Workshop on

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A Background Note

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Context and Scope

Climate change in the terrestrial atmosphere is no more a speculation with increasing evidences in recent years. It has been widely associated with increase in Greenhouse Gas (GHG) concentration. Climate change has been an intense subject of study amongst researchers, not only in atmospheric and earth sciences, ecology, biology, but also in economics, ethics, and other social sciences. Policy makers are mainly concerned with the three crucial phenomena in this context - emissions of GHG, the resultant climate change and the impact of such climate change on the Earth, and more particularly on flora, fauna, and the human ecosystem. The strong inter-relation between the above phenomena makes the subject more complex. The complexity increases if we include the difficulty in understanding various natural physical phenomena at work and the variability and persistence of human and ecological impacts across the planet. The complexity is further exacerbated by the fact that changes in habits and structures in the socio-economic systems may also have a major influence on the emissions of GHGs.

Climate change evidence has forced the policy makers to deliberate and decide upon the levels and timing of the possible emission abatement, climate adaptation and geo-engineering responses to climate change. This is in itself not an easy task given the uncertainties about the future and the diversity of impacts and interests in different countries and regions of the world. The challenge is to develop precise set of measures (techno-economic as well as political) that would achieve some desired Global and National emission targets at minimum social cost. Economic and environmental models (EEMs) present an opportunity to capture the diverse and complex interrelationships in the socio-economic systems and throw light on various options and their pros and cons in pursuit of an environmentally sustainable economic growth strategy.

EEMs are powerful tools for simulating the present and future scenarios incorporating the likely impacts of GHG and aerosol emissions, macro-economic parameters, geographic and demographic characteristics of the region, energy usage patterns, technological mapping of various sectors, and socio-economic development patterns of the regions etc. The "regions" may cover global, regional, national, state or any other smaller level. The sub-systems/sectors may be terrestrial & aquatic ecological systems, human health, and socio-economic systems (e.g. agriculture, forestry, fisheries and water resources), economic sectors (e.g. energy, industry & infrastructure etc.).

No single model, for the time being, is fully global (i.e. represent all major world regions), and at the same time fully local (i.e. provide sufficiently detailed representation of each and every national system for detailed decision making). Various models try to approach such an ideal representation at the expense of some loss of detail and realism for individual country representation. Some of the details which a model based policy analysis has to address include investment requirements and their availability, energy supply (indigenous availability vis-à-vis imports) and their prices, technology R&D and technology transfer issues, local and global environmental implications, institutional requirements and capacity building measures, role of international collaborations, and socio-political implications. An integrated assessment of economic, energy and environment policies is thus imperative for progressing on a path towards a sustainable energy and environment future.

The present set of models can be classified under two paradigms, top-down and bottom-up models, depending on how the model captures the interactions between energy, environment & economy (Figure 1). Top-down models are aggregated and are general equilibrium models whereas Bottom-up models are detailed with representation of energy sources, conversion technologies and end use demands. These models are generally partial equilibrium models.

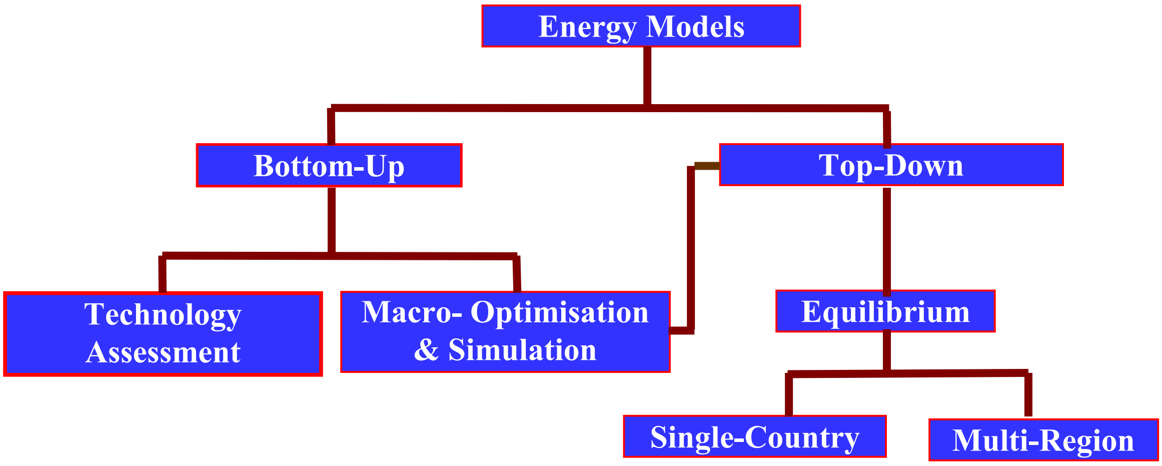

Figure 1: Classification of Energy Sector Models

<u>**Top Down models**</u>

The top-down modeling takes a macro view of the modeled region and intends to reproduce macro level interactions between economic sectors. They have higher sectoral aggregation, but better characterisation of impacts on economic growth, price feedbacks, and trade (Hourcade, 1993). These models represent the macro-economic interlinkages between the aggregate production sectors of an economy, consumers, and the government. They are weak in capturing the technology details. GLOBAL 2100 (Manne and Richels, 1990), Dynamic General Equilibrium Model (Jorgenson and Wilcoxen, 1990), Second Generation Model: SGM (Edmonds et. al, 1993), which is a computable general equilibrium (CGE) model, Edmonds-Reilly-Barns: ERB model (Edmonds and Reilly, 1983; Reilly et al., 1987; Edmonds and Barns, 1992) are some examples of top-down models. These models stress consistency of variables and parameters across sectors, however, they make exogenous assumptions relating to efficiency and social changes. A typical top-down model will help the policy maker in assessing the macro-economic impacts (overall change in GDP, consumption, investments, imports and foreign exchange) of a particular market instrument employed for GHG and aerosol emission mitigating (e.g. Carbon tax).

<u>***Second Generation Model (SGM)***</u>

The SGM is a computable general equilibrium (CGE) model in the top-down group of models. SGM analysis can spread across time-periods more than 50 years. The economy is represented by production sectors, final demand sectors and factors of production. A sector may consist of several sub-sectors, each using a different set of technologies and fuel grades. Each sub-sector within a sector produces a homogenous good. Production relations can be represented by constant elasticity of substitution (CES) functions. Technological change is assumed to be "Hicks Neutral" and is exogenously introduced as change in total factor productivity. Economic growth occurs through enhanced factor supply and improved productivity, i.e. technological progress. Technological progress also results from the selection of new technologies. Investment in a sector (or sub-sector) in each period depends on the savings in the economy and expected profit in the sector. Investment allocation is determined by a logit function.

