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The Modelling of Policy Options for Greenhouse Gas Mitigation in India

Greenhouse gas (GHG) emissions in India have important implications for global climate change. Emission trajectory and mitigation policies for India are analyzed using two models, a bottom-up energy systems optimization model (MARKAL) and a top-down macroeconomic model (Second Generation Model (SGM)). MARKAL is used to analyze technologies, peak electricity demand, carbon taxes, and a range of different policy scenarios. Carbon taxes and emissions permits are analyzed using SGM. In the reference scenario, energy use and carbon emissions increase nearly fourfold between 1995 and 2035. The analysis indicates that investment in infrastructure can substantially lower energy intensity and carbon intensity. A high carbon tax induces the substitution of natural gas and renewable energy for coal, and also causes a significant decrease in gross national product and consumption. The limitations of present models for analyzing mitigation policies for developing countries are discussed. Improvements for realistic representation of developing country dynamics and a policy agenda for GHG mitigation studies in developing countries are proposed.

INTRODUCTION

A least-cost response to global climate change in developing countries presents a variety of challenges and opportunities. Although current emissions from developing countries account for only one-third of global anthropogenic greenhouse gas (GHG) emissions, their future share of emissions will be much higher. GHG mitigation in developing countries is therefore crucial for the stabilization of atmospheric greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system (1).

Within developing countries, there are a large number of low-cost mitigation opportunities such as the promotion of energy efficiency, a less carbon-intensive fuel mix, and renewable energy technologies. Unlike developed countries, in which previous infrastructure investments and consumption practices have locked the economy into a high energy and high emissions path, developing countries can make decisions that promote low energy and carbon intensities. The conventional development path can be leapfrogged by making decisions that encourage patterns of development that can be sustained by low resource use. While such development is desirable, market forces alone may not induce investments along this development path. On the contrary, the competition in global markets often compels developing countries to shift their investments away from a long-term goal of sustainability, which can be regarded as an impediment to economic progress and a hindrance to the competitiveness of national industries. In their formulation of GHG mitigation strategies, developing countries must resolve the conflict between their immediate economic goals and their long-term goal of developing sustainably.

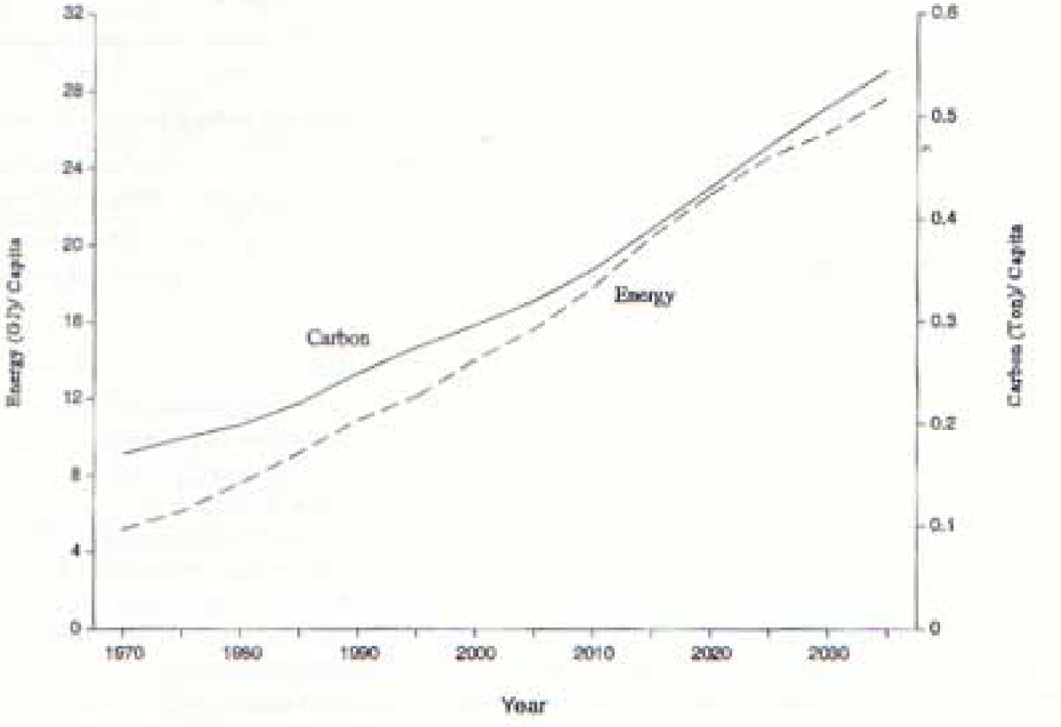

Figure 1. In India, per capita energy consumption and carbon emissions (including biomass) have been rising, and will continue to rise in the future unless strong mitigation efforts are made. Biomass is assumed to be carbon neutral. The data points from 1995 onwards are from the MARKAL reference scenario.

MODELLING PARADIGMS

GHG mitigation requires an understanding of the complex and dynamic interactions among energy, environment, and economy. Models that have been used to capture these interactions are commonly classified as one of two types: bottom-up or top-down. Bottom-up models specify technologies, resources, and demands in detail. Top-down models have higher sectoral aggregation, but better characterization of impacts on economic growth, price feedbacks, and trade (2). Most top-down models are based on an equilibrium framework and assume the economy to be in competitive equilibrium resulting from optimal decisions made by consumers, producers, and the government.

The model dichotomy also reflects two different paradigms. Bottom-up models follow the optimistic "engineering paradigm", whereas top-down models reflect the pessimism of the "economic paradigm". Bottom-up models presume the existence of an efficiency gap. Opportunities such as "no regret" improvements in energy efficiency are identified to make energy services efficient. The existence of an efficiency gap is explained by identifying myriad barriers to efficiency. The pessimism of top-down models originates from the assumption that the present technology mix is the end-product of an efficiently performing market. Recent model developments have attempted to bridge the gap between the two modelling approaches (3), but with limited success (4).

Gaps in the Modelling of Developing Countries

Numerous GHG policy studies have been performed in developing countries (5, 6). Most use bottom-up models. Top-down studies of developing countries are rare (7). The present models express the economic dynamics of developing countries in the image of developed market economies. Developing country realities such as underdeveloped markets, vast informal and traditional sectors, predominant government monopolies, restrictions on trade, and multifarious barriers to competition are inadequately modelled. Consequently, estimation of future GHG emissions and policy prescriptions for their mitigation are distorted.

Both model types need considerable refinement, adaptation, and extension to provide realistic and insightful analysis of mitigation policies for developing countries (8). An adequate modelling framework for developing countries should include: the traditional and informal sectors; developmental priorities beyond economic efficiency, including equity; development alternatives with substantial investment in infrastructure; research and development; institutional arrangements that can alter development patterns; and strategies for influencing consumer behavior.

INDIA: ENERGY AND ENVIRONMENT PROFILE

India is a fast-growing developing economy. Its population of 900 mill. will grow to 1400 mill. by 2025 (9). Three quarters of India's population live in rural areas under a traditional economy. Agriculture's share of the gross national product (GNP) remains around 30% (10). In 1991, per capita income was USD 350 (USD 1150 with purchasing power parity) (11). Although per capita energy consumption and carbon emissions are increasing (Fig. 1), they remain well below the global average. Until 1990, government policies followed a mixed-economy model. Both agriculture and consumer industries were developed in the private sector. Energy, infrastructure, and heavy industry were in the government domain. The prices of energy, essential commodities, and services were regulated. Currency was not convertible. Since 1991, the Indian government has initiated market-oriented reforms. Although these reforms have influenced industries and external trade, their impact on rural and traditional economies has been marginal.

Economic development in India has followed an energy-intensive and carbon-intensive path. Domestic coal is the primary energy source for electricity and industry. Oil consumption has increased rapidly to meet growing transport demand. The domestic oil supply has not met the national demand, leading to growing oil imports. Noncommercial biomass contributes more than 25% of energy. The growing population and limited supply of clean fuels in rural areas, and the inability of the rural masses to buy commercial fuels, has resulted in a rural energy crisis. Unsustainable use of forest biomass by industry and an increasing demand for land has contributed to severe deforestation. Of the anthropogenic carbon emissions, 40% are attributed to changes in land use (12). Substantial use of fossil fuel has led to poor air quality in most Indian cities. Because biomass use is decentralized, its impact on outdoor air quality is low except during the winter months in urban areas. However, the extensive use of biomass fuels for domestic cooking causes severe indoor air pollution (13) and has a significant impact on the health of women and children.

