INDIA'S
GHG Emissions Profile
Results of Five Climate Modelling Studies

Climate Modelling Forum, India

Supported by

सत्यमेव जयते

Ministry of Environment and Forests
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‘The Climate Modelling Forum consists of several independent research institutions, e.g., NCAER, TERI, IRADe, and Jadavpur University who have received support from the Ministry of Environment & Forests, Government of India for their research work. McKinsey & Co and TERI have agreed to lend their inputs to the Forum for a comparative study of their independent modelling results. The results and ideas expressed are those of the authors and are not attributable to the Government of India.’

सत्यमेव जयते

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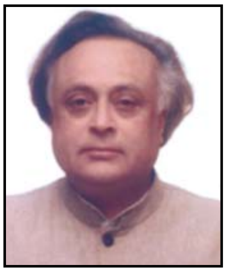

Foreword

I am pleased to introduce the Report: "India's GHG Emissions Profile: Results of Five Climate Modelling Studies".

India has been working on the issue of its Greenhouse Gas (GHG) emissions over the previous many years. A major study in this direction was the 2006 Report of the Expert Committee on India's Integrated Energy Policy, which estimated the carbon dioxide generation profile of India's energy sector up to 2031-32 under 11 different scenarios of fuel mix. India's Ministry of Environment & Forests has also been supporting a number of organizations undertaking studies on India's GHG emissions profile. These institutions include The Energy & Resources Institute (TERI), the National Council of Applied Economic Research (NCAER), Integrated Research and Action for Development (IRADe), and Jadavpur University. McKinsey and Company have also been doing a separate study on this subject. This Report brings together the results of the work of these institutions, a total of five separate studies. These studies are independently undertaken, and use different models, techniques and assumptions. The Ministry's role has been to serve as a platform to bring together the studies and facilitate a rigorous academic peer review process. The effort has been to ensure that these studies are fact-based and objective and are not seen as a "government study". We believe that the debates and negotiations on climate change are best served by rigorous and non-partisan analyses of GHG emissions profiles.

One of the interesting findings of this Report is that there is a broad convergence across the five studies in the estimates of India's aggregate GHG emissions and per capita GHG emissions over the next two decades. As these studies indicate, India's aggregate and per capita emissions over the next two decades will remain quite modest. The per capita GHG emissions of India (average across the five studies) are estimated to be 2.1 tonnes of CO_2e[1] in the year 2020, and 3.5 tonnes of CO_2e in the year 2030. For the sake of comparison, **it is notable that the estimated per capita emissions of India in 2020 are expected to be well below those of the developed countries, even if the developed countries were to take ambitious emission reduction targets (25-40%) as recommended by the Intergovernmental Panel on Climate Change (IPCC) for the mid-term.**

[1] *Carbon Dioxide equivalent*

The results are unambiguous. Even with very aggressive GDP growth over the next two decades, India's per capita emissions will be well below developed country averages and much lower than the scenarios that have been projected by certain sections of academia in the developed countries.

Nevertheless, we are acutely conscious of the need to address the issue of climate change and be a proactive and constructive participant in search of an agreement that is fair and equitable. India's energy intensity of GDP has reduced from 0.30 kgoe[2] per $ GDP in PPP[3] terms in 1980 to 0.16 kgoe per $ GDP in PPP terms. This is comparable to Germany and only Japan, UK, Brazil and Denmark have lower energy intensities in the world. Our Prime Minister has already committed that our per capita emissions will not exceed those of the developed countries under any circumstances.

We have a robust and comprehensive National Action Plan on Climate Change (NAPCC) in place which has a mix of both mitigation and adaptation measures. The Plan is being converted into a large number of specific programmes and projects. The Missions on Solar Energy and Enhanced Energy Efficiency under the NAPCC have recently been approved by the Prime Minister's Council for Climate Change. The remaining Missions under the NAPCC will be finalized by December 2009. We are engaging other countries in collaborative research, development, demonstration and dissemination of clean technologies. We have an active research programme in place which includes the monitoring of the Himalayan Glaciers. India is also an active participant in the Clean Development Mechanism (CDM), with the second highest number of projects registered for any country and estimated to offset almost 10 percent of India's total emissions per year by 2012. Recognising the carbon storage and sequestration potential of forests, we have given a new impetus to our forestry sector, and have more than doubled our forestry budget this year to Rs 8,300 crores (USD 1.85 Bn), which we aim to further enhance. Unlike many other developing countries, India's forest cover is increasing every year, and is helping neutralize annually more than 11 percent of India's GHG emissions. A number of other initiatives have also been launched that are detailed on our website (www.envfor.nic.in).

I would welcome debate and discussion on the results of these studies. This is why detailed technical documentation related to these studies is included in this Report. I hope this will generate a meaningful and informed dialogue on the subject. I would like to thank the various institutions involved in this study for their rigorous work and for cooperating in the process of putting together this joint publication.

Jairam Ramesh

(JAIRAM RAMESH)

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[2] Kilogram of oil equivalent
[3] Purchasing Power Parity

Executive Summary

A. BACKGROUND AND RATIONALE

The international debate on climate change is influenced to a significant extent by studies that estimate the GHG emissions trajectories of the major economies of the world. These studies are based on detailed energy-economy models that project global and region or country-wise GHG emissions. Until recently, most of these studies have been carried out in developed countries, and have often applied assumptions and techniques that do not necessarily reflect the ground realities in developing countries.

With a view to develop a fact-based perspective on climate change in India that clearly reflects the realities of its economic growth, the policy and regulatory structures, and the vulnerabilities of climate change, the Government of India, through the Ministry of Environment & Forests, has supported a set of independent studies by leading economic institutions. This initiative is aimed at better reflecting the policy and regulatory structure in India, and its specific climate change vulnerabilities. The studies, which use distinct methodologies, are based on the development of energy-economic and impact models that enable an integrated assessment of India's GHG emissions profile, mitigation options and costs, as well as the economic and food security implications.

This publication puts together the results of Phase I of three of these studies, together with those of two other recent studies, which focus on estimating the GHG emissions trajectory of India for the next two decades, using a number of different techniques[1] .

B. STUDIES PRESENTED IN THIS REPORT

This report summarizes the initial results of five studies. These studies are:

1. **NCAER-CGE:** A computable general equilibrium (CGE) model study by India's National Council of Applied Economic Research (NCAER)

2. **TERI-MoEF**: A MARKet ALlocation (MARKAL) model study by The Energy & Resources Institute (TERI)

3. **IRADe-AA:** An Activity Analysis model study by the Integrated Research and Action for Development (IRADe)

4. **TERI-Poznan:** Another MARKAL model based study by The Energy & Resources Institute presented at the 14th Conference of Parties (COP) on Climate Change at Poznan

5. **McKinsey:** A detailed sector by sector analysis of GHG emissions by McKinsey and Company

[1] *The next step will involve modelling of mitigation options and costs, as well as the economic and food security implications of climate change on India. These are under investigation and will be published in subsequent reports.*

The first three studies were funded by the Ministry of Environment & Forests, Government of India. The TERI-Poznan and McKinsey studies were supported by other funding sources. All studies were undertaken independently. The Ministry of Environment & Forests functioned as the facilitator, bringing together the various studies under a common platform, facilitating a peer review process and publishing the results.

The studies have differences in model structure, specific model assumptions and parameters, as well as some differences in the definitions of the "Illustrative Scenario" whose results are reported. The results relate to India's emissions profile over the next two decades.

The main results of the illustrative scenarios are in Table 1; details of the assumptions and data sources for illustrative scenarios are presented in Table 2; and details of the model methodologies are presented in Table 3.

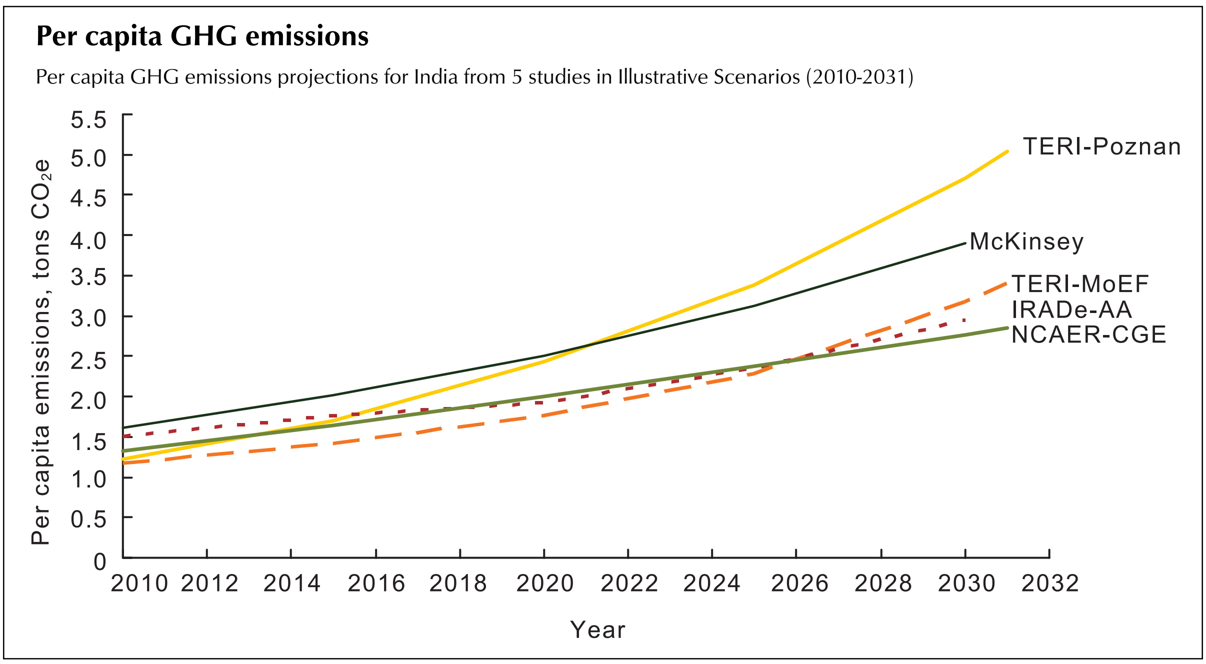
C. KEY RESULTS

The following key results emerge from the studies.