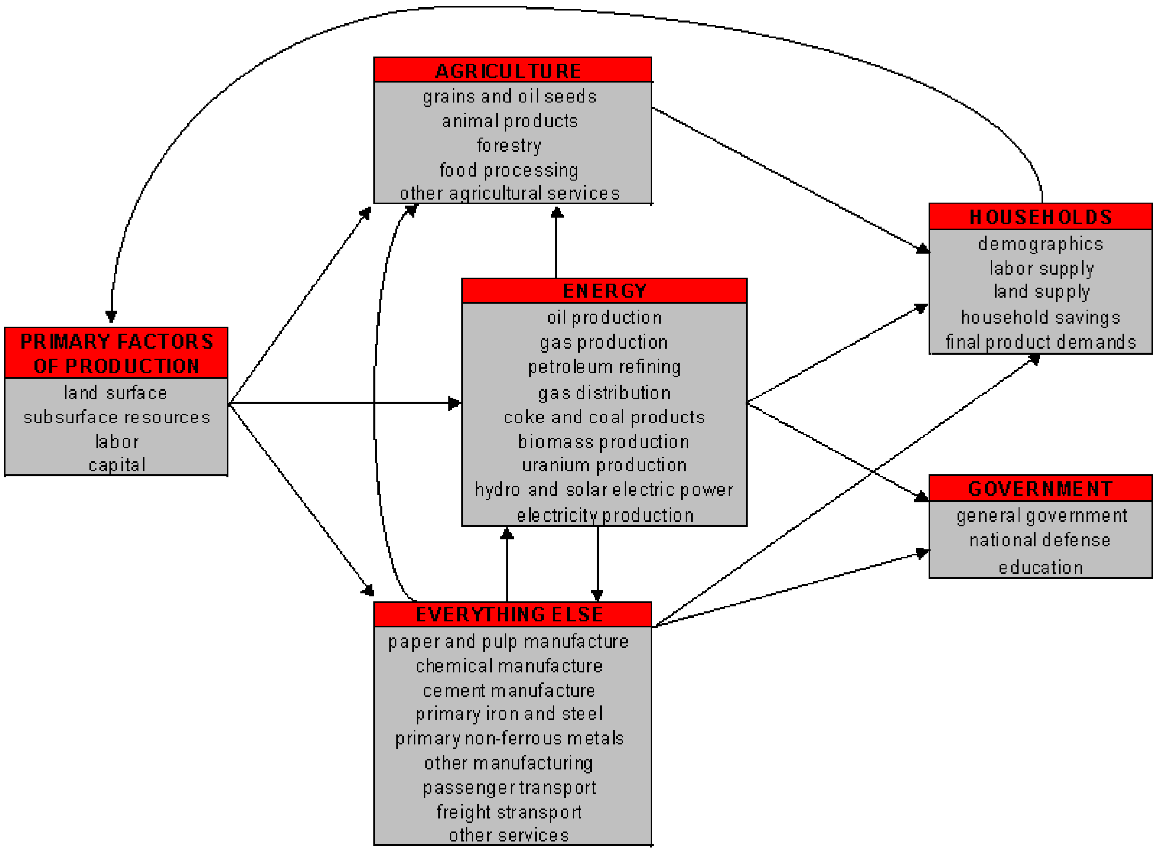

Figure 2: SGM 2000 Model Flow Chart

Capital in SGM assumes that once the investment occurs the technology cannot be changed. Capital is modelled using a vintage approach and investments operate for life or till they cover operating expenses. The data required for the model include input-output tables, past capital investment pattern, labour supply, energy flows in the economy at sub-sector and technology level, reserves of resources, land supply, and current emissions. Carbon tax is modelled as an additive tax per ton of carbon content of fossil fuels. Revenue from carbon tax is recycled to households by adding to income. The SGM endogenously generates the macroeconomic information such as energy prices and loss of sectoral GDP and consumption. An SGM model flow chart is represented in Figure 2.

Edmonds-Reilly-Barns (ERB) Model

ERB is a behavioral, long-term model of global energy and greenhouse gas emissions. The model can forecast for the long-term reaching upto 100 years. The world is divided in nine regions in the model - US, OECD West, Europe, Africa, Russia, Middle East, Japan-Australia-New Zealand, China and Asia (excluding India), and India. The model has four components: supply, demand, energy balance, and greenhouse gas emissions. The supply module projects future supplies and prices of major primary energy categories[1] for each of the nine regions in a given period. Energy supply is disaggregated into renewable and non-renewable sources. For each fuel, different technological progress is specified.