GHG MITIGATION ANALYSIS WITH THE MARKAL MODEL

MARKAL is an energy systems model ideally suited for techno-economic analysis (14). It is driven by exogenously forecasted activity levels for different economic sectors. Technologies are used to signify the input and output relationships among sectoral demands, energy demands, and energy resources. The costs of technologies and resources are specified exogenously. GHG emissions are accounted for as by-products of the energy-consuming technologies used to meet the demand from economic sectors. The model is formulated as a linear program in order to minimize discounted total energy and environmental costs over the planning horizon, while meeting energy needs and other constraints. Linear formulation facilitates the handling of the large number of variables and constraints (more than 5000 and 4000, respectively, for Indian MARKAL) that are required for a detailed bottom-up analysis.

Indian MARKAL: The Reference Scenario

Indian MARKAL is set up for a 40-yr period (1995 to 2035). The reference scenario assumes a 4.5% average annual growth rate in GNP. The growth rate ranges from 6% in the early years to 2.5% in later years. The economy is divided into two segments: modern and traditional. The transition of traditional activities into the modern economy is accounted for by adjusting future demand in the end-use sectors. Demand is disaggregated into 40 sectors and is forecasted for each sector using a logistic function (15) that follows an s-curve pattern. This is realistic for developing economies that are currently experiencing high economic growth but will stabilize at a lower growth rate in the future. Electricity demand is specified separately for daily peak and off-peak hours. An 8% annual discount rate is used.

Technology representation is detailed; 600 present and future technologies, including 90 electricity-generating technologies, are included. The cost of a service delivered by a technology and fuel combination varies by location because of differences in capital costs, natural causes such as the quality of a coal mine or wind pattern, and economic conditions such as the type of institutional arrangements (16). Fuel and technologies are modelled with heterogenous costs to allow realistic competition. Energy consumption and fuel mix for the reference scenario are shown in Figure 2. Analyses of different scenarios and comparison with the reference scenario are discussed below.

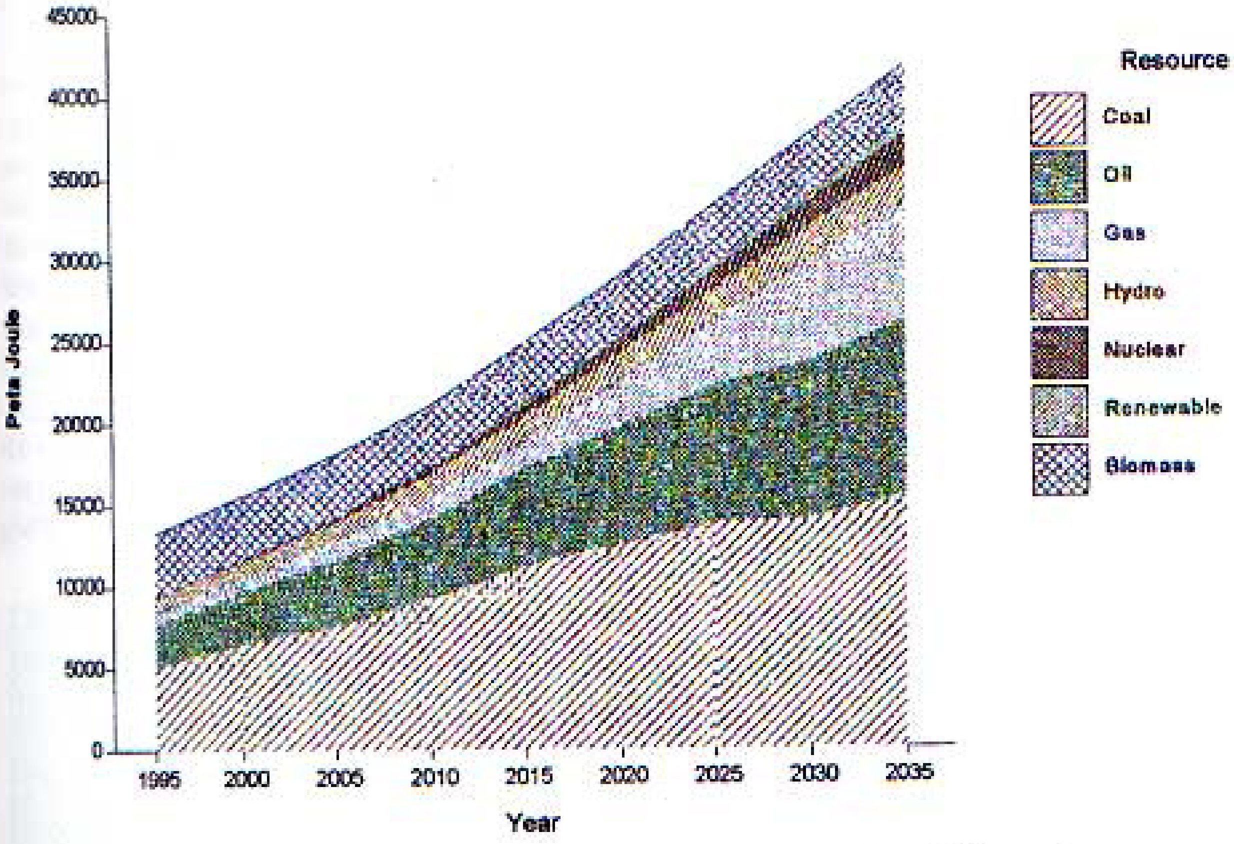

Figure 2. Energy consumption for the reference scenario increases threefold over four decades. Coal continues to dominate the energy supply. Shares of natural gas and oil increase significantly.

Growth Scenarios

The high-growth and low-growth scenarios assume average annual GNP growth rates of 5% and 4%, respectively, compared to 4.5% for the reference scenario. Sectoral demand in the growth scenarios is estimated from demand in the reference scenario and the elasticity of demand with GNP. Both energy intensity and carbon intensity decline over time in the growth scenarios (Figs 3 and 4). Of the reductions in future energy and carbon intensity 90% result from technology improvements, while a change in fuel mix accounts for the remaining 10%.

Energy intensity declined after 1980 due to the decreasing share of traditional biomass fuels in the total energy mix, the increasing shares of petroleum products and natural gas, and the penetration of energy-efficient technologies. Carbon intensity continued to increase until 1990, however, due to the decline in the share of hydropower (which is carbon free) in the electricity sector, the decline in the share of biomass fuels (which are assumed to be carbon neutral), and a rapid increase in the use of coal. Since 1990, carbon intensity has been declining as a result of the relatively higher rate of penetration of petroleum products and natural gas and further improvements in energy efficiency. As can be seen in Figure 3, energy intensity also began to decline at a faster rate after 1990.

In the low-growth scenario, both energy and carbon intensity decline initially as the share of domestic energy from gas and hydropower increases. Both the energy and carbon intensity in the high-growth scenario are greater than the intensities in the reference scenario, but the gap narrows in later years. Initially, high growth is fueled by domestic coal as well as imported oil and gas. In later years, penetration of gas increases as domestic coal becomes more expensive. Evidently, higher growth would require robust mitigation actions such as investments in infrastructure and energy efficiency, promotion of clean coal and renewable technologies, and a carbon tax.

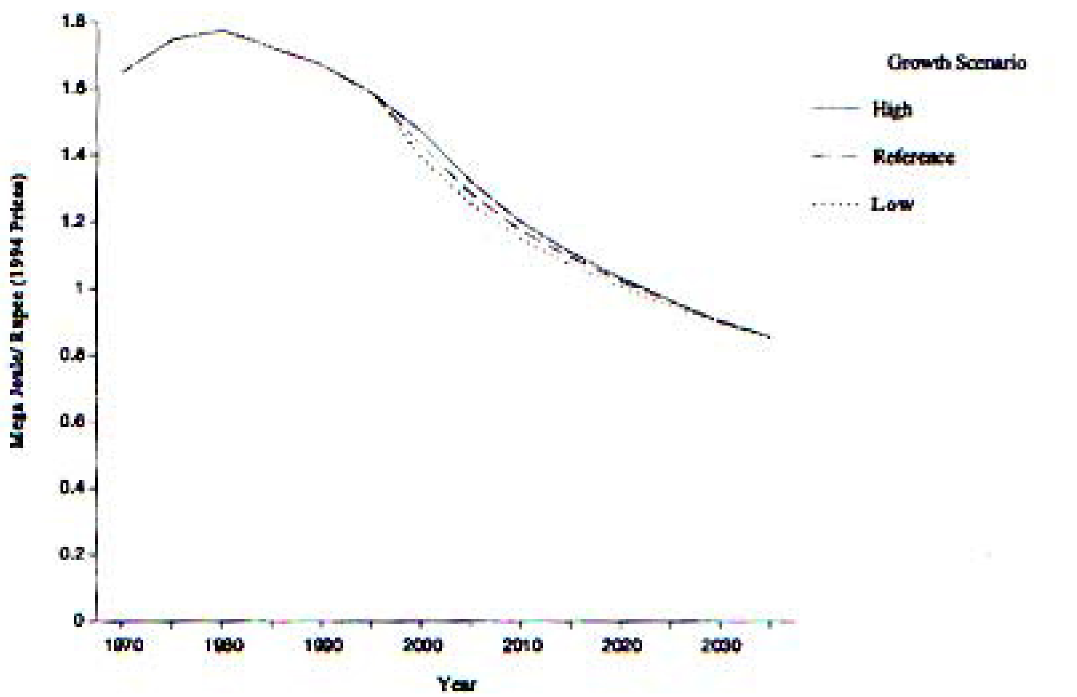

Figure 3. Energy intensity peaked in 1980. Future growth rate does not affect energy intensity. It will decline under any growth scenario.