1. Estimates of India's per capita GHG emissions in 2030-31 vary from 2.77 tonnes to 5.00 tonnes of CO_2e[2], with four of the five studies estimating that India's GHG emission per capita will stay under 4 tonnes per capita[3,4] (see Exhibit 1). This may be compared to the 2005 global average per capita GHG emissions of 4.22 tonnes of CO_2e per capita. In other words, four out of the five studies project that ***even two decades from now*, India's per capita GHG emissions would be well below the global average 25 years earlier.**

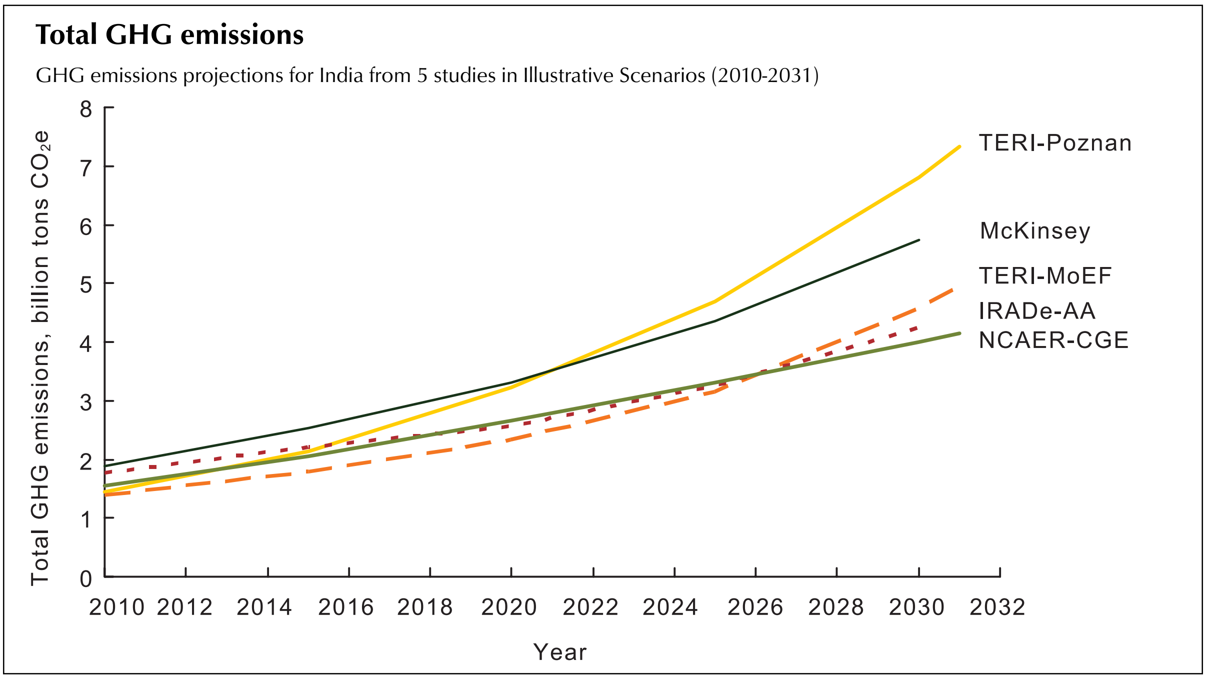
2. In absolute terms, estimates of India's GHG emissions in 2031 vary from 4.0 billion tonnes to 7.3 billion tonnes of CO_2e, with four of the five studies estimating that ***even two decades from now*, India's total GHG emissions will remain under 6 billion tonnes** of CO_2e[3] (see Exhibit 2)**.**

Exhibit 1



[2] *1 tonne of carbon is equivalent to 3.67 tonnes of CO_2e*
[3] *The terminal year is 2031-32 for the TERI-MoEF and TERI-Poznan Studies.*
[4] *McKinsey study estimates include CH_4 emissions from agriculture, not taken into account in the other models*

Exhibit 2



3. All studies show evidence of a substantial and continuous decline in India's energy intensity of GDP and CO_2 intensity of GDP.

4. The key drivers of the range of these estimates are the assumptions on GDP growth rates, penetration of clean energy, assumed energy efficiency improvements etc. There are also justifiable differences in model assumptions, model structure and data, and scenario definitions. **It is therefore neither feasible nor advisable to define a single "baseline" or "business-as-usual" trajectory for a country's GHG emissions.**

D. NOTE ON METHODOLOGIES

- **The NCAER-CGE model** is a 37 sector + Government, top-down, non-linear general equilibrium model, which essentially mimics the behaviour of a competitive market economy in which producers and consumers maximize profits and utility respectively, as per standard economic behavioural assumptions. The Government levies direct and indirect taxes, and spends the revenues on purchase of various commodities in fixed shares determined by policy. The model ensures that all feedbacks between sectors are accounted for, and materials and financial balances in each sector, as well as budgetary balances for all players in the economy are enforced. The country is assumed to be a price-taker in the global economy, but all domestic commodity and factor prices are endogenous in the model. GHG emissions comprise CO_2 and N_2O, from the use of fossil energy and certain industrial processes.

- **The TERI-MoEF model** involves a Linear Programming MARKAL Model set up with an objective function of cost-minimization of the overall energy system over a 30 year modelling timeframe extending from 2001-2031. While minimizing total discounted cost, the MARKAL model must obey a large number of constraints, which express the physical and logical relationships that must be satisfied in order to properly depict the associated energy system. The model is driven by exogenously specified end-use demands and a feasible solution is obtained only if all specified end-use demands for energy are satisfied for every time period. The model comprises of around

35 energy consuming subsectors and a set of conventional and non-conventional primary energy sources. The technology set comprises of a detailed representation of more than 300 technological options that may be adopted across the energy supply and utilization chain at the conversion, transportation, processing, and end-use application stages. Each technology is represented by techno-economic parameters such as its life, costs (investment, fixed and variable O&M costs), efficiency etc., which are provided as inputs to the model. The set of energy carriers consists of all the energy resources that could be available to the energy system through indigenous production, and imports, and is described in terms of its maximum availability, associated costs at various stages and other parameters. The model projects CO_2 emissions from the use of fossil energy and industrial processes.

- **The IRADe-AA model** is a Linear Programming model, which uses the Activity Analysis framework to model the linkages between the national economy and environment. The model is multi-sectoral and inter-temporal and maximizes an objective function, which is the discounted sum of total consumption streams given the resources available to the economy and the various technological possibilities for using them. It traces welfare effects for the low-income groups by examining the incidence of absolute poverty in the population. Differences in consumption patterns among different income classes in a developing country are captured in the model. The model accounts for the behavioural responses of economic agents (such as consumers and producers) to changes in policy. The model ensures a consistent income in a number of ways, including physical flows of commodities, and the financial accounts for each type of economic agent.

- **The TERI-Poznan study** uses the same MARKAL modelling framework as the TERI-MOEF study (see above), but with several differences in assumptions and database. First, it assumes a GDP growth rate of 8.2% per annum during 2001-2031, as compared to CAGR of GDP of 8.84% between 2003-2030 in the TERI-MoEF model, consistent with the GDP projections by the NCAER-CGE. Second, energy prices in TERI-Poznan were considered to evolve over the model simulation period as per expert judgment, whereas in the TERI-MoEF study, international energy prices were obtained from IEAs WEO, 2007, and domestic energy prices were based on price indexes projected by the NCAER-CGE. Third, no explicit improvements in factor productivity were assumed in the TERI-Poznan Study, while the TERI-MoEF Study assumes a total factor productivity growth of 3.0% per annum in the Illustrative Scenario, which is in line with the NCAER-CGE Study. Finally, the TERI-Poznan study considered only limited improvements in energy efficiency based on past trends and expert judgment, whereas TERI-MoEF in the Illustrative Scenario assumed an autonomous energy efficiency improvement of 1.5% per annum, in line with NCAER-CGE, but subject to technical feasibility limits determined through expert judgment.

- **The McKinsey study** estimates greenhouse gas emissions from the 10 largest emitting sectors by 2030 based on certain assumptions of growth and energy patterns in these sectors. The illustrative case is a bottom-up analysis of GHG emissions by sector. It assumes reasonable technological development across all these industries and also includes a range of mature, proven technologies. At the core of the study is an analysis of over 200 technologies (some of which have been built into the illustrative case) to improve energy efficiency and reduce GHG emissions.