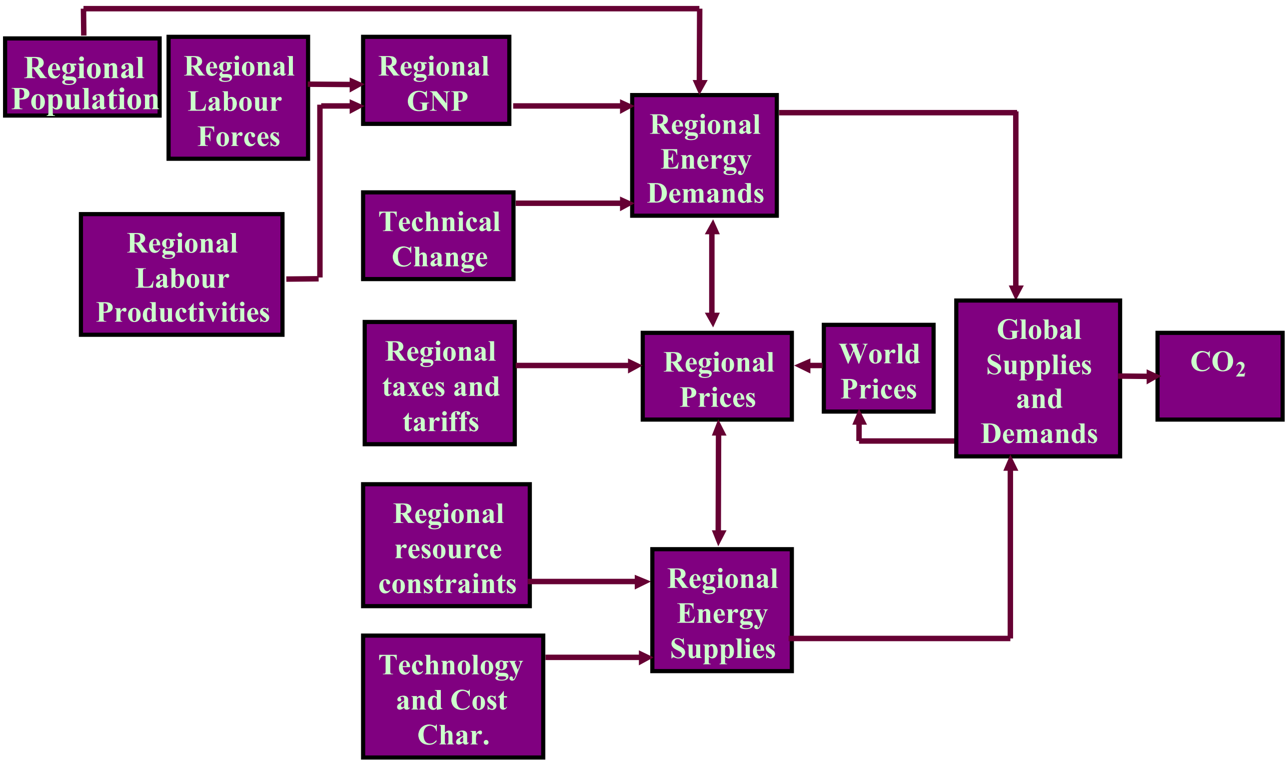

Figure 3: ERB model flow chart

The demand module in the ERB computes primary fuel requirements based on population, labour productivity, energy end-use intensity, energy prices, energy taxes, subsidies and tariffs. Energy end-use intensity is a time dependent index of energy productivity. Demand for energy services in each region's end-use sectors is determined by the cost of providing these services, and by income and population. For all regions, energy demand is disaggregated into residential/commercial, industrial and transport sectors. The energy balance module ensures market equilibrium, given assumptions on technologies and income and price elasticities and other factors such as resource availability. An ERB model flow chart is represented in Figure 3.

Mini Climate Change Assessment Model (MiniCAM)

The MiniCAM was developed by Pacific Northwest Laboratory (PNL) as part of its GCAM (Global Change Assessment Modeling) effort to develop an integrated-assessment model. It integrates three existing models viz. ERB, Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC) (Wigley and Raper 1992) and the MERGE model (Manne, Mendelsohn, and Richels 1993). The MAGICC and the SCENGEN [2] provide estimates of atmospheric concentration, climate change, and sea level rise. MAGICC uses a combined set of gas-cycle, climate, and ice-melt

[1] Conventional oil, conventional natural gas, coal, nuclear power, hydroelectric power, and solar electric power.
[2] Regional climate change SCENario GENerator of the Climatic Research Unit (CRU) at the University of East Anglia

models to determine changes in global-mean temperature and sea level based on various user-specified emissions scenarios. MAGICC can be used to compare the implications of a greenhouse-gas emission scenario with a reference case and to determine the sensitivity of results to changes in model parameters. ERB and MAGICC yield market and non-market damages using simple damage functions drawn from the MERGE model. A model structure of the MiniCAM model is represented in Figure 4.

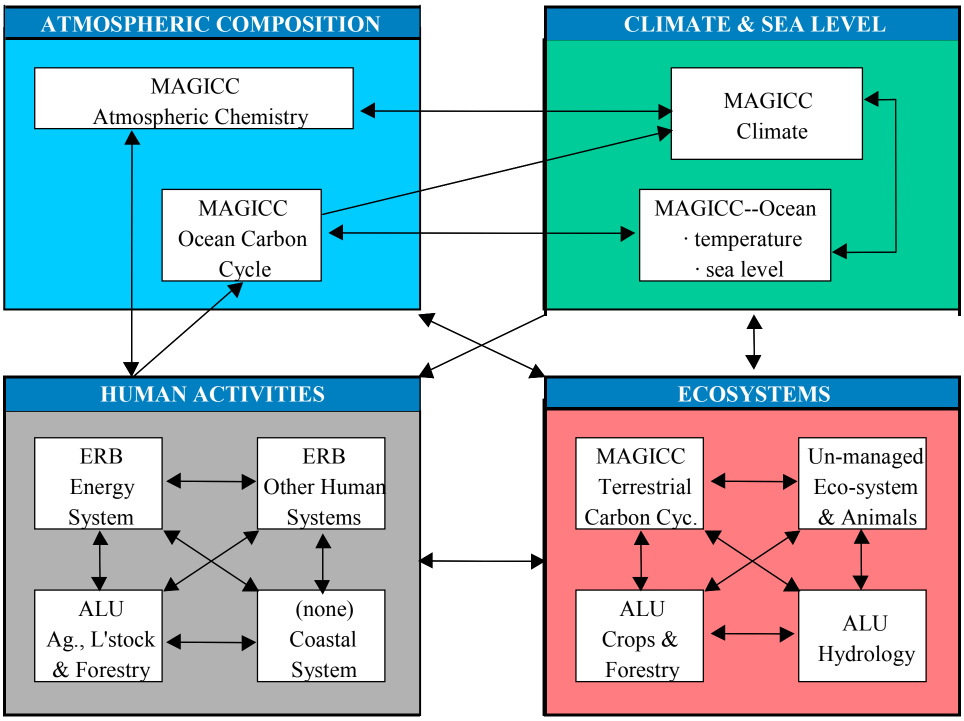

Figure 4: MiniCAM model structure

<u>Bottom-up models</u>

The bottom-up models have a technology focus. They take into account the various technologies available for the system and region under consideration, and then work upwards. They reproduce detailed changes in societies and stress "reality" .The bottom-up models, however, make exogenous assumptions about macro-economic interactions. Asian-Pacific Integrated (AIM) Model-Enduse (Morita et.al, 1996), Brookhaven Energy Economic Assessment (BEEAM) Model (Rogers et. al, 1981), Market allocation (MARKAL) Model (Fishbone & Abilock, 1981; Shukla, 1996) and LDC Energy Alternatives Planning (LEAP) model (Raskin, 1986) are some important bottom-up models. These models are being utilised extensively throughout the world.

<u>*Market Allocation Model (MARKAL)*</u>

MARKAL is a multi-period energy systems model suitable for national or regional analysis. MARKAL provides technology, fuel mix and investment decisions at detailed end-use level while maintaining the consistency with system constraints such as energy supply, demand, investment, emissions etc. (Loulou et. al, 1997; Manne and Wene, 1992). It is a dynamic model which consistently links the decisions over time.