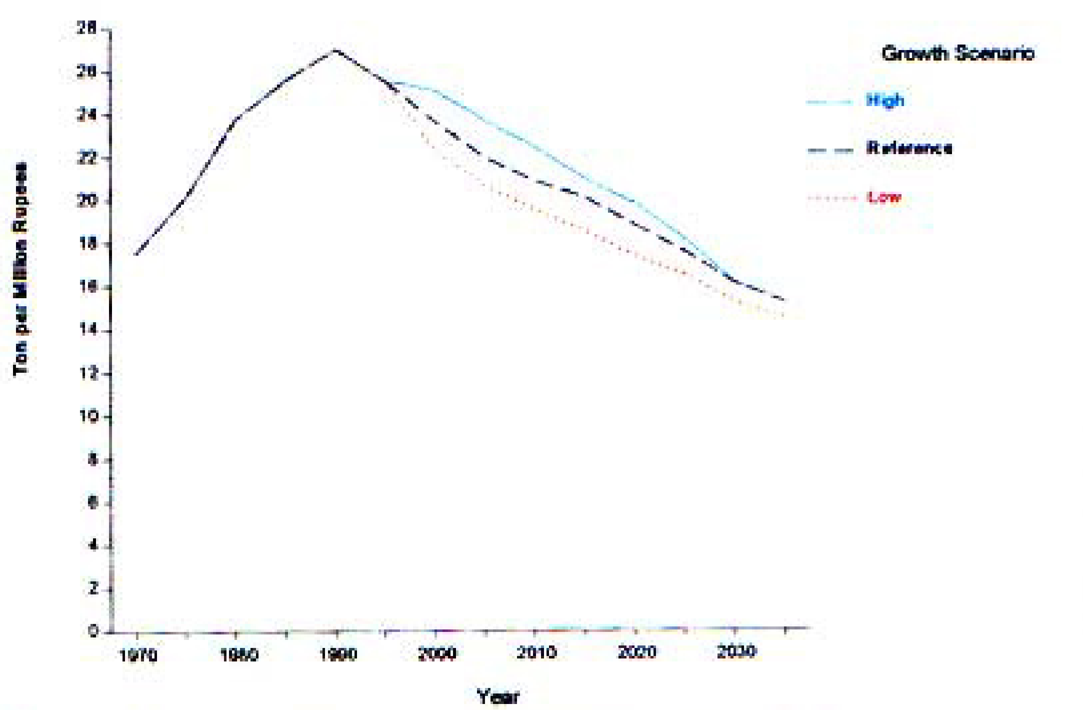

Figure 4. Carbon intensity peaked in 1990. It will decline in the future under any growth scenario.

Carbon Tax Scenarios

Five carbon tax scenarios are analyzed (Table 1). The carbon tax scenarios range from a no tax scenario, to a stabilization tax scenario in which the tax is the amount necessary to stabilize the atmospheric GHG concentration over the long-term (17). Compared to the no tax scenario, carbon emissions under the stabilization tax decline by 25% (Fig. 5). Successively higher tax levels lead to lower emissions, but marginal mitigation gains are low at higher tax levels. The implementation of a carbon tax reduces emissions by promoting a change in fuel mix, wherein coal is replaced by gas and, to a lesser extent, by hydro and renewable energy. Coal demand declines drastically under higher carbon taxes (Fig. 6).

Penetration of Renewable Energy

Supported by government programs in India, several renewable energy technologies have penetrated decentralized and rural applications as well as centralized electricity generation. An analysis of renewable electricity-generating technologies (Fig. 7) suggests that several of the technologies have competitive potential. The penetration of renewable technologies is vitally influenced by a carbon tax. Wind power and small hydropower have much potential within the next decade. These technologies are at a takeoff stage and can penetrate rapidly if a level playing field is provided by taxing fossil fuels. A stabilization tax would accelerate the penetration of wind power by four times (to 4750 MW) in 2005 relative to the no tax scenario. The penetration of small hydropower would receive a similar boost as a result of the stabilization tax. The present cost of solar photovoltaic (PV)

Table 1. Carbon tax scenarios (USD per ton of carbon), 1995 to 2035.

Scenario	1995	2000	2005	2010	2015	2020	2025	2030	2035
Stabilization tax	11.96	26.99	40.00	59.99	79.00	99.00	120.04	143.57	162.00
High tax	7.50	20.24	30.00	44.99	59.25	74.25	90.03	107.68	121.50
Medium tax	0.00	5.00	20.00	29.99	39.50	49.50	60.02	71.78	81.00
Reference	0.00	0.00	10.00	15.00	19.75	24.75	30.01	35.89	40.50
No tax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

power is too high. A stabilization tax and the declining cost of PV technologies make them competitive after the year 2010. A higher carbon tax accelerates the penetration of all renewable technologies. For example, under the no tax regime, PV technology takes off after the year 2030; under the stabilization tax regime, PV technology takes off two decades earlier. Interestingly, each successively higher tax level advances the take-off of PV penetration by about five years.

Infrastructure Scenarios

The four infrastructure scenarios analyzed are: *i*) a transport scenario, shifting traffic from road to rail; *ii*) a clean coal scenario, with additional coal washing capacity; *iii*) an electricity transmission and distribution (T&D) scenario aimed at reducing losses and extending electricity reach to rural areas; and *iv*) a demand-side management (DSM) scenario with efficient electricity use and peak load measures. Simultaneous implementation of these scenarios lowers energy and carbon intensities by 10%. The infrastructure scenarios assume only modest institutional changes and investments; they do not include more far-reaching alternatives such as relocating activities, changing consumption behavior, substituting communication for transportion, or mandating the use of renewable technologies. Although difficult to implement, such far-reaching changes could lead to an economy with very low energy and carbon intensities.

Transport Scenario: Transport is among the fastest-growing sectors. Between 1990 and 2030, passenger travel (in person km) is projected to increase more than ninefold; freight travel (in ton km) is projected to increase approximately sevenfold. In the past two decades, road transport's share of freight movement increased from 35% to 56% while its share of passenger movement increased from 59% to 77% (18). A rapid increase in road traffic has contributed to rapidly declining standards of road safety and an increase in urban pollution. Rail capacity in India is constrained by limited track length, slow electrification of tracks, and inadequate locomotive supply and wagon capacity. Excess demand exists for freight and passenger movement by rail. The transport scenario assumes that, over a decade, the investment in rail capacity will shift 25% of road movement to