Table 1: Results for Illustrative Scenarios

	NCAER CGE Model	TERI MoEF Model	IRADe AA Model	TERI Poznan Mode	McKinsey India Model
GHG emissions in 2030-31 (CO_2 or CO_2e) (billion tons)	4.00 billion tons of CO_2e	4.9 billion tons (in 2031-32)	4.23 billion tons	7.3 billion tons in 2031-32	5.7 billion tons (including methane emissions from agriculture); ranges from 5.0 to 6.5 billion tons if GDP growth rate ranges from 6 to 9 per cent
Per capita GHG emissions in 2030-31 (CO_2 or CO_2e)	2.77 tons CO_2e per capita	3.4 tons CO_2e per capita (in 2031-32)	2.9 tons CO_2e per capita	5.0 tons CO_2e per capita (in 2031-32)	3.9 tons CO_2e per capita (2030), all GHGs
CAGR of GDP till 2030-31, %	8.84%	8.84% (Exogenous – taken from CGE)	7.66% (Endogenous, 2010-11 to 2030-31)	8.2% 2001-2031 (Exogenous)	Exogenous – 7.51% (2005-2030) from MGI Oxford Econometric model
Commercial energy use in 2030-31, mtoe	1087 (Total commercial primary energy forms)	1567 (Total commercial energy including secondary forms) in 2031-32	1042 (Total commercial primary energy)	2149 (Total commercial energy including secondary forms) in 2031-32	NA
Fall in energy intensity	3.85% per annum *(compound annual decline rate)*	From 0.11 in 2001-02 to 0.06 in 2031-32 kgoe per $ GDP at PPP	From 0.1 to 0.04 kgoe per $ GDP at PPP	From 0.11 in 2001-02 to 0.08 in 2031-32 kgoe per $ GDP at PPP	Approximately 2.3% per annum between 2005 and 2030 (at PPP GDP, constant USD 2005 prices)
Fall in CO_2 (or CO_2e) intensity	From 0.37Kg CO_2e to 0.15 Kg CO_2e per $GDP at PPP from 2003-04 to 2030-31	From 0.37 to 0.18 kg CO_2 per $ GDP at PPP from 2001-02 to 2031-32	From 0.37 to 0.18 Kg CO_2 per $GDP at PPP from 2003-04 to 2030-31	From 0.37 to 0.28 kg CO_2 per $ GDP at PPP from 2001-02 to 2031-32	Approximately 2% per annum between 2005 and 2030 (at PPP GDP, constant USD 2005 prices)

[5] National Energy Map for India: Technology Vision 2030

Table 2: Assumptions and data sources for Illustrative Scenarios

	NCAER CGE Model	TERI MoEF Model	IRADe AA Model	TERI Poznan Model	McKinsey India Model
Assumptions	TFPG = 3.0% AEEI = 1.5% No new GHG mitigation policy	TFPG = 3.0%. Energy efficiency improvement consistent with AEEI assumption in corresponding CGE run but constrained by limits to energy efficiency improvements in specific technologies as given in international published literature. No new GHG mitigation policy; discount rate = 15%, Financial Costs	TFPG = 3.0% AEEI = 1.5% (amounting to 36.5% improvement in specific energy consumption from 2003 to 2030). No new GHG mitigation policy, max. savings rate = 35%, Social discount rate = 10%, Govt. annual consumption increase=9%	Efficiency improvements as per past trend and as per expert opinion considering level of maturity of specific technology in India. Discount rate = 10%, Economic Costs, No new GHG mitigation policy	Sector by sector assumptions of demand and technology mix leading to Illustrative scenario emissions
Data Sources					
Population	Registrar General of India(till 2026, extrapolated at same rates till 2030)	Registrar General of India(till 2026, extrapolated at same rates till 2030)	Registrar General of India(till 2026, extrapolated at same rates till 2030)	Registrar General of India(till 2026, extrapolated at same rates till 2030)	Registrar General of India (till 2026, extrapolated at same rates till 2030)
Global / domestic energy price projections	International Energy Agency (WEO 2007) for international, endogenous for domestic	International Energy Agency (WEO 2007) for international; price indices from CGE model for domestic fuel prices; taxes and subsidies included to compute financial prices	International Energy Agency for international; endogenous for domestic	TERI estimates for both international and domestic prices based on prevailing market conditions	International Energy Agency for international energy prices
GDP growth rates	Endogenous	Exogenous – from CGE output	Endogenous	Exogenous – 8.2% (2001-2031)	Exogenous – 7.51% (2005-2030) from MGI Oxford Econometric model
Foreign Savings projections	Study by Bhide et.al. (2006)	NA	Endogenous	NA	NA
Domestic savings rate	National Accounts Statistics	NA	Max 35%	NA	NA
Specific Energy Technologies Data	NA	Data set of > 300 technologies[1] compiled by TERI in study for Principal Scientific Adviser, and technology diffusion consistent with AEEI assumptions as reflected in CGE model	Eight electricity generation technologies (thermal, hydro, natural gas, wind, solar, nuclear, diesel, wood and more efficient coal technology)	Data set of > 300 technologies compiled by TERI in study for Principal Scientific Adviser with recent update	Data set of 200 technologies incorporated in the McKinsey Global Cost Curve model, adapted for Indian volumes, capex and cost

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	NCAER CGE Model	TERI MoEF Model	IRADe AA Model	TERI Poznan Model	McKinsey India Model
GHG emissions coefficients	National Communications	National Communications	National Communications	National Communications	National communications + IPCC + own estimates for power sector
Various other key parameters	Published Literature, NCAER and Jadavpur University estimates	Govt of India Data, other published literature	Govt of India Data	Govt of India Data, own estimates, expert opinion, published literature	Govt of India data, own estimates

Table 3: Models' / Methodology Descriptions

	NCAER CGE Model	TERI MoEF Model	IRADe AA Model	TERI Poznan Model	McKinsey India Model
Model/ Methodology Type	Computable General Equilibrium	Linear Programming minimizing discounted energy system cost	Linear programming maximizing discounted value of consumption over defined time horizon	Linear Programming minimizing discounted energy system cost	Proprietary McKinsey India Cost Curve model to estimate GHG emissions from the 10 largest emitting sectors
Key features of model/ methodology	Top-down, sequentially dynamic, non-linear, market clearance, endogenous prices of commodities and factors	Bottom-up optimization over defined period, detailed energy technologies matrix, set of energy system technical and non-technical constraints, including limits to enhancement in energy efficiency of different technologies	Top-down optimization model over defined period (over 30 years with 3 years for each sequential run) with various resource, capacity and economic constraints	Bottom-up optimization over defined period, detailed energy technologies matrix, set of energy system technical and non-technical constraints with limits to energy efficiency enhancement based on past trends	Factors in estimates of bottom up improvements in technology levers; analyses potential of a selected set from over 200 technologies to increase energy efficiency and reduce emissions; Includes CO_2, N_2O and CH_4 emissions (from agriculture) Demand feedback between sectors: between consuming sectors and power/ petroleum sectors

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	NCAER CGE Model	TERI MoEF Model	IRADe AA Model	TERI Poznan Model	McKinsey India Model
Key inputs	Population, global energy prices, foreign capital inflows, savings rates, labour participation rates	GDP growth rates, final demands of commodities (both from CGE model), global and domestic energy prices both consistent with the CGE model), population, and detailed technology characterization	Population, global energy prices, savings rates, discount rate, minimum per-capita consumption growth rate	GDP growth rates based on doubling of per capita incomes every decade, final demands of energy end-use services, technology characterization, global and domestic energy prices, population based on Government projections	1. GDP growth rates 2. Projected demand for number of inputs (e.g., steel, power, automotive) 3. Population 4. Global energy costs 5. Base and non-base load demand
Key outputs	CO_2e (CO_2 +N_2O weighted by GWPs) emissions, GDP, energy and CO_2e intensities, final demands of commodities, costs of mitigation policies	CO_2 emissions, energy use patterns, energy and CO2 intensities, operating level of each technology, energy system costs, investment and marginal costs for each technology	CO_2 emissions, energy and CO_2 intensities, commodity-wise demand categorized by end-use, income-class wise commodity demand, costs of mitigation policies, poverty impacts	CO_2 emissions, energy use patterns, energy and CO2 intensities, operating level of each technology, energy system costs, investment and marginal costs for each technology	Estimates Illustrative Scenario emissions across GHGs (CO_2, N_2O, CH_4) over time by sector
Number of sectors	37 production sectors + Government	35 energy consuming subsectors + energy supply options including conventional and non-conventional	34 activities with 25 commodities + Government	35 energy consuming subsectors + energy supply options including conventional and non-conventional	10 sectors: Power, Cement, Steel, Chemicals, Refining, Buildings, Transportation, Agriculture, Forestry, Waste
Greenhouse Gases included	CO_2 + N_2O (energy and industry only)	CO_2 (energy and industry only)	CO_2 (energy, industry, households, and government consumption only)	CO_2 (energy and industry only)	CO_2 + N_2O + CH_4 (energy, industry, and agriculture)
Primary Energy forms	Coal, oil, gas, hydro, nuclear, and biomass	Coal, oil, gas, hydro, nuclear, renewables, and traditional biomass	Coal, oil, gas, hydro, nuclear, wind, solar and biomass	Coal, oil, gas, hydro, nuclear, renewables, and traditional biomass	Coal, oil, gas, hydro, nuclear, wind, solar, geothermal and biomass

India's GHG Emissions till 2030:
A Compilation of Results of Five Recent Studies

1. BACKGROUND

Anthropogenic climate change poses perhaps the most complex policy issue faced yet by the global community, moreover, one that is fraught with existential consequences for humankind at one level, and with major implications for the future division of global economic labour at another. Policy analysis in this field involves multidisciplinary inputs – from climate science, technology, economics, and ethics, besides international law and politics.