The model is driven by a set of demands for energy services. A MARKAL model flow chart is represented in Figure 5.

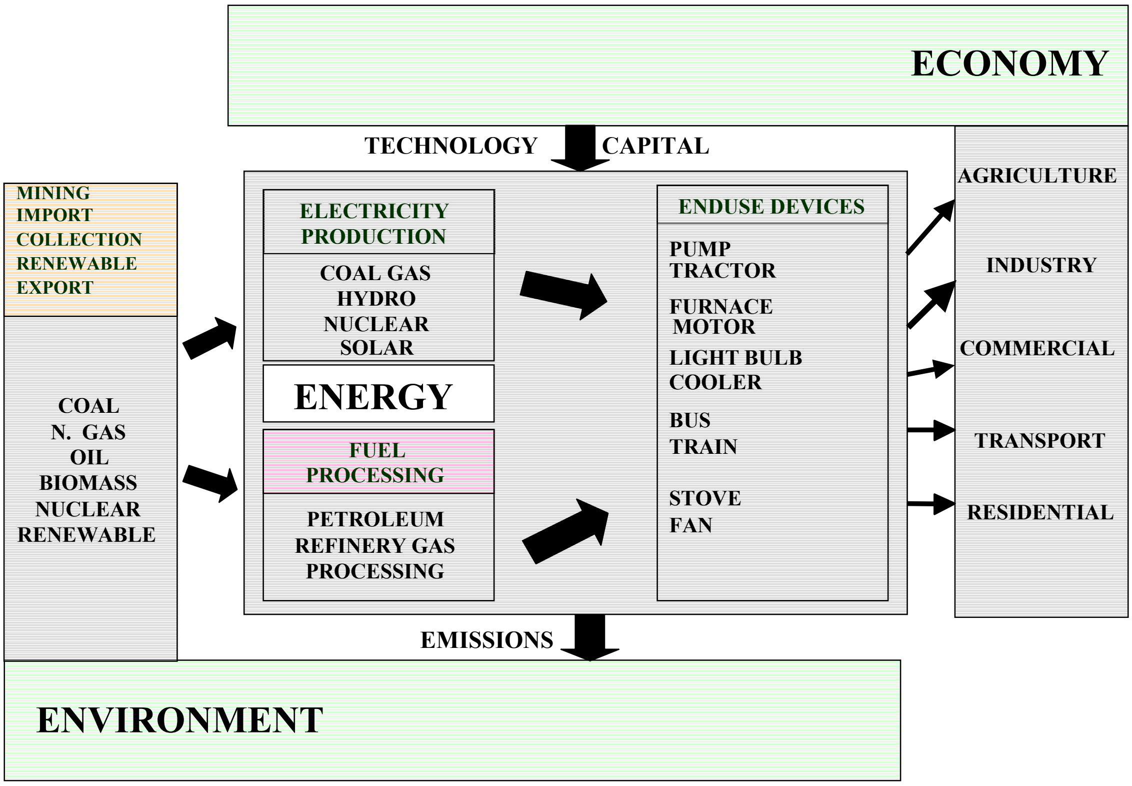

Figure 5: MARKAL Model Flow Chart

An important feature of MARKAL is the separate representation of peak and off-peak demands for electricity. Energy demand technology representation is fairly detailed. The supply technologies represent different fuel mix and cost structure. The technology and fuel costs vary across nations, especially large nations like U.S. or India due to variable natural and location specific causes like resource endowment, logistics costs and factor costs. The cost for a resource or a technology is therefore not a single number but a non-linear distribution which can be captured by the MARKAL model as a step-wise linear approximation through multiple grades for a technology or a fuel. This allows realistic competition among technologies and fuels. The model makes decisions, which minimize the discounted cost of energy system. MARKAL thus 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).

Integrated Assessment models (IAM)

IAMs are progressively being adopted by international researchers to utilize the advantages of both the bottom-up and top-down energy and economy models. They provide a formal and quantitative framework to integrate information from across the diverse scientific disciplines to assist the policy making process. There is a variety of IAMs in use for the climate policy analysis, which differ in objectives, scope and detail while sharing a defining trait of incorporating knowledge from more than one discipline. What makes IAMs useful is their ability to provide long-term assessments with consistent, replicable and transparent framework. IAMs have been extensively used in global environmental assessment projects such as IPCC Emissions Scenarios, Millenium Ecosystems Assessment, UNEP GEO project, Eco-Asia project and various country studies including India. Prominent integrated assessment models include IIASA (1995), MiniCAM (Edmonds et al 1994), TARGETS (Rotman's et al, 1995), AIM (Morita et al, 1994).

<u>Asia-Pacific Integrated Model (AIM)</u>

The AIM family of models (Figure 6) are most freguently used for environment assessment in the world. The distinguished feature of AIM is the cooperative approach that involves several Asian country teams. Although AIM is developed primarily to assess climate change policie, it can be used for assessment of related environmental problems such as air pollution, waste management and water resources. The AIM model facilitates detailed desription of technologies and links to geographical information system to assess and present the distribution of impacts at local and global levels. AIM system includes various component models suited to access macro-economic trends, energy and technology forcasts, ecosystem impacts and material balances. Besides detailed local and country level applications, the model is suited for global level assessment of international economic relationships and climate impacts.

Individual countries have combined different models in a framework of soft linkages for an integrated assessment of energy and environment. One integrated modeling framework used in India is represented in Figure 7. The Indian IAM framework consists of MARKAL - an energy systems optimization model which is used for overall energy system analysis; AIM/ENDUSE model which is a sectoral optimization model used to model fourteen end-use sectors; a demand model which projects demands for each of the thirty seven end-use services; Stochastic MARKAL model for uncertainty analysis; a power sector linear programming (LP) model for regional analysis; and a GIS based health impact assessment model.