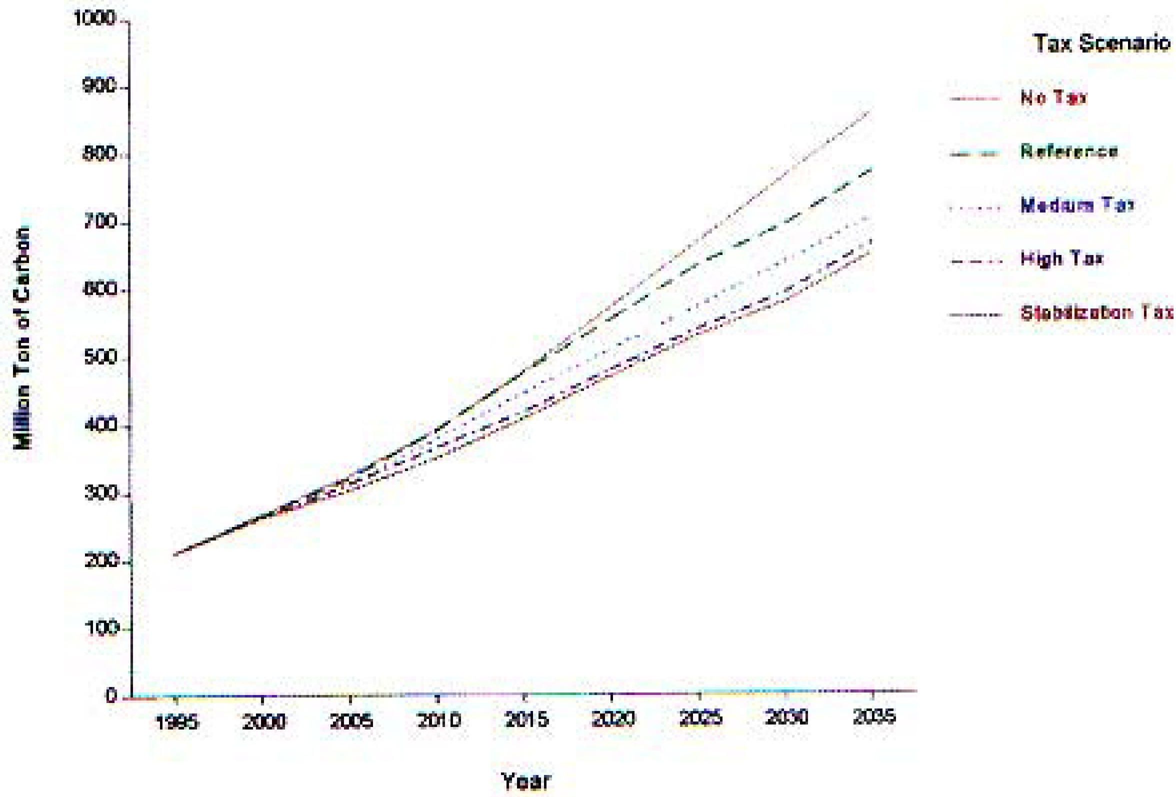

Figure 5. Carbon emissions under different tax scenarios. In the reference scenario, carbon emissions increase fourfold over 40 years. Higher taxes reduce emissions because gas and some renewable energy are substituted for coal.

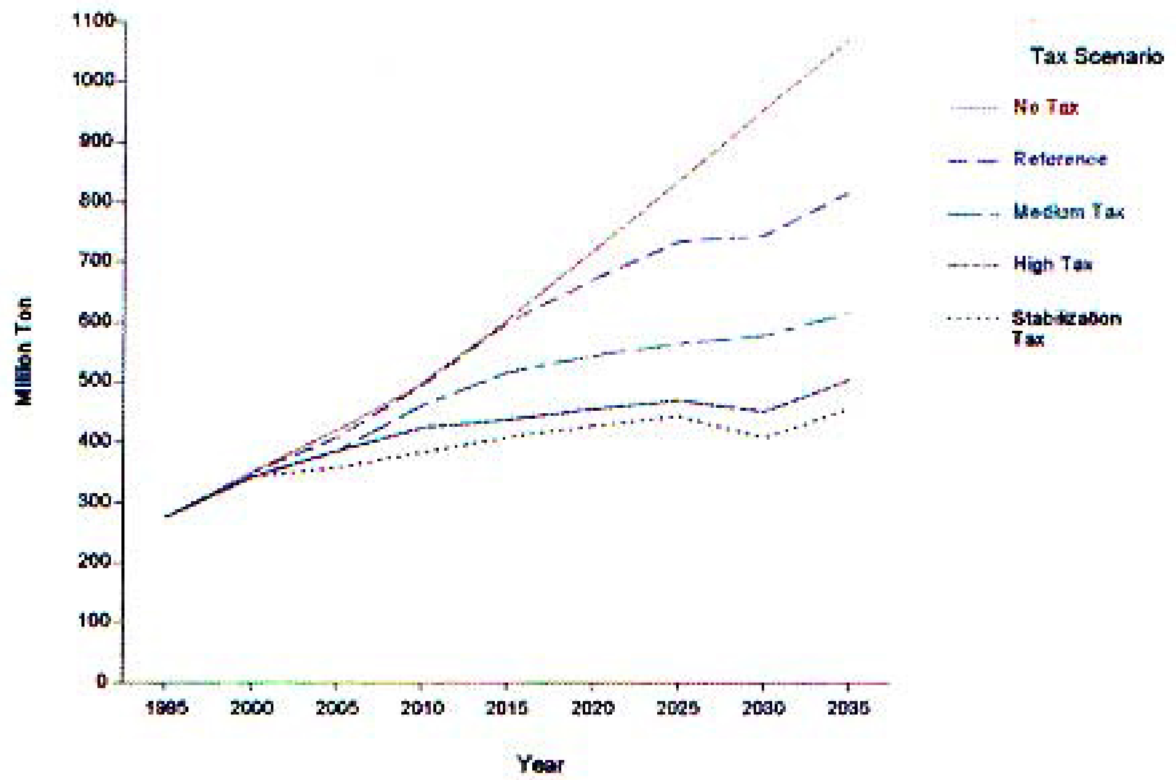

Figure 6. Carbon taxes have dramatic effects on coal consumption. If no tax is applied, coal consumption in 2035 exceeds one thousand million tons. Under the stabilization tax, coal consumption declines to 400 million tons.

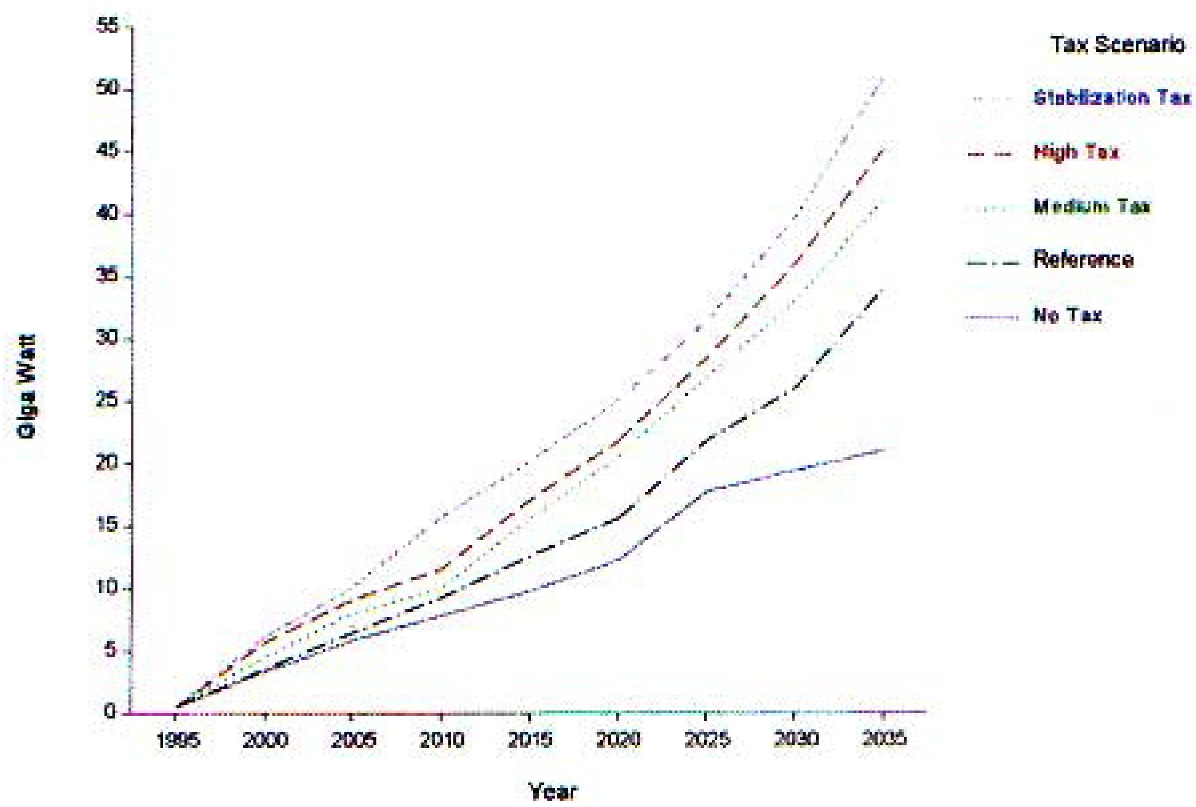

Figure 7. Higher carbon taxes accelerate the penetration of renewable technologies for electricity production. In 2035, renewable power capacity under the stabilization tax is more than twice as high as in the no tax scenario.

rail and investment in road infrastructure will enhance efficiency by 5%. These infrastructure improvements translate into 2% energy savings and 0.5% savings in carbon emissions in 2035. There are additional benefits such as reduced oil consumption (Fig. 8) and better air quality in cities due to lower traffic.