Mitigation of GHG emissions will, beyond a fairly modest level, involve appreciable economic costs to a society. On the other hand, the adverse impacts of climate change would be felt in diverse sectors which are at the core of livelihood concerns, especially of the poor – agriculture, water resources, coastal resources, vector borne disease, "natural" calamities, etc. Assessment of the costs of GHG mitigation on a economy-wide basis, identifying the technologies that would need to be deployed, and assessment of the losses from climate change impacts, or alternatively, the costs of adaptation activities, are critical inputs to climate policy-making.

Much of the global debate on climate change has been driven by the results of several types of complex analytical models. In the absence of a critical mass of model based studies from India and other developing countries, the terms of the debate have tended to be driven by researchers from the developed countries.

With a view to making a contribution to the global debate, as well as providing such assessments for national policy-making on a formal basis, using rigorous, defensible methodologies, and nationally sourced data and estimated parameters, the Ministry of Environment and Forests, Govt. of India, launched and supported a Climate Change Modeling Forum in 2006. In its present phase, the Forum comprises three national economic-energy-technology models, that are partly linked, to study different types of policy questions on GHG mitigation.[1] The models work under common and consistent sets of assumptions, and are designed to examine alternative policy scenarios in terms of their implications for the levels of energy requirements, the changes in socio-economic outcomes, environmental impacts resulting from different energy utilization patterns, investment requirements, etc.

This Technical Report describes the energy-economic models developed with MoEF support, and the results of initial simulations with these models. In addition, the results of two other studies recently conducted in India are also provided. Accordingly, Part I provides the detailed technical descriptions of the three economic models included in the climate modeling forum, as well as the model assumptions and methodology of the two other studies conducted by other institutions. Part II furnishes the initial results of simulations involving these models and studies on the future path of GHG emissions of the Indian economy till 2030-31/2031-32.

[1] *Also under development, in respect of climate change impacts, are two linked models on water resources and agricultural crops. These two models are not further discussed in this report*

2. PART I: TECHNICAL DESCRIPTIONS OF MODELS/METHODOLOGY:

2.1 Overview: The Models and Methodologies:

The models presently comprising the Forum are as follows:

(i) India Computable General Equilibrium (CGE) Model: developed by the National Council of Applied Economic Research (NCAER) and Jadavpur University (NCAER-CGE)

(ii) India MARKAL Model: adapted from the generic version, by The Energy & Resources Institute (TERI). (TERI-MoEF)

(iii) India Activity Analysis Model: developed by Integrated Research and Action for Development (IRADE) (IRADe-AA)

Apart from these, the two studies conducted by other institutions included in this report are:

(i) Results of MARKAL model analysis by TERI (with assumptions and data distinct from TERI-MoEF above) and presented at a side-event at the 14th Conference of Parties to the UNFCCC at Poznan in December 2008 (TERI-Poznan).

(ii) Bottom-up study by McKinsey and Co., based on the McKinsey GHG abatement cost-curve for India (McKinsey).

The specific features of the NCAER-CGE Model are:

- A top-down macroeconomic 37 Sectors + Government, sequentially dynamic, non-linear model with market clearance and endogenous prices of commodities and factors
- Primary energy sectors are: coal, oil, gas, hydro, nuclear, and biomass; it is possible to include (dynamic) supply constraints for each energy form
- GHG emissions arise in fixed coefficients for each energy form and for specified industrial processes such as cement manufacture
- Factors of productions include: labor and capital + land for agriculture and forestry
- Consumers maximize utility subject to their budget constraints, and producers maximize profits.
- Armington aggregation for domestically produced and imported commodities, as well as for different energy forms, enabling non-linear substitutions
- Fixed coefficients Government expenditure, which can be varied across time periods
- Technological change is described in terms of Total Factor Productivity Growth (TFPG) and Autonomous Energy Efficiency Index (AEEI). These are exogenous model inputs
- Policy variables include full set of direct and indirect taxes, subsidies, export and import taxes. It is possible to include QRs and other policy instruments.
- Outputs include: GDP (and GDP growth), outputs, prices, incomes, quantities of imports and exports, final consumption and Government demands, besides GHG emissions.

CGE is a predictive model to simulate the effects of particular policy and parameter assumptions. It is not a prescriptive modeling framework, and there is no economy-wide objective function.

The specific features of the TERI-MoEF model, developed on the MARKAL (MARKet ALlocation) Framework are:

- An energy-technology-economy linear programming model which minimizes discounted energy system costs over a defined planning horizon to meet a vector of final demands for commodities and energy services
- Uses a bottom-up representation of energy producing, transforming, and consuming technologies. GHG emissions are by fixed coefficients for each energy technology (and cement production)

- Includes TFPG and AEEI for dynamic representation of technologies. *Technological change is limited in case of each technology by considerations of feasibility based on the international literature and expert opinion (energy efficiency gains are thus well short of thermodynamic limits).*
- Finds a least cost set of technologies to satisfy end-use energy service demands and constraints specified in the defined scenario
- Outputs are resulting energy-technology combinations (feasible, optimal)
- Fuel availability constraints are as per Government of India's policies and plans
- The model may be run using either economic or financial costs.

The MARKAL is a prescriptive model, and can be used to predict the future evolution of the energy sector and GHGs trajectory only under the assumptions that there is in existence a central planner for the energy sectors whose objective function relates to minimization of discounted energy system costs over the simulation period, and that the exogenous parameters assumed, in particular GDP growth rates and rates of technological change hold true. The simulations of the TERI-MoEF MARKAL model are coordinated with simulations of the NCAER-CGE model, and used to determine the "optimal" (in the MARKAL sense) choice of technologies for the scenarios simulated. Comparisons between simulated scenarios can also provide the incremental investment costs, as well as the differences between the energy system costs between the scenarios.

The specific features of the IRADe Activity Analysis Model are:

- The model is a "stand-alone", non-linear, multi-sectoral, inter-temporal model which maximizes the discounted sum of total *consumption streams* across the entire planning horizon, subject to specified constraints
- A total of 25 commodities are produced using 35 production activities
- Five categories of rural and five categories of urban households are included, based on per capita consumption expenditure limits
- Endogenous income distribution helps in estimating poverty in rural and urban households

This model too, is not predictive, *but prescriptive*, from the standpoint of a economy-wide central planner who seeks to maximize the discounted aggregate consumption in the economy for each simulation period.

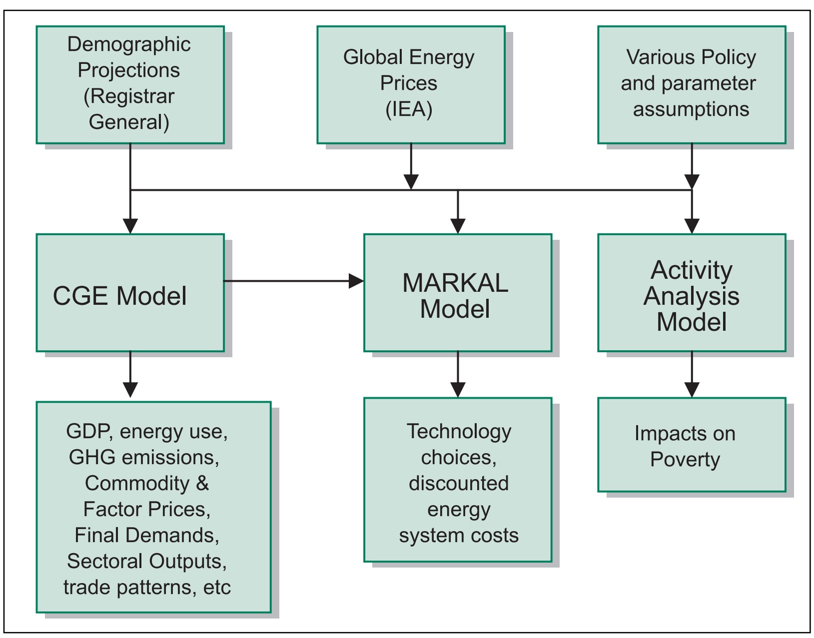

Figure 1: Structure of Partially Linked Energy-Economy Models

While the models do not have a wired link, the outputs of the CGE model feed into the MARKAL model. The structure of the Activity Analysis model does not lend itself to similar inputs from the CGE model. All models take population projections from the Registrar General, global energy prices from International Energy Agency (IEA), and various common policy and parameter (especially technological change related) assumptions.

To summarize: the NCAER-CGE, TERI-MoEF (MARKAL), and IRADe-Activity Analysis models are used to run defined Illustrative Scenarios which do not involve any new policies relevant to GHG mitigation, to determine the trajectory of GHG emissions in the economy without GHG constraints till 2030/31.

The TERI-Poznan model uses the same MARKAL structure as the TERI-MoEF model. However, it diverges in respect of several key assumptions and data base. For example, it assumes a lower GDP growth rate than the TERI-MoEF study (which draws upon the GDP projections obtained from the NCAER-CGE model). It also projects future energy prices (international and domestic) by in-house expert opinion, whereas TERI-MoEF uses the WEO, 2007 projections with respect to international energy prices, and uses the price indices generated by the NCAER-CGE model for domestic energy prices. Finally, it is much more conservative than the Illustrative Scenario of TERI-MoEF with respect to improvements in specific energy consumption, and assumes that there is little improvement in total factor productivity. *The last set of divergent assumptions from TERI-MoEF seem to largely drive the differences in their results for the future CO2 emissions path.*

The McKinsey study employs a bottom-up approach to estimate energy use patterns in 10 sectors. It factors in bottom-up estimates of improvements from technology levers and optimizes costs by determining a merit order for aspplication of over 200 abatement technologies. There is comprehensive coverage of sectors and GHGs i.e. CO2, N2O and CH4, as well as accounting for demand feedback between consuming sectors and power/petroleum sectors. Projections of GDP growth are obtained from a separate global macroeconomic model .