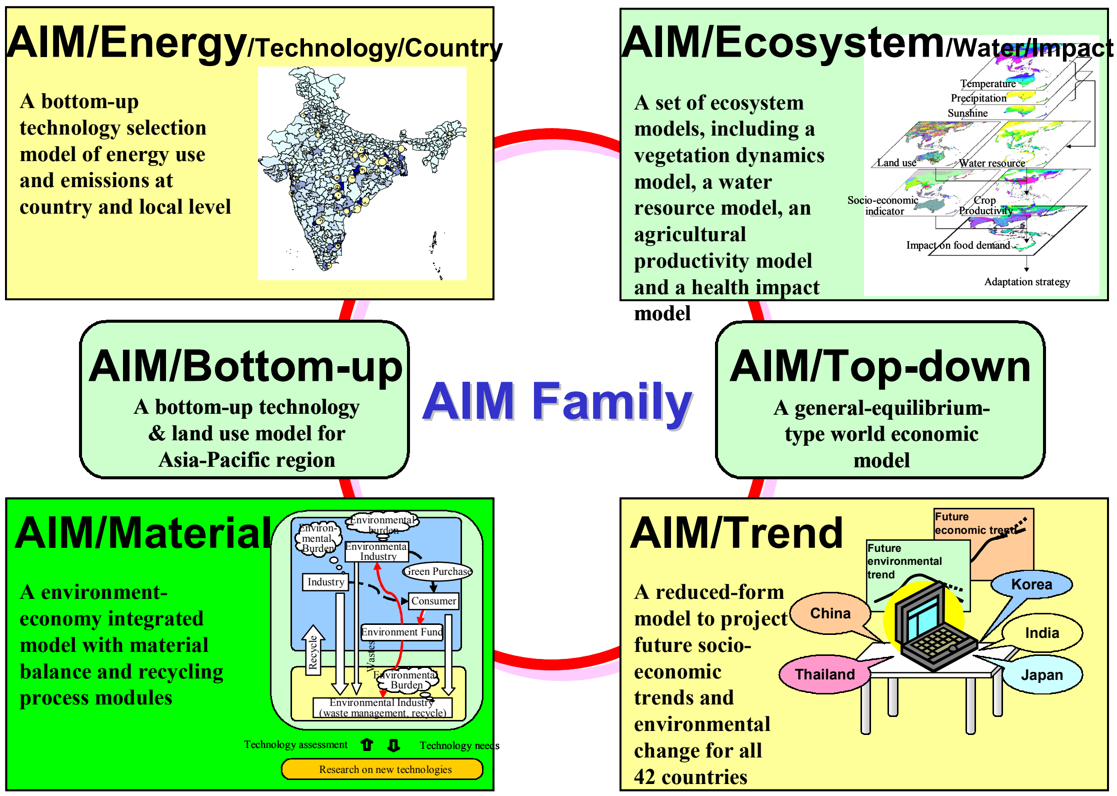

Figure 6: AIM family of models

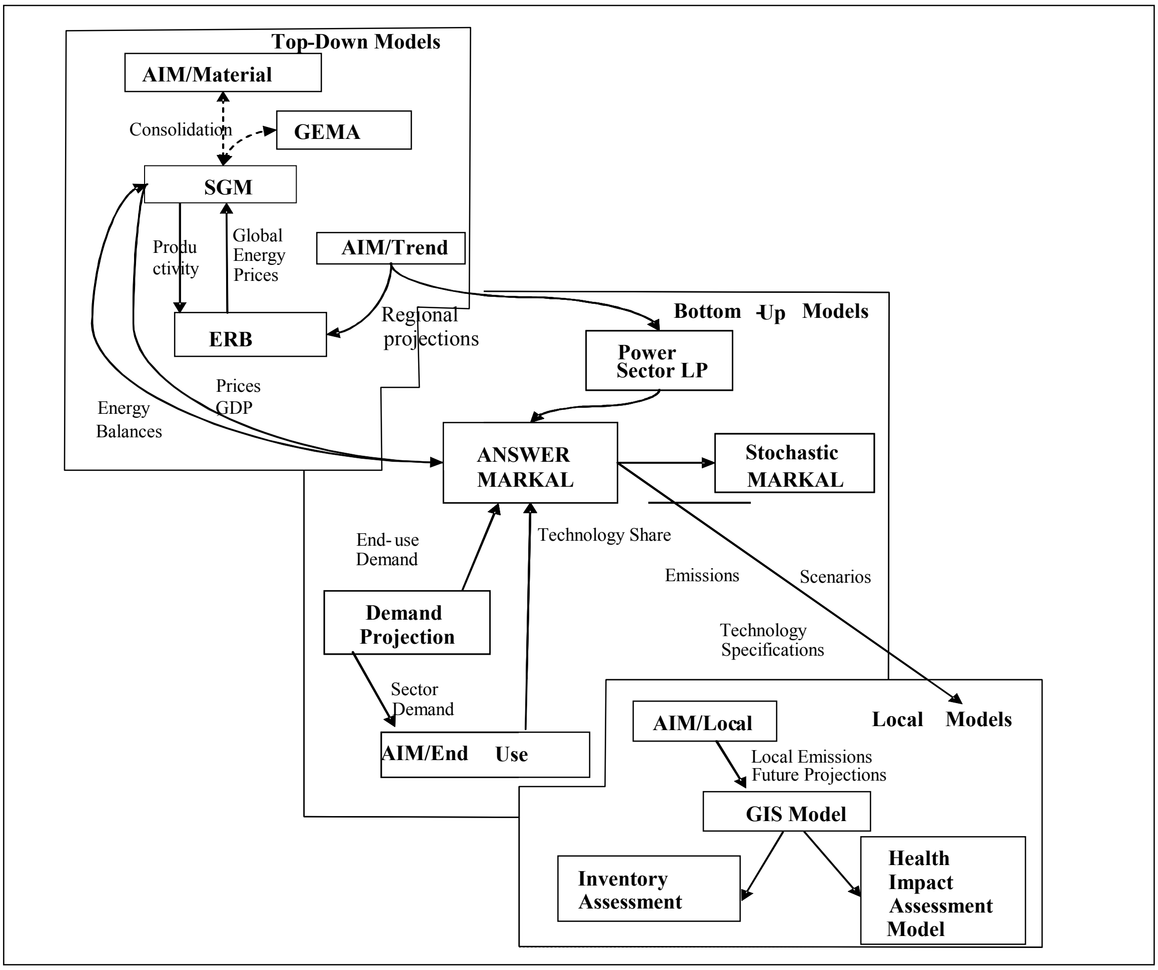

Figure 7: An Integrated modeling framework used in India

Model Applications

SGM application

The output from the SGM is often summarized as a set of marginal abatement cost curves that show the relationship between a carbon price and emissions reduction relative to a baseline. Figure 8 displays several marginal abatement cost curves from the U.S. component of SGM (SGM-USA) where a carbon price was applied in 2010 and held constant thereafter[3] (Sands et al, 2002). Reductions in carbon emissions relative to a baseline case are plotted against the carbon price for years 2010 through 2030. Even with a constant carbon price, the marginal abatement curves shift outward, or to the right, over time for two reasons: it takes time for capital stocks to turn over in the model, and carbon emissions are steadily increasing in the baseline case. Several factors influence the slope of the marginal abatement cost curves, especially elasticities of technical substitution in production, and consumer income and price elasticities of demand. Another factor is the share of coal in the baseline energy system. The area under a marginal abatement cost curve is often used to approximate the cost of a carbon mitigation policy. The baseline case in SGM-USA is constructed to generally follow projections from the U.S. Energy Information Administration (USEIA, 2002) until 2020, and then continue with the same rates of change in energy and labor productivity through 2050.