Clean Coal Scenario: Coal-washing capacity has stagnated at about 10% for the last two decades. Indian coal has a high ash content (35%). Associated problems such as ash disposal, particulate and sulfur dioxide emissions, and excess transport burden can be mitigated by coal washing. Washed coal has better combustion efficiency and lower weight for the same energy content. The clean coal scenario assumes that 15% of coal produced in the year 2000 and 50% of that produced in year 2035 will be washed, compared to 10% for the reference scenario. In 2035, ash disposal and sulfur dioxide emissions decline by one-third, freight transport demand on railways declines by 3%, and energy use and carbon emissions decline by 1%.

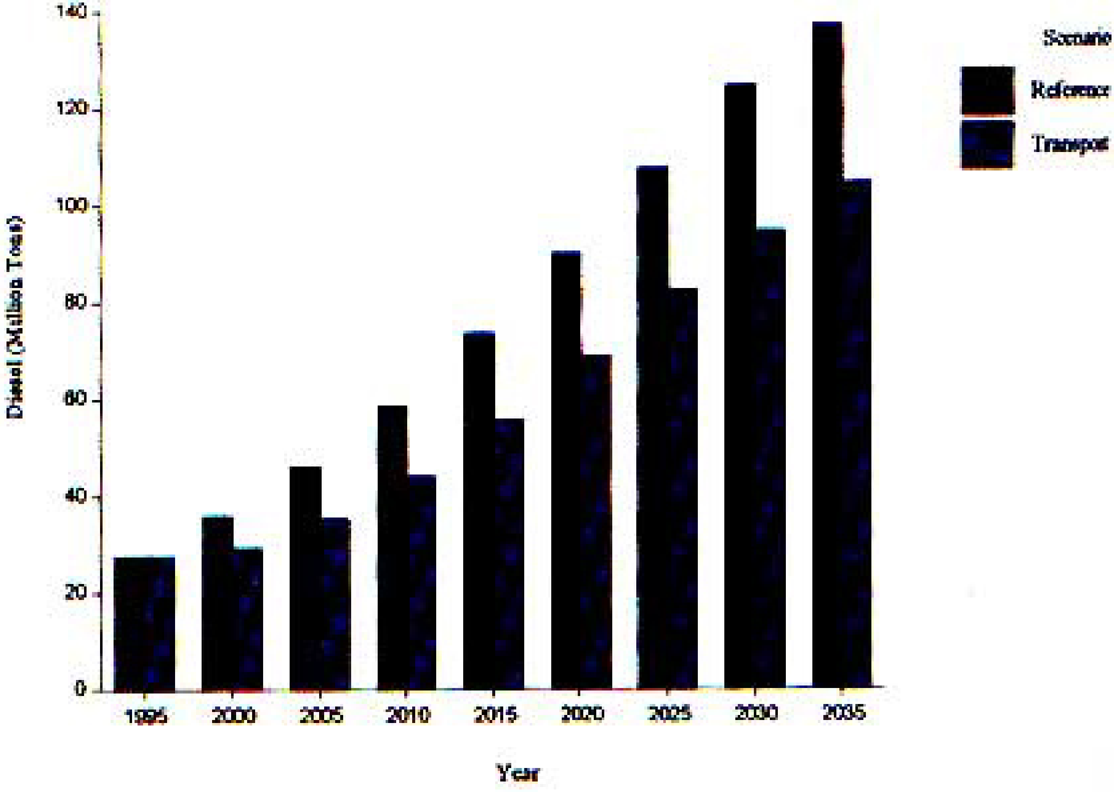

Figure 8. Diesel consumption increases fivefold over 40 years in the reference scenario. Improvement in transport infrastructure and shifting 25% of road traffic to rail will reduce diesel consumption by 25%.

Electricity T&D Scenario: Two deficiencies of the electricity T&D network in India are high losses and inadequate reach in rural areas. High T&D losses translate into direct system inefficiency. Inadequate reach and disruptions in electricity supply during peak load hours induce energy and economic inefficiencies and, at the same time, adversely affect social development. Two direct energy consequences of poor rural electrification are the inefficient use of kerosene for lighting and diesel engines for irrigation. The electricity T&D scenario assumes investment in efficient T&D technologies, extension of the rural electrification network, and adequate electricity supply to rural areas. These investments reduce energy and carbon intensities through savings in electricity, diesel, and kerosene. The long-term impact on India of the electricity T&D scenario is a reduction of 3.8% in energy intensity and 2.7% in carbon intensity in year 2035.

DSM and Peak Electricity Scenario: Demand-side management of electricity use refers to a broad range of strategies for influencing the consumption behavior of energy users in terms of quantity and timing of energy use. Electricity planning in India has focused on the supply side. Within the integrated least-cost energy planning framework, many DSM options are less expensive than investment in new power plants. In addition, DSM conserves energy resources and reduces emissions. A central problem of electric power planning in India is meeting the peak demand. At present, there is a 19% shortage in electric power capacity for meeting peak demand (19). This causes frequent power shut-downs, which lower economic productivity as well as quality of life. DSM strategies also influence users to shift their time of electricity use away from peak load hours. Implementation of DSM will require creating institutions, financing users to replace inefficient appliances, enforcing equipment standards, reforming electricity pricing to include economic and social costs, and establishing differential tariffs for peak and nonpeak hours. Analysis of DSM measures with the MARKAL model shows a 9% reduction in electricity generation and 15% decline in electric power capacity in the year 2035, relative to the reference scenario. These translate into a decline of 4% in energy intensity and 5% in carbon intensity.

GHG MITIGATION ANALYSIS WITH SGM

The Second Generation Model (SGM) used for top-down analysis is a computable general equilibrium model (20) calibrated for 1985. Our analysis spans 45 yrs, from 1985 to 2030. The economy is represented by nine producing sectors (including seven energy sectors), four final-demand sectors, and three factors of production. Each sector has several subsectors that represent different technologies or fuel grades. For example, there are six subsectors for the electricity sector. There are 20 subsectors in total and each produces a homogenous good. Production relations are represented by constant elasticity of substitution functions. Technological change is assumed to be "Hicks Neutral" and is exogenously introduced as change in total factor productivity. Technological progress also results from selection of new technologies. Economic growth occurs through enhanced factor supply and improved productivity (e.g., technological progress).

Investment in a sector (or subsector) in each period depends on the savings in the economy and expected profit in the sector. Investment allocation is determined by a logit function. Capital is assumed to be the "putty-clay" type; that is, once the investment occurs, the technology cannot be changed. Capital is modelled using a vintage approach and investments operate for life or until they cover operating expenses. Data are required for the 1985 input-output table, past capital investment pattern, energy flows in the economy at subsector and technology level, reserves of resources, land supply, and current emissions. The labor supply is estimated using a separate demographic model. Both renewable and natural resources are explicitly treated. Only commercial energy sources are considered. Traditional biomass fuels are ignored since national accounts and official input-output data do not include their value.

The Reference Scenario

The reference scenario's carbon tax trajectory for SGM is identical to the trajectory for the MARKAL reference case (Table 1). The carbon tax is modelled as an additive tax per ton of carbon content in fossil fuels. Revenue from the carbon tax is recycled to households by adding to income. In SGM, the carbon tax alters the macroeconomy. Demand and supply respond to endogenous price changes and the economy moves to a new equilibrium state. In MARKAL, demands from economic activities are inelastic to the price of servicing the demand, and energy supply and costs are exogenous. Thus, in MARKAL, the carbon tax influences the energy and emissions only through changes in technology investments and fuel mix.

The SGM reference scenario predicts annual growth rates of 3.5% for GNP and 3% each for energy use and carbon emission between 1990 and 2030. Coal and oil are projected to be the dominant fuels. Coal is the primary source of electricity. Strict comparability between SGM and MARKAL is not possible due to differences in model specifications and assumptions. SGM ignores the traditional biomass fuels that are accounted for in MARKAL. Unlike MARKAL, where it is exogenous, the growth rate of the economy is endogenous to SGM. In addition, the different perspectives of top-down and bottom-up models discussed earlier are pertinent. Keeping these caveats in mind, it is interesting to compare the results of the two models.