2.2 Technical Description of the India Computable General Equilibrium Model

The CGE model developed by NCAER is used to project India's GDP growth and GHG emissions, and to evaluate the impacts of GHG emissions abatement policies. This model is a single-country model interacting with the rest-of-the-world (ROW).

2.2.1 Model Structure

This CGE model is based on a neoclassical CGE framework that includes institutional features peculiar to the Indian economy. Figure 3 depicts the building blocks of CGE model. It is multi-sectoral and recursively dynamic. The overall structure of the model is similar to the one presented in Ghosh (1990). However, in formulating certain details of the model, such as, the income distribution mechanism a more eclectic approach is followed keeping in mind the focus on the linkages between inter-fossil-fuel substitutions, CO_2 emissions, GDP growth and the distribution of income across the rural and urban socioeconomic classes.

The model includes the interactions of producers, households, the government and the rest of the world in response to relative prices, given certain initial conditions and exogenously given set of parameters. Producers act as profit maximizers in perfectly competitive markets, i.e., they take factor and output prices (inclusive of any taxes) as given and generate demands for factors so as to minimize unit costs of output. The factors of production include intermediates, energy inputs and the primary inputs - capital, land and different types of labour. Production is organized through a multi-level nested production function which has Cobb-Douglas, CES and Translog functions at different levels in the production nest. For households, the initial factor endowments are fixed. They, therefore, supply factors inelastically. Their commodity-wise demands are expressed, for given income and market prices, through the Stone-Geary linear expenditure system (LES). Also households save and pay taxes to the government. Furthermore, households are classified into five rural and four urban socio-economic groups. The government is not assumed to be an optimizing agent. Instead, government consumption, transfers and tax rates are exogenous policy instruments. The total GHG (CO_2 and N_2O) emissions in the economy are determined on the basis of inputs of fossil fuels in the production process, the gross outputs produced, and the consumption demands of the households and the government, using fixed emission coefficients. The rest of the world supplies goods to the economy which are imperfect substitutes for domestic output, makes transfer payments and demands exports. The standard small-country assumption is made, implying that India is a price-taker in import markets and can import as much as it wants. However, because the imported goods are differentiated from the domestically produced goods, the two varieties are aggregated using a constant elasticity of substitution (CES) function, based on the Armington assumption. For exports, a downward sloping world demand curve is assumed. On the supply side, a constant elasticity of transformation (CET) function is used to define the output of a given sector as a revenue-maximising aggregate of goods for the domestic market and goods for the foreign markets. The model is Walrasian in character. Markets for all commodities and non-fixed factors clear through adjustment in prices. Capital stocks are fixed and intersectorally immobile. However, by virtue of the Walras' law, the model determines only *relative* prices. The overall price index is chosen to be the numeraire and is, therefore, normalised to unity. With the (domestic) price level and the foreign savings fixed exogenously, the model determines endogenously the nominal exchange rate in the external closure and the level of investment in the domestic macro closure (Robinson, 1999). In other words, because the foreign savings is exogenously fixed, the model follows a saving-driven macro closure in which the investment level adjusts to satisfy the saving-investment balance.

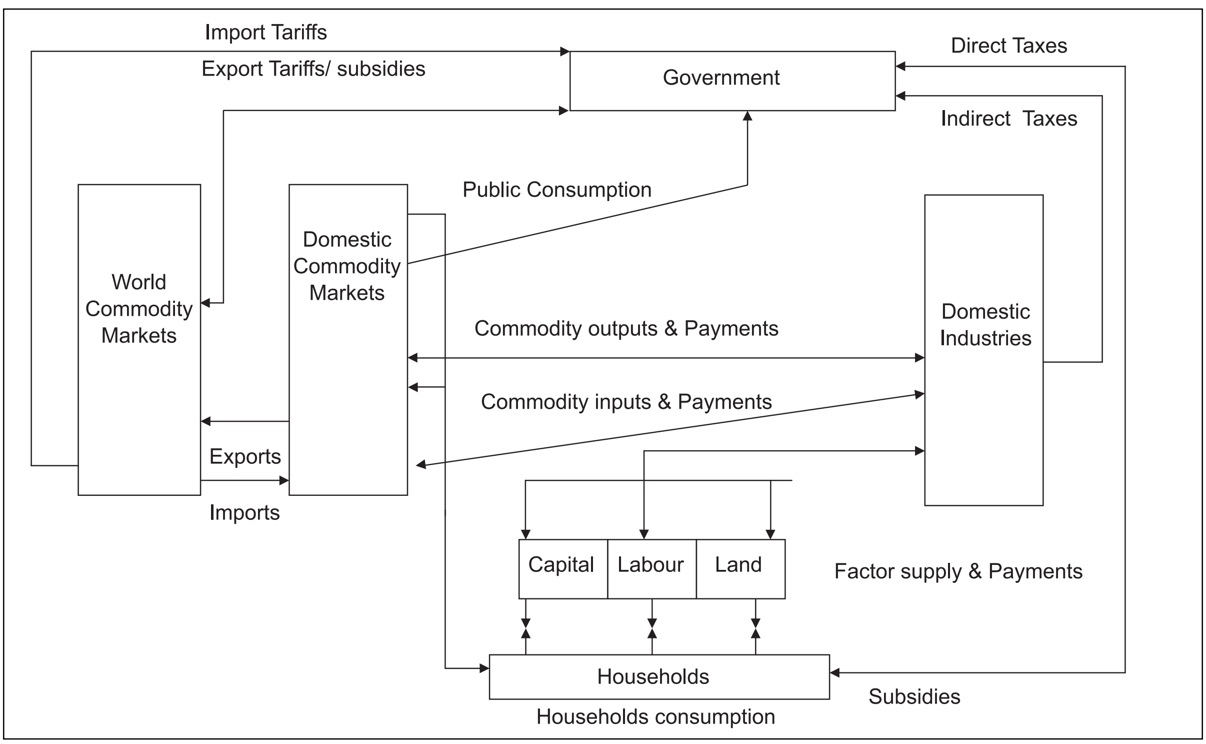

Figure 2: Flow of Conventional Commodities, Factors, Payments and Transfer in the Economy

2.2.2 Sectoral Disaggregation

The model is based on a 37-sector disaggregation of the Indian economy. The sectoral disaggregation was decided after much deliberation on what would be the optimal number of sectors in a trade-off between the theoretical requirement of having a large number of sectors differentiated on the basis of their emission intensities, and the practical compulsion of maintaining a manageable number of sectors that would facilitate computation and policy relevant interpretations of the computed results. The list of 37-sector of the Indian economy is given in the Table 1.

Table 1: Sectoral Disaggregation in the CGE model

	Code	Description of Sectors		Code	Description of Sectors
1	PAD	Paddy Rice	20	IRS	Iron & Steel
2	WHT	Wheat	21	ALU	Aluminium
3	CER	Cereal, Grains etc, other crops	22	OMN	Other manufacturing
4	CAS	Cash crops	23	MCH	Machinery
5	ANH	Animal husbandry & prod.	24	HYD	Hydro
6	FOR	Forestry	25	NHY	Thermal
7	FSH	Fishing	26	NUC	Nuclear
8	COL	Coal	27	BIO	Biomass
9	CUP	Crude Oil	28	GMN	Gas Manufacture & Distribution
10	NGS	Natural Gas	29	WAT	Water
11	FBV	Food & beverage	30	CON	Construction
12	TEX	Textile & Leather	31	RTM	Road Transport motorised
13	WOD	Wood	32	RNM	Road Transport non motorised
14	MIN	Minerals n.e.c.	33	RLY	Rail Transport
15	ROL	Refined Oil & Coal Prod.	34	AIR	Air Transport
16	CHM	Chemical, Rubber & Plastic prod.	35	SEA	Sea Transport
17	PAP	Paper & Paper prod.	36	HLM	Health & medical
18	FER	Fertilizers & Pesticides	37	SER	All other services
19	CEM	Cement			

2.2.3 The Production Structure

Each producing sector has a nested production function, with the structure of nesting being the same across sectors. Each sector produces its gross output, employing capital, labour and an aggregation of its own and other sectors' inputs, known as intermediate inputs. The intermediate inputs are broadly of two kinds – energy and non-energy. The different types of inputs, however, combine through differently specified production functions at the various levels in the production nest whose diagram is shown below (Figure 4).