[3] One-half of the final carbon price was applied in 2005 to approximate a gradual introduction of a carbon policy. The 2005 time step in SGM can be thought of as covering years 2003-2007.

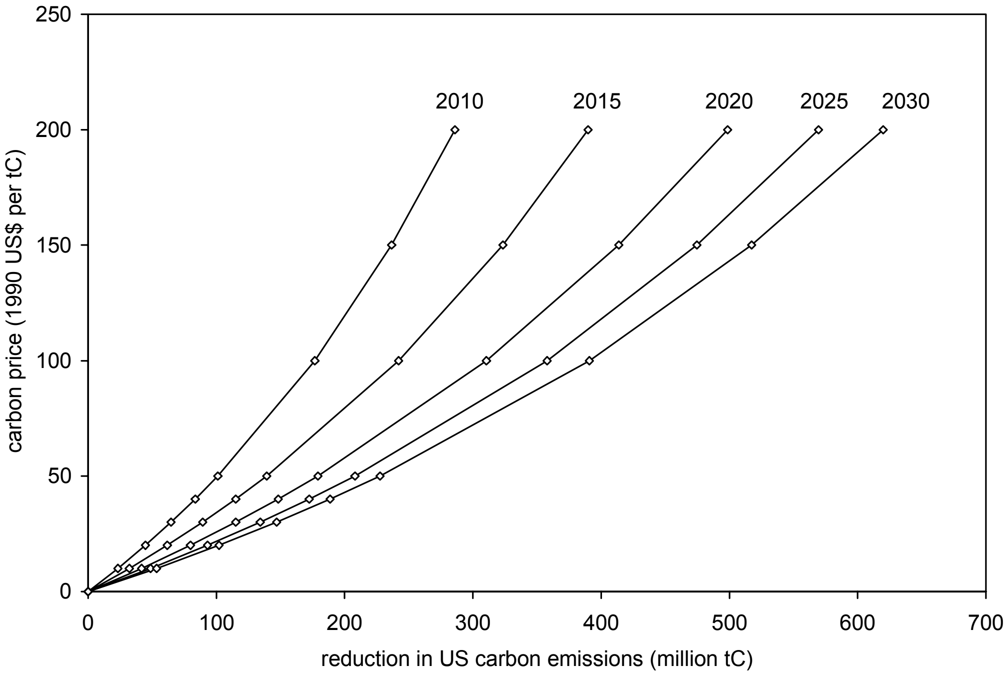

Figure 8: Marginal abatement cost curves for carbon emissions from the U.S. energy system using PNNL SGM.

The SGM model, along with many other leading econometric models, participates in the Stanford-based Energy-Modeling Forum (EMF). The EMF's often compilation of the results of these models shows the SGM in the middle of the pack of estimates of the costs of Kyoto, when standardizing on the policy experiment under consideration. The SGM's estimates of costs in 2010 are near the median, in the experiment with no international trading of emission credits or in the case with Annex I trading. With full global emissions trading, SGM cost estimates are a bit below the median, but far from the lowest of the models (Frankel, 2000).

Frankel further reports that on running SGM with international emissions trading, the important quantitative findings which support the contention that cost of meeting Kyoto commitments for the United States of America would be modest, are as follows:

- Full and successful implementation of Annex I trading would reduce costs by one-half, relative to a situation where each country had to satisfy its commitment domestically.
- Full and successful implementation of global trading (including developing countries) would reduce costs by 80-87%, again relative to the no-trading case. This illustrates the importance of developing country participation in any future emissions trading regime.
- Global emissions trading would reduce resource costs to an estimated $7-$12 b/yr in 2010, which is 0.1 % GDP in 2010.
- The effect on the price of carbon is estimated at $14-$23/ton.
- The effect on the energy bill of the average U.S. household is estimated at $70-$110.

MiniCAM

Results from MiniCAM include an analysis of the effects of advanced energy technologies on climate change (Edmonds et al. 1994) and an analysis of strategies (using results from MiniCAM and MERGE) to stabilize carbon dioxide concentrations (Richels & Edmonds 1994). Recent changes include the addition of an agriculture land-use module and the capability to estimate emissions of all the Kyoto gases. At present the model consists of 11 regions that provide complete world coverage. A 14-region more disaggregated version is nearing completion (IPCC, 2000).

AIM integrated modeling application

Results from the application of AIM model integrated assessment by Kainuma et al (2002) are presented below:

- Findings from global assessment:

1. Without the Kyoto target, the global temperature would increase by more than 2°C in 2100. In such a case, severe impacts can be predicted on water resource supply, agriculture productions, vegetation and human health.
2. Their impacts would be significant and with serious negative damages in the low latitude regions, especially developing countries in tropical and sub-tropical zones, while climate change could cause positive effects in the high latitude regions.
3. Future development of the Asia-Pacific region has significant influence on global emission scenarios. The Developing Asia-Pacific becomes dominant in climate change issue.
4. Different development paths require different technology/policy measures and show different costs of mitigation to stabilize atmospheric CO_2 concentrations at the same level. No single type of measure will be sufficient for the timely development, adoption and diffusion of mitigation options for CO_2 stabilization.
5. It is predicted that ratification of the Kyoto Protocol may cause economic impacts. However there are several ways including technological development and international cooperation to mitigate the economic impacts and a possibility of promoting the growth of economies.

- Findings from regional and country assessment

1. It could be possible for the Developing Asia-Pacific to continue high economic growth while maintaining GHG emissions at a low level. Technological progress and technology transfer should be emphasized to maintain low GHG emissions in the Developing Asia-Pacific's economic development. The market mechanism is an efficient way to achieve the diffusion of advanced technologies.