The GNP growth rate predicted by the SGM reference case is lower (3.5%) than the growth rate predicted for the low-growth case in MARKAL (4%). To compare the results of the two models, a new MARKAL scenario was developed with a 3.5% annual growth in GNP. This scenario is identical to the MARKAL reference scenario in all respects, except for the end-use demands which are adjusted to the 3.5% growth rate. After correcting for biomass fuels, which are ignored in SGM, the aggregate energy and carbon intensities in the new scenario are 20% lower than in the SGM reference scenario. In both cases, coal dominates the energy supply. SGM restricts gas imports to maintain the trade balance endogenously. Gas consumption and penetration of renewables are higher in the new MARKAL scenario than in the SGM reference scenario. In SGM, in the year 2030, a carbon tax causes 0.1% GNP loss annually and 0.4% consumption loss compared to a no carbon tax future. The no tax scenario in SGM has 25% higher energy- and carbon-intensity than the reference scenario.

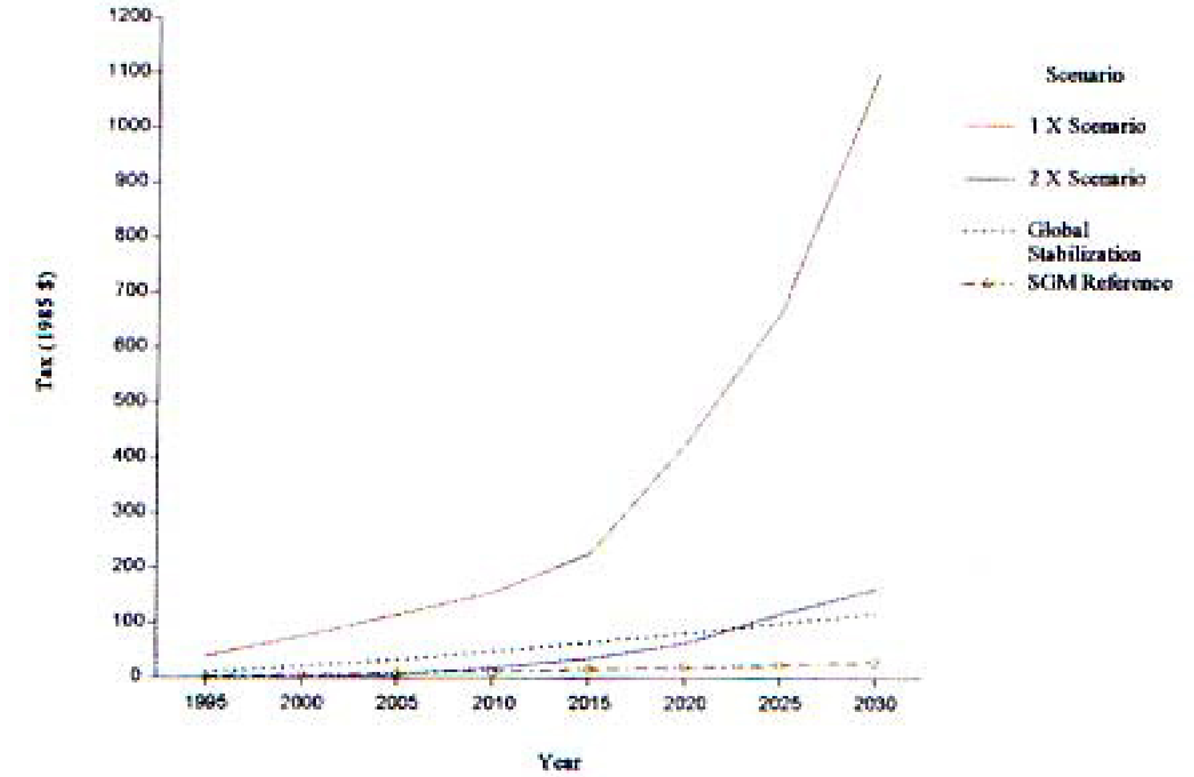

Figure 9. The carbon tax necessary to stabilize emissions at 1990 levels (1 X scenario) is very high. Emissions under the global stabilization tax will be twice the 1990 level.

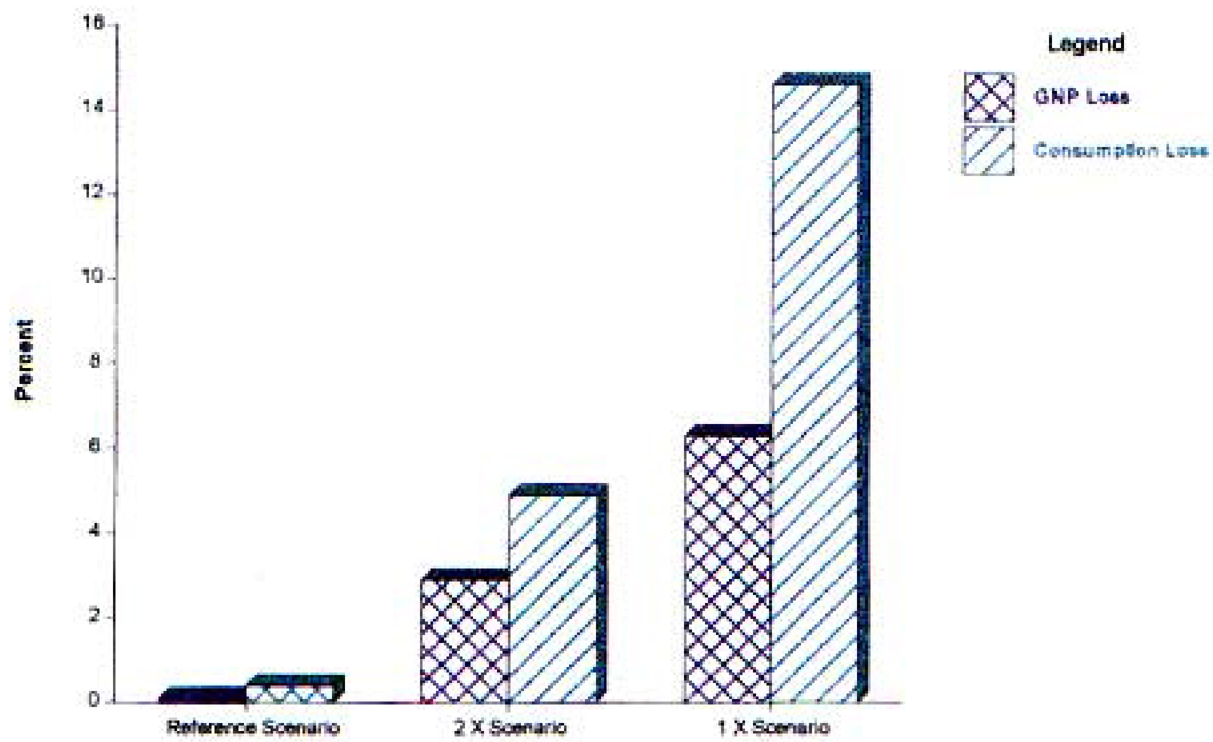

Figure 10. Higher mitigation targets for India will cause a significant reduction in annual GNP and consumption. In this figure, losses are indicated for the year 2030.

Mitigation Scenarios

Top-down models are highly suitable for analyzing the effects of economic instruments such as taxes, subsidies, emission quotas, and permits. Carbon taxes alter the cost structure of fossil fuels. Two mitigation scenarios are analyzed using SGM. Carbon emissions in the SGM reference scenario are three times higher in 2030 than in 1990. The 1 X mitigation scenario assumes the application of a carbon tax to stabilize future carbon emissions at the 1990 level. The 2 X scenario assumes that carbon emissions stabilize at twice the 1990 level. SGM computes the optimal carbon tax trajectory for achieving each mitigation scenario (Fig. 9). The tax level required for achieving the 2 X scenario is 25% higher than the reference scenario after 2025. The carbon tax induces stronger response in SGM than in MARKAL. In SGM, the tax results in inputs to existing technologies rather than energy; investment in technologies that are not carbon intensive; and price-induced losses in consumption and GNP (Fig. 10). In MARKAL, the tax influence is limited and stems only from future technology investments.