Note that aggregate of energy inputs, AENG, is formed through a Translog function which combines the five sources of energy, namely, electricity, coal, natural gas, refined oil, and biomass, where electricity itself is a linear aggregation of the three main sources of electricity - thermal, hydropower, and nuclear. The Translog function is used because it allows different (Allen-Uzawa) substitution elasticities between different pairs of the aforesaid five sources of energy. The remaining non-factor inputs is referred to as the aggregate materials, AM, which represents a fixed-coefficients bundle of inputs from the non-energy sectors. The AENG and the AM combine into aggregate non-factor inputs, ANFI, through a CES function for which only one substitution elasticity is required. Further

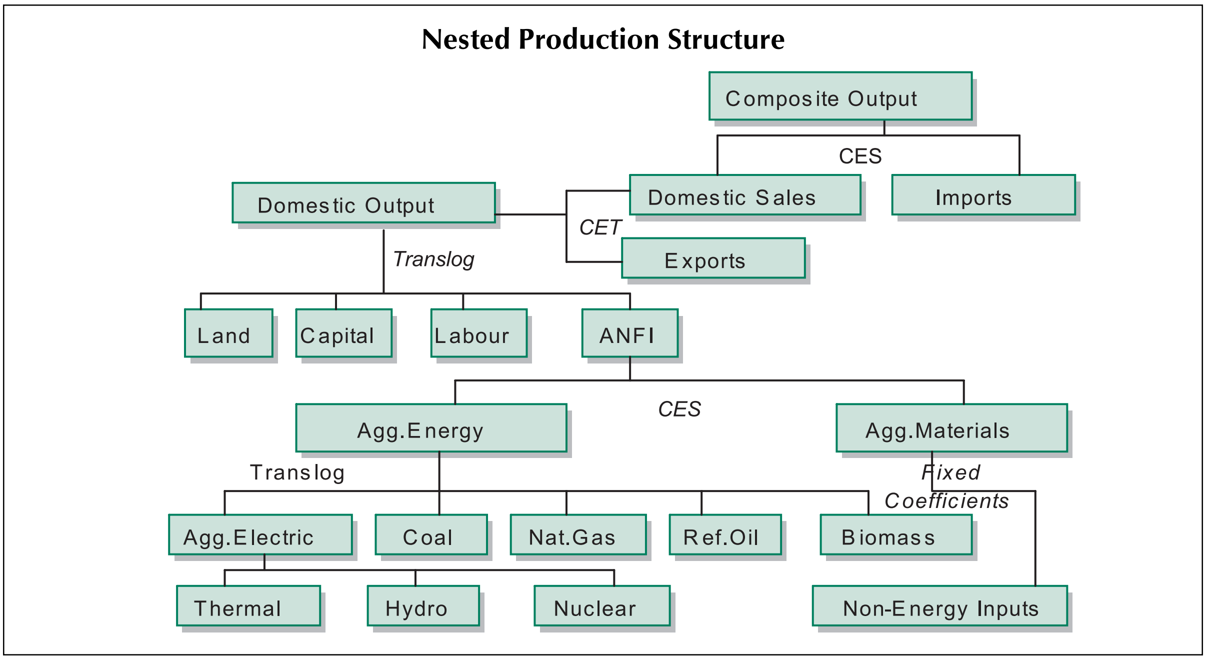

Figure 3 : The Production Nesting Diagram

up, the ANFI, labour, capital and land (in case of agricultural sectors) are coalesced into the domestic gross output using a Translog function having different substitution elasticities for different pairs of inputs. Note that the TL function reduces to the much simpler Cobb-Douglas form in case of unit substitution elasticities between the various input pairs (this does happen for a subset of the 37 sectors).

Domestic gross output itself is an aggregate of its two constituents – domestic sales and exports – obtained through a CET function. Finally, at the top end of the production nest, domestic sales and final imports into a sector are aggregated into a composite output for that sector by making use of a CES aggregation function.

2.2.4 Description of Model - Model Equations, Variables and Parameters

The CGE model is a system of simultaneous, nonlinear equations. The model is square in a sense that the number of equations is equal to the number of variables. In this class of models, this is a necessary (but not a sufficient) condition for the existence of a unique solution. In our case also we have developed a set of equations in such a way that the number of equations is equal to the number of endogenous variables of the model. The sets, parameters and variables appeared in the equations are described below:

Sets

1.	AS	All Sectors (All 37 Sectors of 2003-04 SAM)
2.	DOMS	Sectors with Domestic Sale (All 37 sectors of 2003-04 SAM)
3.	FMAT	Factors of Production (k - Capital, l - Labour, la - Land, q – Commodity Input)
4.	GHGS	Greenhouse Gases (CO_2 – Carbon Dioxide, N_2O – Nitrous Oxide)

5. HHSC Households Classes
(rh1, rh2, rh3, rh4, rh5, uh1, uh2, uh3, uh4)
6. PFAC Primary Factors of Production
(k, l, la)
7. SIMP Sectors with Imports
(pad, wht, cer, cas, anh, frs, fsh, col, oil, gas, fbv, txl,wod, min, pet, chm, pap, fer, irs, alu, omn, mch, rtm, rnm, air, sea, ser)
8. SNIMP Sectors without Import
(cem, hyd, nhy, nuc, bio, gmn, wat, con, rly, hlm)
9. SEXP Sectors with Exports
(pad, wht, cer, cas, anh, frs, fsh, col, gas, fbv, txl, wod, min, pet, chm, pap, fer, irs, alu, cem, omn, mch, rtm, rnm, rly, air, sea, ser)
10. SNEXP Sectors without Export
(oil, hyd, nhy, nuc, bio, gmn, wat, con, hlm)
11. SMANU Manufacturing Sectors
(txl, wod, min, pet, chm, pap, fer, irs, alu, cem, omn, mch, con, gmn, oil)
10. SNMAN Non-Manufacturing Sectors
(pad, wht, cer, cas, anh, frs, fsh, fbv, col, gas, bio, hyd, nhy, nuc, wat, rtm, rnm, rly, air, sea, hlm, ser)
11. SEN Conventional Energy Sectors
(col, gas, pet, hyd, nhy, nuc, bio)
12. SMAT Material Input Supply sectors
(pad, wht, cer, cas, anh, frs, fsh, oil, fbv, txl, wod, min, chm, pap, fer, irs, alu, cem, con, wat, gmn, omn, mch, rly, rtm, rnm, air, sea, hlm, ser)

Endogenous Variables of the Model

AEN_i	Aggregate energy input
$AENC_i$	Aggregate Energy Costs
CD_j	Consumer Demand for Armington Commodity
CO_2C_i	Cost for carbon emission
CO_2E_i	CO_2 Emission
CO_2Fi	Quantity of CO_2 offsets generated in each industry
CO_2N_i	Net CO_2 emission by each industry
CO_2Q_i	Quantity of domestic CO_2 quota and offsets purchased by industries
CO_2PUB	Quantity of CO_2 emission due to public energy use
CO_2PVT	Quantity of CO_2 emission due to private energy use
$CHSTK_j$	Change in Stocks
DENei	Quantity of domestic energy used by each industries
$DHIC_h$	Disposable household income
EC_i	CO_2 Emission Cost
EXR	Exchange Rate
$EPN_{e,i}$	Effective price of composite energy inputs
$FINV_i$	Quantity of fixed investment demand for each Armington commodity
GOVI	Government Income
GDP	Gross Domestic Product
HI	Household income
HIC_h	Class wise households class wise income
$HCD_{h,j}$	Households consumption demand
HCE_h	Hoseholds Consumption Expenditure
$INT_{j,i}$	Intermediate input demand

INV	Total investment of the economy
$INVD_i$	Investment demand by each industry
INTei	Intermediate use of Armington energy commodity by industries
MAT_i	Material Inputs
$NATCO_2$	Net national CO_2e emission
PWE_j	World price of exports
PM_j	Domestic Price of Imports
PE_j	Price of export commodities in domestic market
PDD_j	Price of domestic good j used domestically
PQ_j	Price of Armington composite of good j in domestic market
PX_j	Price of composite of export and domestically used good j
$PF_{f,i}$	Return from primary factors
PEN_i	Aggregate energy price
PMA_i	Aggregate material price
PWC	World trade price of CO_2e
PC	Price of CO_2e
$PUBD_j$	Public Consumption Demand
PUBE	Total Public consumption expenditure
QM_j	Total quantity of commodity j imported
QD_j	Quantity of domestic good j used domestically
QQj	Quantity of Armington composite of good j
QX_j	Total quantity of demand of domestic commodities
QE_j	Total quantity of domestic commodity j exported
$QF_{f,i}$	Quantity of factors used in each industry
QCT	Quota of CO_2e traded internationally
QA_j	Quantity of commodity j produced by industry j
QCS	Quantity of CO_2e quota sold or purchased
RMD_j	Ratio of import to domestic sales
RQD_j	Ratio of domestic commodity to Armington composite
RUW	Rural wage
REN	Rental rate of land
TC_i	Total cost for production

Parameters of the Model

α_j^{ex}	Scaling parameter for CET equation
α_j^{m}	Scaling parameter for Armington CES function
α_{0i}	Scaling parameter of translog energy aggregation function
$\alpha_{e,i}$	Translog energy aggregation parameter
$\alpha_{mat,i}$	Fraction of materials input in total material input of each industry
$\alpha_{q,i}$	Scale parameter of input aggregation function
$b^i_{e,ep}$	Translog Armington energy aggregation parameter, $b_{i,f}$ and $\gamma^i_{f,f'}$ are Translog cost function parameter and

Translog cost function parameter and

$$\sum_f b_{i,f} = 0 \text{ and } \sum_f b^i_{ff'} = \sum_{f'} b^i_{ff'} = 0$$

$\beta_{h,j}$	Beta parameter of LES function
capital0	Initial quantity of capital
cfor	Foreign exchange inflow in the CO_2e account