2. It is important for the Developing Asia-Pacific to introduce sophisticated measures to control GHG emissions before 2030. Robust policy options should be designed to respond to very wide range of alternative development path. In China, sophisticated policies should be designed at the sectoral level, especially in transport, commerce and the chemical industry.

3. New environmental policies are required that are designed for the early stages of development in China and India in order to integrate strategies for both the global environment and local environment including pollution control and waste management. Although under a SO2 mitigation policy regime, the SO2 and CO2 trajectories get decoupled in India, extents of SO2 mitigation and CO2 mitigation are strongly correlated under a CO2 mitigation policy regime.

4. Long-term adaptation investment for climate change could create co-benefit in other policy fields. Chinese current flood damage could be drastically reduced by the adaptation investment in flood prevention infrastructure to mitigate climate change impact.

5. The LPS would continue to be responsible for considerable part of the carbon emissions. Power sector is the predominant emission source for CO2 and SO2. 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 in India and China.

6. Energy savings or low CO2 emitting devices could be difficult to introduce into the market in every sector by 2020 without any climate policy measures in Korea. The marginally higher cost of new low CO2 emitting devices is too large for them to penetrate the Korean market.

7. Japanese cost to reach Kyoto target depends on Japan's future development pattern and climate policy design. The development toward "Recycle-based Society (B1)" could reduce cost and lead economic growth. Japanese cost could also be reduced by increased environmental investment, environmental industry encouragement, technology improvement, integration with waste management policy, shift to green consumption, and introduction of Kyoto mechanism.
8. International collaboration for capacity building and knowledge transfer on IA and IAM is essential for global participation in climate change mitigation.

India IA model application

The integrated modeling application in India provides insights to the energy and environmental policy concerns. It integrates ten models in a consistent framework and demonstrates the methodological soundness of the analysis. The results of the models and scenario analysis generate information required for strategic policy analysis. The top-down results in the model are consistent with the bottom-up model results. Garg (2000, 2001 and 2003), Ghosh (2001), Kanudia (1996 and 1998), Nair (2003) and Shukla (1996, 1997, 2001, 2002 and 2003) have extensively used this model for useful policy insights into Indian energy planning and emission mitigation.

A typical output from the demand projection model is shown in figure 9 below. It projects the end-use demand for cement sector up to 2035. Such projections are input to AIM/ENDUSE and MARKAL models. The AIM/ENDUSE model optimizes the technology fuel mix for individual sectors. Figure 10 is a typical output indicating the technology selection for the Indian cement industry. These outputs are used to provide initial exogenous bounds in the MARKAL model as explained earlier. The technology selection under the carbon mitigation scenario is a MARKAL result and indicates higher penetration of less carbon intensive technologies when a carbon tax is employed. This figure also demonstrates the usefulness of integrated modeling system for policy analysis.

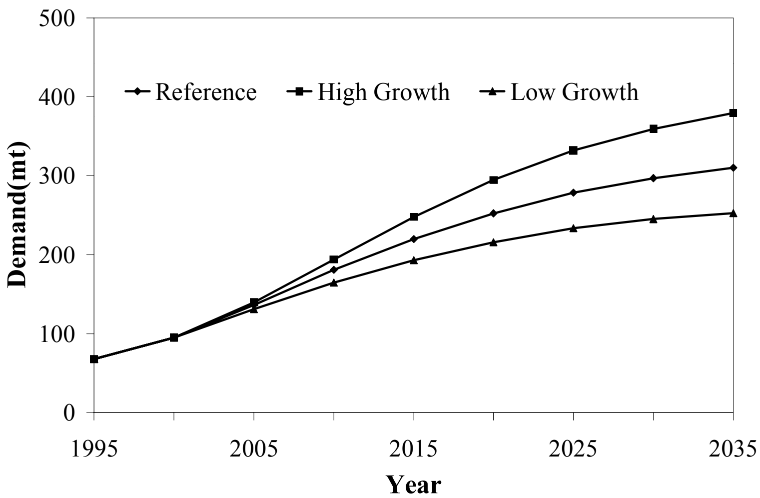

Figure 9: Cement sector demand projections

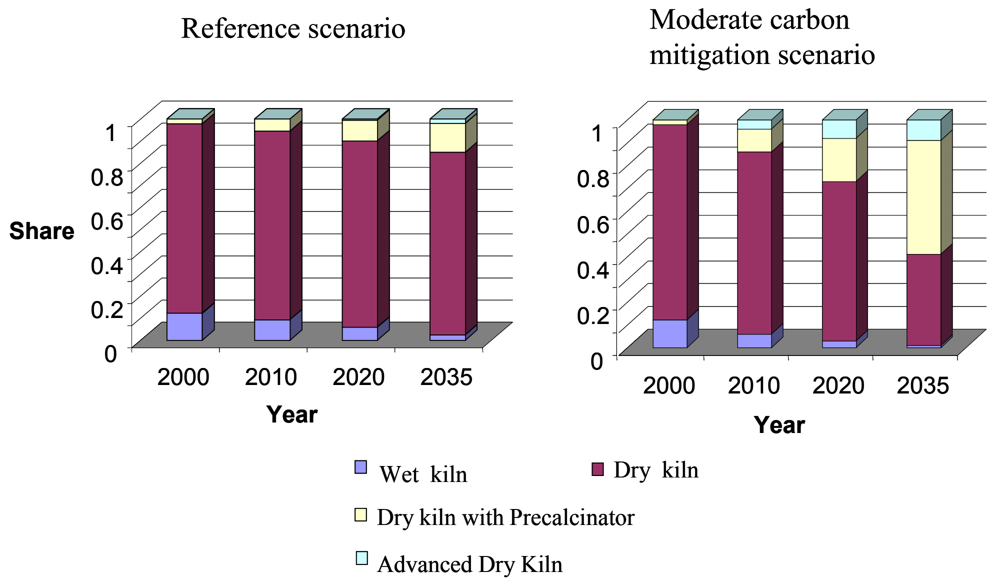

Figure 10: Technology selection in cement industry under different carbon mitigation scenarios

The MARKAL model mainly provides energy system optimization results. Some important results include future projections for the Indian energy system indicating a three times increase in the energy demand in the reference scenario over a period of forty years. Coal continues to dominate the Indian energy sector, although its share in the commercial energy consumption reduces from above 60 percent in 1995 to 53 percent in 2035. However coal use becomes more efficient and cleaner due to higher penetration of clean coal technologies in future and it partly offsets reduction in coal share. The decline in coal share is mainly due to coal to gas substitution, mainly in the power sector, with the natural gas share rising from the present 7 percent to 12 percent in forty years.