The carbon tax that is necessary to achieve the 1 X scenario is very high. Meeting such a low-emission target requires considerable adjustments in the economy, such as totally phasing out coal-based electric power by 2010, and large investments in nuclear, renewable, and energy-efficient technologies. Emissions are also reduced as a result of substituting other inputs in production and consuming sectors throughout the economy for fossil energy; this substitution leads to an annual 6% loss in GNP and an annual 14% loss in consumption in the year 2030 (Fig. 10). The tax trajectory for stabilizing India's emissions at the 1990 level is very high compared to the tax trajectory for stabilizing global carbon emissions. The global stabilization tax trajectory is in fact closer to the 2 X scenario (Fig. 9). Reduction of emissions in India to the 2 X level is thus beneficial within a global greenhouse regime, but further mitigation is too expensive. Reduction to the 2 X level, however, is in itself a substantial gain. India's participation in the global greenhouse protocol thus has mutual advantages.

Emissions Trading: Permit Scenarios

The use of tradable permits is a much discussed instrument for achieving greenhouse gas mitigation efficiently. Permits are created to match a global emission target. Each country is allocated permits based on an agreed-upon allocation scheme. A country can sell excess permits if its emissions are below the allocation. Otherwise, permits must be purchased from the global permits market to cover excess emissions. The suitability of alternate allocation schemes, in terms of satisfying the principles of equity, efficiency, and widest participation, is a subject of considerable debate (21, 22). Due to its large population and low per capita emissions, the alternate allocation schemes have significantly different equity implications for India. SGM was used to analyze two extremely different types of permit allocation schemes: a "Grandfathered Emission" scheme in which each country is allocated permits for emissions equal to 1990 emissions within that country, and an "Equal per Capita Emission" scheme in which each country is allocated permits for a share of global emissions that is equal to its share of the global population.

A global protocol for stabilizing greenhouse gas concentrations will specify the annual GHG emission trajectory over a long-term horizon, and the total global tradable permits released in a given period will correspond to this annual emission trajectory. Each nation will be allocated permits according to the agreed-upon allocation scheme. Under the tradable permits regime, the price of a permit in the global market will be equal to the marginal cost of mitigation. India will be a net buyer of permits under the "Grandfathered Emission" scheme and a net seller under the "Per Capita Emission" scheme. For the stabilization policy, the permit price will follow the stabilization tax trajectory (Table 1). Under these schemes, the net gain (loss) for a nation is the sum of the GNP loss from the global carbon tax and the gain (loss) from selling (buying) permits. Under these allocation schemes, India's net loss or gain will be very high (Fig. 11). For example, under the "Grandfathered Emission" scheme, India's net annual loss is USD 50 bill. (1985 dollars) in the year 2030, 5% of India's projected GNP for that year. The net annual gain under the "Equal per Capita Emission" scheme is USD 57 bill. in the year 2030. India, therefore, has a strong motivation for participating in the global negotiations of the protocol for the initial allocation of permits.

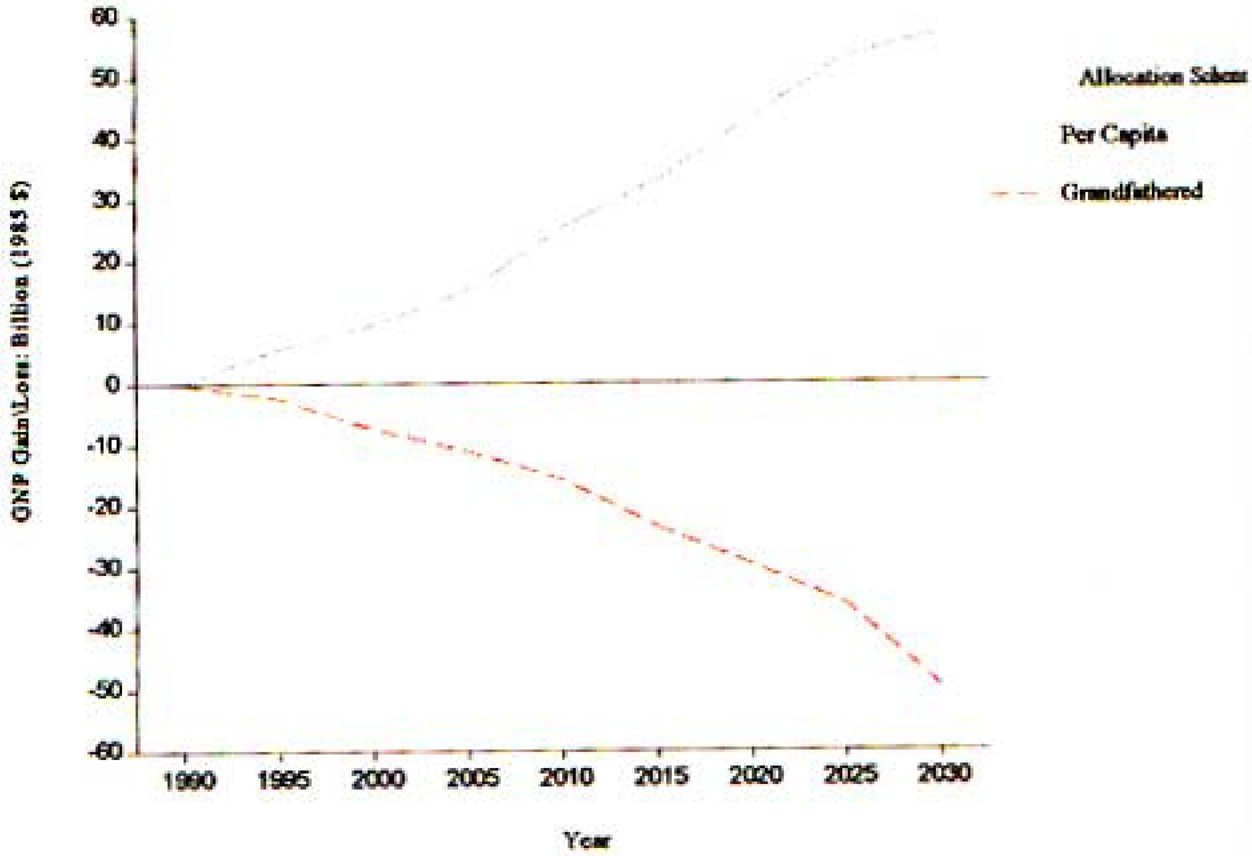

Figure 11. India gains substantially under schemes that allocate permits in proportion to population. Schemes using previous emissions for allocation will cause substantial losses. India's stake in the permit negotiations is very high.

Modelling Insights and Observations

The two mitigation policy studies for India suggest that: *i)* the choice of a model paradigm is crucial for this type of policy analysis; *ii)* model results can be reconciled by making comparable assumptions; and *iii)* policy analysis is enriched by comparing consistent top-down and bottom-up model scenarios. Although the policy analysis from the two studies provides valuable insights, the structure and perspective of models treat India like a developed market economy and thus impose serious conceptual and practical limitations. Model results remain questionable because of weak and incomplete representation of reality; policy prescriptions lack conviction; and the often observed skepticism of policy makers towards formal models is amplified.

DEVELOPING COUNTRY DYNAMICS

Developing countries are dual economies where the modern industrial sector co-exists with a vast informal and traditional economy. The traditional economy accounts for up to 70% of GNP and includes most rural markets and the urban periphery (23). The traditional economy is nonmonetized and has weak market linkages that restrict the flow of finances across regions and sectors. Personalized transactions and informal contracts are made to circumvent imperfect information (24) and the institutional gap. Informal financing dominates the credit submarkets catering to small, poor, and risky borrowers and also competes with and complements the formal financing in other submarkets (25).

The informal sector includes economic activities that are deliberately under-reported in national accounts (26). For example, in India, the income from undeclared sources was estimated at 50.7% of GNP in 1987 (27). The informal sector's share in employment was 50% in Calcutta in 1971 and 45% in Jakarta in 1976 (28). Informal credit accounts for up to two-thirds of total credit in Bangladesh and China and two-fifths in India (29). Interest rates in the traditional and informal sectors tend to be very high and hinder the penetration of efficient technologies.

Developing country dynamics include the processes that govern the transition of the traditional and informal economy into a modern industrial economy. These processes alter the institutions, technology, investment, land use, capabilities, income, behavior of producers, government policies, and consumer preferences.

Development Process and Paradoxes

The development process reveals numerous paradoxes. The coexistence of diverse technology vintages, inefficient use of traditional biomass energy, and great resistance to penetration of efficiency measures are some paradoxes that have tormented energy and environmental policy makers. The explanation of these paradoxes is rooted in transitional dynamics. For example, contrary to conventional technology assessment that emphasize the trade-off between capital cost and fuel cost, the decisive factor for the penetration of efficient technologies in the traditional sector is the value of labor. Because labor is abundant and lacks monetized value (30), it is substituted for capital and commercial energy at every opportunity. Traditional biomass fuels are collected or home-grown, and have value only in use. Substituting technology for biomass fuels is resisted as long as biomass resources are accessible and labor is abundant; thus, energy-efficient technologies and commercial fuels fail to penetrate. Ironically, technological inefficiency emerges not as a cause, but as a result of underdevelopment that is characterized by inadequate employment and exchange opportunities.