δ_j^m	Share parameter for j in Armington function
δ_j^{ex}	Share parameter of CET composition function
$\delta_{q,i}$	Share parameter of commodity input aggregation function
δt_h	Households direct tax
$end_{h,f}$	Endowment of primary factors by households classes
exp_j	Quantity of exports when supply price equals to world price
$fdem^{pub}_j$	Post tax structure of public demand
gsav	Government savings.
$\gamma_{h,j}$	Gamma parameter of LES function
κ_i	Industry wide CO_2e emission permit
$kap_{i,j}$	Capital composition parameter
λ_i	Depreciation rate
labor0	Initial quantity of labour.
μ	Average annual inflation rate
natnlco20	National CO_2e emission
pwm_j	World Price of Imports
pwc	World trade price of CO_2e
pop_h	Population of each Households Class
prcl	Price level
π_j^m	Windfall profit from import
π_j^{ex}	Windfall profit from export
$\phi_{e,g}$	Coefficient of GHG emission by each energy types
r	Interest rate
rew_i	Real wage
ρ_j^{ex}	Elasticity of transformation for exports and domestics
$\rho_{q,i}$	Commodity input aggregation function
ρ_j^m	Elasticity of substitution for j in Armington function
str_h	Share of households in total transfer
sub	Subsidy rate
sr_h	Households savings rate
sctk	Share of total change in stocks in total investment
σ_i	Elasticity between material and energy inputs
σ^{ex}_j	Export demand price elasticity
tm_j	Tariff rate
te_j	Export tax rate
ta_i	Taxes on gross output except export and import tax
ta_i	Taxes on gross output except export and import tax
θ_g	CO_2e equivalent of GHG emission
tc	Carbon tax
τ	Price level
ϑ_i	Investment share by industry of destination
xch_j	Share of sectoral change in stocks in total change in stocks

Equations of the Model

1. Domestic price of Import Commodities.

$$PM_j = (1+tm_j).pwm_j.EXR - \pi_j^m$$ j ε SIMP

2. World price of Export Commodity.

$$PWE_j = PE_j(1+te_j) - \pi_j^{ex}$$ j ε SEXP

3. Ratio of Import to Domestic Demand

$$RMD_j = \left\{\left(\frac{\partial_j^m}{1-\partial_j^m}\right)\left(\frac{PDD_j}{PM_j}\right)\right\}^{\frac{1}{1+\rho_j^m}}$$ j ε SIMP ∩ DOMS

4. Demand for Imports

$$QM_j = RMD_j.QD_j$$ j ε SIMP ∩ DOMS

5. Armington Aggregation Equation

$$QQ_j = \alpha_j^m\left\{\partial_j^m QM_j^{-\rho_j^m} + \left(1-\partial_j^m\right)QD_j^{-\rho_j^m}\right\}^{-\frac{1}{\rho_j^m}}$$ j ε SIMP ∩ DOMS

6. Price of composite for imports and domestically used commodity

$$PQ_jQQ_j = QM_jPM_j + QD_jPDD_j$$ j ε AS

7. Armington Aggregation equation for the case of no imports

$$QQ_j = \alpha_j^m QD_j$$ j ε SNIMP

8. CET equation for exports and domestic

$$QX_j = \alpha_j^{ex}\left\{\partial_j^{ex} QE_j^{\rho_j^{ex}} + \left(1-\partial_j^{ex}\right)QD_j^{\rho_j^{ex}}\right\}^{\frac{1}{\rho_j^{ex}}}$$ j ε SEXP ∩ DOMS

9. Ratio of exports and domestic demands

$$\left(\frac{QE_j}{QD_j}\right) = \left\{\left(\frac{PE_j}{PDD_j}\right)\left(\frac{1-\partial_j^{ex}}{\partial_j^{ex}}\right)\right\}^{\frac{1}{\rho_j^{ex}-1}}$$ j ε SEXP ∩ DOMS

10. Price of composite of exports and domestic commodity

$$PX_jQX_j = PE_jQE_j + PDD_jQD_j$$ j ε AS

11. CET equation for no exports

$$QX_j = \alpha_j^{ex}QD_j$$ j ε SNEXP

12. Commodity Market Balance

$$QX_i = QA_i$$ i ε AS

13. Average cost pricing rule for industries

$$QA_i\left(\frac{PX_i}{(1+ta_i)}\right) = TC_i$$ i ε AS

14. Commodity Market Balance

$$QX_j = QA_j$$ j ε AS

15. Average cost pricing rule for industries

$$QA_i\left(\frac{PX_i}{(1+ta_i)}\right) = TC_i$$ i ε AS

16. Production costs for industries.

$$TC_i = \sum_f QF_{f,i}PF_{f,i} + \sum_j INT_{j,i}.PQ_j + CO2C_i$$

i ε AS
f ε PFAC

17. Quantities of factor inputs (Translog Production Function)

$$QF_{f,i}.PF_{f,i} = (TC_i - EC_i)b_{f,i} + \sum_f \gamma^i_{f,f'}.\log(PF_{f,i})$$

i ε AS
f ε FMAT

18. Commodity Inputs Aggregation Equation for Industries (cobb-Douglas Production function)

$$\ln(QF_{q,i}) = \ln(\alpha_{q,i}).\left(\partial_{q,i}.\ln(MAT_i) + \left(1 - \partial_{q,i}\right)\ln(AEN_i)\right)$$

i ε AS
i ε AS

19. Ratio of materials and energy inputs in aggregate commodity inputs

$$MAT_i = AEN_i\left(\left({PEN_i}\big/{PMA_i}\right)\left({\partial_{q,i}}\big/{1-\partial_{q,i}}\right)\right)^{\sigma_i}$$

i ε AS

20. Price of aggregate commodity inputs faced by industries

$$PF_{q,i}.QF_{q,i} = \left(PMA_i.MAT_i + PEN_i.AEN_i\right)$$

i ε AS

21. Effective cost of aggregate of Armington energies

$$AENC_i = \sum_e INT_{e,i}.EPN_{e,i}$$

i ε AS

e ε SEN

22. Quantity of aggregate of Armington energy inputs

$$\ln(AEN_i) = \ln(AENC_i) - \alpha_{0,i} - \sum_e \alpha_{e,i}.\ln(EPN_{e,i}) - \frac{1}{2}\sum_e\sum_{ep} b^i_{e,ep}.\ln(EPN_{e,i}).\ln(EPN_{ep,i})$$

i ε AS
e ε SEN

23. Quantity of each type of Armington energy employed in each industry

$$INT_{e,i}.EPN_{e,i} = \left(\alpha_{e,i} + \sum_{ep} b^i_{e,ep}\ln(EPN_{ep,i})\right) * AENC_i$$

i ε AS

e ε SEN

24. Aggregation of Non-energy commodities as Industry Intermediate inputs

$$INT_{mat,i} = \alpha_{mat,i}.MAT_i$$

i ε AS
mat ε SMAT

25. Price of aggregate material input faced by industry

$$PMA_i.MAT_i = \sum_{mat} PQ_{mat}.INT_{mat,i}$$

i ε AS

mat ε SMAT

26. Ratio of domestic commodity to Armington composite.

$$RQD_j.QQ_j = QD_j$$ i ε AS

27. Quantities of Domestic and Imported Energy of each type used as input by each industry.

$$DEN_{e,i} = RQD_j.INT_{e,i}$$ j ε AS

e ε SEN

28. GHG emission by each industry in carbon equivalent

$$CO2E_i = \sum_e \sum_g \theta_g.\phi_{e,g}.DEN_{e,i}(1+RMD_e)$$ i ε AS

e ε SEN
g ε GHGS

29. Quantity of CO_2 offsets generated in each industry

$$CO2F_i = \eta_i.QF_{la,i}$$ i ε AS

30. Net taxable or saleable CO_2 emission by each industry

$$CO2N_i = CO2E_i - CO2F_i - CO2Q_i - \kappa_i$$ i ε AS

31. Penalty due to positive net CO_2 emission by each industry.

$$CO2C_i = CO2N_i.tc + CO2Q_i.PC$$ i ε AS

32. Effective price of energy input for industry

$$EPN_{e,i} = PQ_e + PC.RQD_e.(1+RMD_e).\sum_g (\theta_g.\phi_{e,g})$$ i ε AS

e ε SEN
g ε GHGS

33. Effective price of capital for industry I in GE model

$$PF_{k,i} = \tau.(r-\mu) + \lambda_i$$ i ε AS

34. Effective price of labour for industry I in GE model

$$PF_{l,i} = RUW.rew_i$$ i ε AS

35. Effective land rental rate in each industry in GE model

$$PF_{l,i} = REN$$ i ε AS

36. Gross domestic product at factor costs

$$GDP = HI + \sum_j \pi_j^m.QM_j + \sum_j \pi_j^{ex}.QE_j + pwc.QCT.EXR$$ j ε AS

37. Households income by households class

$$HIC_h = \sum_f end_{h,f}.\sum_i PF_{f,i}.QF_{f,i}$$ i ε AS

38. Disposable Household income by households class h

$$DHIC_h = HIC_h - dt_h.(HIC_h - end_{h,la}.\sum_i PF_{la,i}.QF_{la,i}) + str_h.(GDP.sub)$$

i ε AS

h ε HHSC

39. Net household income

$$HI = \sum_h HIC_h$$

h ε HHSC

40. Net households expenditure

$$HCE_h = DHIC_h.(1 - sr_h)$$

h ε HHSC

41. Total government income

$$GOVI = \sum_h dt_h.\left(HIC_h - end_{h,la}.\sum_i PF_{la,i}.QF_{la,i}\right) + \sum_j QM_j.pwm_j.tm_j.EXR + \sum_j QE_j.PE_j.te_j$$
$$+ \sum_j QA_j.\left(PX_j / 1 + ta_i\right).pwc.QCT.EXR + PC.QCS + \sum_i tc.CO2N_i + cfor.EXR$$

