removal available in power sector, transport sector, and large industries, have been selected in BAU itself. Marginal cost of SO_2 mitigation over BAU through such exclusive options is higher than the marginal cost of its mitigation through fuel switch options. This could be because of two reasons: (i) we have not considered SO_2 removal options in small and medium industries, and (ii) further advanced technologies for SO_2 removal in power sector and large industry boilers are expensive. We would expect more decoupling between CO_2 and SO_2 emissions if small and medium industrial processes are modeled and heavy subsidies are given to the advanced sulfur removal technologies.
- Average undiscounted cost of CO_2 reduction increases with the level of carbon tax (from US$ 99/t-C for US$ 50 tax to US$ 140/t-C for US$ 200 tax). This is due to increasing marginal cost of mitigation resulting from higher investment cost of renewable energy technologies and higher cost of supplying natural gas and other cleaner fuels.

7.5 Concluding Remarks

Using a simple methodology for analyzing co-benefits using AIM/Enduse model, our initial study demonstrates that under application of carbon tax, there is a strong overlap between most economic options for SO_2 mitigation and CO_2 mitigation. 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. Even without any carbon tax 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).

Although under a CO_2 mitigation policy regime, extents of SO_2 mitigation and CO_2 mitigation are strongly correlated, the two trajectories get decoupled under a SO_2 mitigation policy regime. It is difficult to comment on the extent of this decoupling because we have not considered several SO_2 removal options in small and medium industries in India.

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 (as is assumed under BAU), independent of GHG mitigation objective. However, for GHG mitigation policy, preparing institutions and infrastructure for facilitating medium-term penetration of natural gas is a robust GHG mitigation option. Although this strategy is economically desirable under GHG mitigation commitment, it will help in achieving medium-term reduction of both CO_2 and SO_2 emissions.

While the SO_2 limitations do generate co-benefits of carbon mitigation, the residual reduction of carbon vis-à-vis BAU would be relatively less significant compared to reduction of SO_2 under carbon control policies. The co-benefits are thus likely to be asymmetric, i.e. carbon limitation has much greater residual impact on SO_2 trajectory whereas SO_2 limitation has milder residual effect on carbon trajectory. The GHG mitigation policies for India therefore may have to be crafted for its own sake, in accordance with the global GHG mitigation dynamics.

Since our analysis in based on initial stage of the study, a few words of caution deserve mention here. Firstly, potential for exclusive SO_2 removal in India is far more than what we have considered in this study, especially in small and medium industries. We intend to enrich our technological database for these industries in future. This potential may lend economic credibility to strong decoupling of SO_2 and CO_2 mitigation objectives for a long period of time.

Secondly, we have not studied the effect of rapid changes going on in the policy regime, markets, and technological progress in the electricity industry. These are global trends and most countries including India have initiated power sector reforms, guided mainly by the reforms model of some of the more advanced countries like the UK. Several experts predict that changes in the structure and technologies in electricity industry worldwide will tilt the economic balance decisively in favor of smaller scale generation technologies like those based on natural gas (Pandey 2002; Patterson 1999). These trends, independent of GHG mitigation commitments, may lend economic credibility to substitution away from coal in the Indian power sector.

Since AIM/Enduse permits exhaustively detailed modeling of technological systems and their emission characteristics, it is an effective vehicle to analyze co-benefit policies. In the next stage, we intend to include small and medium industrial processes too in our study.

References

Berger C, Haurie A, Loulou R (1987) Modelling long range energy technology choices: the MARKAL approach. Technical paper, GERAD, Montreal

Edmonds J, Wise M, Pitcher H, Wigley T, MacCracken CN (1996) An integrated assessment of climate change and the accelerated introduction of advanced energy technologies. Pacific Northwest National Laboratory, Washington, D.C.

Finon D (1974) Optimization model for the French energy sector. Energy Policy 2(2): 136-151

Fishbone LG, Abilock H (1981) MARKAL, a linear programming model for energy systems analysis: technical description of the BNL version. International Journal of Energy Research 5: 353-375

Garg A, Shukla PR (2002) Emissions inventory of India. Tata McGraw-Hill Publishing Company Limited, New Delhi

Hourcade JC (1993) Modelling long-run scenarios: Methodology lessons from a prospective study on a low CO_2 intensive country. Energy Policy 21(3): 309-326

IPCC (2001) Climate change 2001: mitigation. Contribution of Working Group III to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Kainuma M, Matsuoka Y, Morita T (2000) The AIM/End-use model and its application to forecast Japanese carbon emissions. European Journal of Operational Research 122: 416-425

Kainuma M, Matsuoka Y, Morita T, Hibino G (1999) Development of an end-use model for analysing policy options to reduce greenhouse gas emissions. IEEE Transactions on Systems, Man, and Cybernetics – Part C: Applications and Reviews 29(3): 317-324

Kainuma M, Matsuoka Y, Morita T (1998) Analysis of post-Kyoto scenarios: The AIM model. In: Economic modeling climate change: OECD workshop report. Organization for Economic Development and Cooperation, Paris

Morita T, Kainuma M, Harasawa H, Kai K (1996) A guide to the AIM/Enduse model - technology selection program with linear programming. AIM Interim Paper, National Institute for Environmental Studies, Tsukuba

Pandey R (2002) Energy policy modeling: agenda for developing countries. Energy Policy 30(2): 97-106

Patterson W (1999) Transforming electricity. Brookings Press, UK

Sengupta B (2001) Vehicular pollution control in India: technical and non-technical policy measures. Presented at Regional workshop on transport sector inspection and maintenance policy in Asia. ESCAP/UN, Bangkok, Dec 10-12

Zhang Z, Folmer H (1998) Economic modelling approaches to cost estimates for the control of carbon dioxide emissions. Energy Economics 20(1): 101-120