The sectoral fuel consumption indicates continued dominance of power sector in coal use and transport in petroleum products with each having 70 percent share in 2035. Power sector share in natural gas consumption increases to more than half from the present one fourth, caused by increasing competitiveness of Combined Cycle Gas Turbine technologies (CCGT) for electricity generation. Absolute gas consumption also rises in other industries like fertilizers and petro-chemicals. While the share of gas in primary energy still remains low, the trends suggest a rising penetration of natural gas that emerges as the main hedging option to coal in future.

The emission inventory projections for emissions basket of GHGs and local pollutants are given in table 1. The carbon and local pollutant emissions are MARKAL outputs while those for methane and N2O are Inventory Estimation Model outputs since these two are mainly due to non-energy activities, mainly in the agriculture sector, that are not covered by MARKAL. While the carbon emissions grow by about 3.5 times over 1995-2035, those for local pollutants in general grow less than twice. Methane emissions grow along agriculture sector rate while N_2O trajectories follow those of nitrogen fertilizer use. The emissions growth rates follow a decreasing trend for almost all the gases and are in fact negative for some local pollutants in later years.

The national 1995 emissions from the above models are calibrated with the district and sector level inventory estimates from the Inventory Estimates Model. The GIS interface of the integrated modeling system provides regional distribution maps of emissions. Figure 13 is a typical output and gives the distribution for Carbon dioxide emissions across the country. This analysis also suggests that pollution control is not as horrendous as it appears. Concentrate on 70-point sources to tackle 50% of sulfur and carbon emissions. These include 50 power plants, 5 steel plants and 15 cement plants.

Table 9: Emission inventory projections for India

Emissions (MT)	1995	2000	2010	2020	2035	CAGR*
Carbon	212	253	411	572	738	3.14
Methane	18.6	19.5	21.5	23.2	25.7	0.95
N_2O	0.25	0.25	0.41	0.61	0.84	3.48
CO_2 equivalent GHG	1219	1424	2063	2752	3504	2.67
SO_2	4.76	5.58	6.46	8.09	7.39	1.11
NO_X	4.66	5.57	6.08	7.64	8.66	1.87
Particulate	3.10	4.10	4.70	4.26	3.03	-0.06
CO	37.1	39.3	40.8	42.7	43.5	0.40

- **Compounded Annual Growth Rate over 1995-2035 (%)**

The analysis of regional and sector specific gas inventories contributes to effectiveness of emissions mitigation by indicating the hotspot locations and sectors where controls can lead to maximum benefits (Garg, 2000c). However measures like stricter enforcement of ESP norms at cement and power plants, sulfur reduction in petroleum oil products (especially diesel and fuel oil) through out the country and gradual replacement of older vehicles with at least Euro-II complaint stocks should continue simultaneously to speed up local air cleaning. These policies also constitute the priorities for reducing the adverse health impacts of local air pollution. Such comprehensive policy analysis is possible since we employ diverse models to probe the individual policy issues keeping a consistent integration across the models.

The health impact model indicates that if the health impacts of various industries are compared based on per unit of energy used in production by each plant, brick and cement sector impacts are most pronounced. This indicates the relative damage potential to human health from these sectors. The policy implications are to have stricter monitoring of these industries for local pollutant emissions especially particulate. We may even consider placing these industries far away (more than 25 km) from human populations.

The grid integration results from the power sector LP model indicate a reduction in capacity requirements due to better performance of generation technologies and lower transmission and distribution losses. There is a 3 to 4 percent lowering of the electricity generation costs due to changes in the technology mix and better performance of the technologies. Grid integration results in both local and global environmental benefits caused by alterations in the energy mix. There are substantial savings in the investment requirements in generation capacity. However large additional investments will be needed in setting up of state-of-the-art technology in transmission and distribution and upgradation of the existing facilities.

A regional analysis application in South Asia using ANSWER MARKAL

The South Asian ANSWER MARKAL model was set up in India (Nair, 2002, Shukla, 2004) for regional cooperation scenarios including the Dynamics as Usual scenario, the Medium Cooperation Scenario and the Accelerated Cooperation Scenario. It was found that with stronger cooperation regimes the total energy consumption in the region reduces. This is due to the improvements in efficiency in the supply and demand side technologies. As regional cooperation grows, better technologies become available to less developed countries in the region. The efficiency benefits for the region in the accelerated cooperation scenario is the sum of the benefits accruing as a result of savings in primary energy consumption, and savings in investments in both demand side and supply side technologies. The sum of these benefits is about US $ 321 Billion or 0.9 % of the regions GDP over this period. This may be considered as the cost to the region for not cooperating. Table 11 summarizes the benefits of the accelerated cooperation scenario.

As a result of cooperation, a shift is expected from the consumption of fossil fuel like coal, to cleaner fuels like natural gas and hydro. This results in an overall reduction of carbon emissions. With the cooperation regime becoming stronger the energy system becomes cleaner.

The total savings on carbon amounts to 1.4 billion tones of carbon or US$ 28 billion (at an average price of $20 per tonne of carbon). The reduction in coal consumption also leads to reduction in SO2 emissions. SO2 emissions reduce by about 50 million tones cumulative during the twenty-year period. At an average price of $ 200/ ton of SO2, the savings on SO2 emissions is about $ US 10 billion for the period 2010-2030. The total environmental benefit through reductions in emissions is about $US 38 billion. This is about 0.1% of the regions GDP over this period.

Other than the benefits discussed above there are benefits to individual countries resulting from trade in primary energy and electricity. Countries like Bhutan, Nepal, and Sri Lanka export electricity to India while Bangladesh exports natural gas. These exports form an important source for foreign exchange earnings for these countries. Bangladesh's gain from the export of natural gas is about 0.30% of the country's cumulative GDP. Through the export of electricity to India during the period 2010-30, Bhutan has the potential to earn valuable foreign exchange. Both Nepal and Sri Lanka too stand to gain from trade in electricity with India. Benefits from export of electricity for Nepal amounts to 1.3% of the country's cumulative GDP during the period 2010-30. Sri Lanka on the other hand benefits from economies of scale resulting from cooperation. This benefit amounts to 0.12 % of the country's cumulative GDP for the twenty-year period.

With stronger cooperation regimes there is a reduction in electricity prices, which would be beneficial for the overall growth of the economy. In the accelerated cooperation scenario the off peak cost of delivered electricity reduces by 11% in the year 2030 while the peak cost declines by 5% in 2030.