Poor infrastructure and institutional arrangements breed new paradoxes. It is a paradox that poor people in developing countries use more expensive and yet unclean fuels. For example, kerosene is used extensively for lighting by the poor. Per unit of light delivery (in lumens), kerosene is 20 times more expensive than tube light in India. In addition, kerosene use is cumbersome and polluting. This paradox is the result of poor access to infrastructure (poor rural electrification) and institutions. Inefficiency is rooted in underdevelopment. Such paradoxes reflect the duality of transitional processes in the development phase. These paradoxes are not cases of market failure. On the contrary, they point to the fact that the market dynamics presumed by models are nonexistent.

POLICY MODELLING FOR DEVELOPING COUNTRIES

Most of the models used for GHG mitigation studies have originated in developed countries. They presume the existence of institutions, interconnected and global markets, competition among producers, and perfect information. When applying these models to the economies of developing countries, analysts most often model developing economies in the image of developed market economies. As a result, the development process is overlooked, an entire epoch is ignored, and policy prescriptions become unrealistic. Model dynamics and policy analysis must be altered to reflect developing country realities. Some of the crucial aspects needing explicit representation in mitigation modelling are described below.

Dual Economy

In the traditional and modern sectors of the economy, production, consumption, investment, market relations, resources, technologies, and institutional structure differ significantly. For example, rice production in modern agriculture is capital- and energy-intensive whereas, in traditional agriculture, it is labor-intensive (31). Representation of the traditional sector requires explicit inclusion of nonmarket activities, local resources, subsistence behavior, biomass energy, excess labor, multiple and high discount rates, and technological stagnation. Unpaid tasks, such as biomass collection, need to be valued and added to national accounts. Other important issues to be considered include representation of labor supply, rural to urban migration, changing consumer preferences, shifts in government policy, technological progress in both sectors, and transactions between the two sectors.

Disequilibrium and Distortions

Commodity and factor markets are assumed by the models to be in equilibrium. However, this is not true for developing countries. Energy markets perpetually experience excess demand. Energy supply and infrastructure are often controlled by government monopolies, and there are myriad barriers to competition and restrictions on international trade that distort the market response. In India in 1994, for example, the electricity sector had excess peak power demand of 19%. Estimation of parameters, such as the price elasticity of demand, using equilibrium assumptions tend to be misleading. Poor data availability and reliability also distort the representation of reality.

Biomass: The Missing Fuel

Biomass contributes 35% of energy in developing nations (32). Most biomass is home-grown or collected by family labor. Under sustainable production and use, the biomass fuels are carbon neutral. But their present use pattern is unsustainable and adds to deforestation and consequently to the carbon flux. Fourteen million hectares of land were deforested globally in 1989, with the net effect of adding 1.4 gigatons to the atmospheric carbon flux (33). Traditional biomass use is very inefficient. The energy efficiency of traditional cook stoves is only 8%. Policies regulating biomass use in developing countries can offer vital opportunities for least-cost global GHG mitigation. Yet, the traditional use of biomass continues to be inadequately represented in most bottom-up studies; and biomass use is totally ignored by top-down models because its economic value is not accounted for in national statistics.

Biomass is used to meet the cooking energy needs of most rural households and half of the urban households in India. Biomass collection requires the work of many people, mainly women. Collection time, about three hours per household daily, is increasing due to depletion of village woodlots. Biomass does not acquire monetary value because it is collected by unpaid labor and is not traded. Eight billion person days are spent annually for biomass collection in India. This is equivalent to full-time employment for 30 mill. persons, 11% of India's total employment. Valued at minimum wage, biomass is worth 150 bill. Rupees or 2% of India's GNP in 1994. Its kerosene equivalence is more than 20 mill. tons. Biomass acquires implicit value either from the opportunity cost of labor used for its collection or the price equivalent of a substitute fuel, which in India is kerosene. Policies that enhance the value of labor, such as employment generation, women's development, education, and minimum wage can therefore alter biomass use. Pricing policies for kerosene would also affect the use of biomass energy.

Kerosene Subsidy in India

Kerosene is highly subsidized in India and is used by low-income and rural households for cooking and illumination. Typical top-down model analysis usually recommends removal of the kerosene subsidy because any tax or subsidy is treated by the model as a distortion which, if corrected, enhances the gross domestic product. Although the income elasticity of biomass energy is negative, its elasticity to the price of kerosene is positive (34). Reduction of the kerosene subsidy would thus increase biomass use as well as its negative environmental impacts, deforestation and indoor air pollution. Both deforestation and indoor air pollution are detrimental to the quality of life of the poor, especially women. In this context, the kerosene subsidy is an environmental and developmental instrument rather than an energy policy intervention and has a positive impact on GHG mitigation.

Choosing a Development Path

The United Nations Framework Convention on Climate Change appropriately recommends, and reminds us, in its statement of objective that policies for stabilizing GHG concentrations should enable economic development to proceed in a sustainable manner (1). Choice of a development path has crucial implications for the future resource use pattern and the energy and GHG intensities of a nation. In the past, a lop-sided emphasis on economic efficiency led to extremely resource-intensive development in industrialized countries. This path is now unsustainable. Most developing countries are prepared to make major investment decisions in the coming decades. They can shift to a much less resource-intensive trajectory by investing in infrastructure such as rail and communication, renewable resources, location planning to promote lower logistical costs, education of consumers, and by investing in people. Superior technological and developmental alternatives provide developing countries with a window of opportunity for leapfrogging developed countries in terms of sustainable development.

GHG mitigation studies for developing countries should focus on analysis of alternative policies that tranform the development pattern rather than incremental and isolated project-level interventions. Although market dynamics ensure economically efficient choices, they often reject choices that are superior in terms of other criteria such as equity, conservation of resources, preservation of environment, biodiversity, and cultural diversity. Present models need to be adapted so that they include these additional criteria. In their consideration of GHG mitigation strategies, developing countries will benefit by explicitly considering developmental choices such as investment in education, demographic measures, institutions, infrastructure, employment, consumer education, sustainable agriculture, land use planning, and decentralization.

CONCLUSION

The participation of developing countries in GHG protocol has global benefits. Numerous low-cost mitigation opportunities exist in developing countries. New investments in infrastructure and institutions open a window of opportunity for developing countries to switch to a development path that is not resource-intensive. The conventional development pattern is both energy and carbon intensive. Mitigation gains will be substantive if the development path chosen for the future is not energy or emission intensive. For India, conventional development with no carbon tax and little investment in mitigation will increase carbon emissions nearly fourfold between 1995 and 2035. In addition to a carbon tax, other mitigation policies such as investment in infrastructure and institutions will be necessary to achieve substantial mitigation. A carbon tax to stabilize India's emissions at the 1990 level will cause a 14% loss in consumption and a 6% loss in GNP in the year 2035. Developmental actions will achieve similar mitigation at lower costs.

Present mitigation models lack realistic representation of developing country dynamics. Mitigation policy analysis for developing countries will improve if activities in the traditional and informal sectors are accounted for, disequilibrium and distortions are explicitly treated, traditional biomass energy is included, and innovative policy options are emphasized. Present models emphasize only economic efficiency. Other objectives such as equity and sustainability require consideration. Climate change modelling has made notable advances in recent years. Integrated assessment models provide a unified framework for evolving mitigation and adaptation policies (35). Modelling frameworks linking climate change policies with sustainable development (36) are also proposed. Notwithstanding these advances, model dynamics are still governed by a developed country perspective. Reorientation of model dynamics and perspective to address developing country realities are refinements needing immediate attention.

Developing countries have a large stake in decisions regarding global GHG protocol. Under different GHG allowance schemes, India's loss or gain can be equivalent to 5% of its GNP. An equitable and just policy regime will encourage wide participation of developing countries in GHG mitigation endeavors. Stabilization of GHG concentrations calls for a quantum change in future emissions. The problem of climate change is a challenge as well as an opportunity to move the global economy towards sustainable development. Challenges posed by climate change are too serious to be ignored. But the opportunity it has offered the global community to shift the development pattern towards a sustainable path will prove too costly, if missed. It is a test of our ability to resolve truly global problems, many more of which will be forthcoming as developing economies are integrated into the global economic system in the next century.

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