i ε AS

j ε AS

h ε HHSC

42. Net public consumption expenditure

$$PUBE = GOVI.(1 - gsav) - (sub.GDP)$$

43. Consumer LES demand equations by households class

$$HCD_{h,j} = \left(\gamma_{h,j} + \left(\beta_{h,j} / PQ_j\right).\left(\left(HCI_h / pop_h\right) - \sum_j PQ_j.\gamma_{h,j}\right)\right).pop_h$$

j ε AS

h ε HHSC

44. Consumer demand equation

$$CD_j = \sum_h HCD_{h,j}$$

j ε AS

h ε HHSC

45. Public demand equation

$$PUBD_j = (fdem_j^{pub}.PUBE) / PQ_j$$

j ε AS

46. Value of gross investment in the economy

$$INV = \sum_h DHIC_h.sr_h + GOVI.gsav + fsav.EXR$$

h ε HHSC

47. Investment demand by each Industry

$$INVD_i.PQ_i = \vartheta_i.(1 - sctk)INV$$

i ε AS

48. Quantity of fixed investment demand for each Armington commodity in the economy.

$$FINV_j = \left(\left(\sum_i kap_{i,j}.INVD_i\right) / PQ_j\right)$$

i ε AS

j ε AS

49. Quantity of change in stock demand for each Armington commodity

$$CHSTK_j.PQ_j = xch_j.sctk.INV$$ j ε AS

50. Total demand of Armington Composites in the Domestic market.

$$QQ_j = PUBD_j + CD_j + INVD_j + CHSTK_j + \sum_i INT_{j,i}$$ j ε AS
i ε AS

51. Export Demands for domestic Commodities

$$QE_j = \exp_j \cdot \left(\frac{pwm_j}{\left(PWE_j / EXR \right)} \right)^{\sigma_j^{ex}}$$ j ε SEXP

52. Labour market balance holds for GE model

$$\sum_i QF_{l,i} = labor0$$ i ε AS

53. Capital market balance holds for GE model

$$\sum_i QF_{k,i} = capital0$$ i ε AS

54. CO_2e emission due to final consumer demands for energy commodities.

$$CO2PVT = \sum_e \left(CD_j.RQD_j.(1+RMD_j) \right) \sum_g \left(\theta_g.\phi_{e,g} \right)$$ j ε AS
e ε SEN
g ε GHGS

55. CO_2e emission due to final public demands for energy

$$CO2PUB = \sum_e \left(PUBD_j.RQD_j.(1+RMD_j) \right) \sum_g \left(\theta_g.\phi_{e,g} \right)$$ j ε AS
e ε SEN
g ε GHGS

56. Net national CO_2e emission.

$$NATCO2 = CO2PVT + CO2PUB + \sum_i (CO2E_i - CO2F_i)$$ i ε AS

57. Domestic CO_2e balance in the economy

$$QCT - \sum_i CO2Q_i = 0$$ i ε AS

58. External CO_2e balance of the National Economy

$$NATCO2 + QCT = natnlco2$$

59. Price normalisation equation

$$\sum_j wgt_j.PQ_j = prcl$$ j ε AS

2.2.5 Data and Implementation of the Model

In the above section the system of simultaneous non-linear equations comprising the model have been set out. These equations are solved to determine the equilibrium values of the endogenous variables based on the available information on exogenous variable and structural parameters. The model has been solved for the base year 2003-04 and, subsequently, for the future 28 years, till 2030-31 with no specific GHG abatement policies Therefore to implement the model, one needs to derive estimates of the parameters of the model and the values of the exogenous variables of the same.

The principal exogenous variables and parameters of the model are as follows:

Exogenous Variables

(1) Population.
(2) Foreign Savings.
(3) Land Endowment in the Economy.
(4) Total Labour Supply in the Economy.
(5) Total Capital Stock in the Economy.
(6) World Prices of Commodities.

Technological Parameters

(1) Substitution Elasticities in the Production Functions.
(2) Scale Parameters in the Production Functions.
(3) Share Parameters in the Production Functions.
(4) Emission Coefficients.

Behavioral Parameters

(1) Savings Rates.
(2) Demand System Parameters.
(3) Share of aggregate Investment earmarked for inventory investment.
(4) Shares for allocation of total inventory investment into sectoral "Change in Stocks".
(5) Share of Fixed Investment by sector of origin.

Policy Parameters

(1) Tax and Tariff rates.
(2) Subsidy rates.
(3) Share of public consumption demand by sector of origin.

The principal data source for estimating these parameters is the 37-sector SAM. The NCAER and Jadavpur University have pooled their respective efforts to construct a 37-sector SAM for the year 2003-04. This SAM for the year 2003-04 helps to estimate the share parameters of our model. This estimation of share parameters is based on the assumption that the base-year (2003-04) values in the SAM is represents an "equilibrium" set of values which the CGE model must replicate as closely as possible,. This assumption of base-year equilibrium is a very useful one as it enables a great deal of prior information on parameter estimation.

However, the SAM does not provide the data for estimating the policy parameters of our model. To estimate these parameters data from National Accounts Statistics (NAS), Annual Survey of Industries (ASI), Public Finance Statistics of India, and various rounds data of National Sample Survey Organization (NSSO) have been used.

Knowledge of a base-year SAM and the assumption that the base year is in equilibrium does not provide any information about the values of elasticities. Additional information and data are required for estimation of these parameters. The elasticity parameters describe the curvature of various structural functions. The structural functions used in the CGE model are: Translog production function, Cobb-Douglas production function, LES demand function for consumers, CES import demand function, and CET export supply function. Estimation of values of these parameters, and in some cases by reference to the published literature was undertaken by Jadavpur University.

2.2.6 Time Path of Exogenous Variables

It has been mentioned earlier in the description of the model that several exogenous variables that have been used in the solving the model. To be specific, they are the following:

1. Foreign Savings.
2. Population.
3. Land Endowment.
4. Total Labour Supply in the Economy.
5. World Prices of Commodities.

The sources of the data for the parameters and the exogenous variables are elaborated below.

To obtain the time series data on foreign savings the projected growth rate from the macro-econometric model for the Indian economy prepared by Bhide et.al. (2006) has been used. This study reveals that the capital inflow other than FDI and net invisibles will grow by 18 percent per year for the next ten years i.e. 2005-06 to 2015-16. But during 2015-16 to 2025-26 this growth rate will fall to 15 percent only for net invisibles. The FDI growth rate will move around 5 to 15 percent in different sectors for the time span 2005-06 to 2015-16. During 2015-16 to 2025-26 it will fall to 3-5 percent for different sectors. After getting the series of these variables, the series of foreign saving has been computed with the help of the following relations.

Foreign savings (i.e.Trade balance) = (Current Account balance – Invisibles Net).
Current Account Balance (i.e. C.A.B) = (Capital Account + Monetary movement).
Capital account = (Foreign Direct Investment (FDI) + Capital inflow other than FDI).

The time series data on population for the time period 2003-04 to 2025-26 is available from the Registrar General of India. A projection of the population growth rate has been made for the time period 2026-07 to 2029-30. Data reveals that India's population will increase throughout the period 2003-04 to 2029-30.

To estimate the labour supply for India the data on Labour force Participation Rate (LFPR) of India has been used. The National Sample Survey Organization (NSSO), in its 61st round report, gives the same for the five years 2000-05. As per this report the usual status LFPR increased by nearly 2 percentage points for males and about 3 percentage points for females during this five years time span. This growth rate has been taken as constant throughout the time period 2003-04 to 2029-30 to estimate the labour supply of India for that time period.

The total land endowment of India for the base year is available from the SAM of the year 2003-04.

The world prices are fixed at unity in the model.

2.2.7 Solution, Validation and Assumptions of the Model

The 37-sector CGE model has been calibrated to the benchmark "equilibrium" data set of the Indian economy for the year 2003-04 represented in the 37-sector SAM mentioned above. Further, using a time series of the exogenous variables of the model, a sequence of equilibria for the 28-year period from 2003-04 to 2030-31 has been generated using the General Algebraic Modeling Systems (GAMS) software. From the sequence of equilibria, the growth paths of selected (macro) variables of the economy are outlined to describe the Illustrative Scenario.

For validation purposes, the 4-year period from 2003-04 to 2006-07 has been considered as firm macroeconomic data is presently available only upto 2006-07. Since the model runs replicate reasonably well the actual macroeconomic magnitudes for this period, the model may be treated as satisfactorily validated.

Finally, it must be noted that for generating the Illustrative the following key assumptions have been made.

Assumptions on Technological change

Total factor productivity growth (TFPG) happens exogenously in the model. After examination of almost all the available empirical evidence, soliciting expert opinion and making reasoned judgements of different baseline GDP scenarios generated for annual TFPG rate of 2, 3, and 4 percent, (coupled with different energy efficiency growth rates) it was decided to assume an annual TFPG of 3 percent for the Illustrative Scenario.

Improvement in specific energy consumption is incorporated in the model by making the autonomous energy efficiency improvement (AEEI) assumption used in other carbon emission abatement models such as, GREEN (Burniaux *et al*, 1992) and EPPA (Babiker *et al*, 2001). As in the EPPA and GREEN, it is also assumed that AEEI occurs in all sectors except the primary energy sectors (coal, crude petroleum and natural gas) and the refined oil sector. India has embarked on a path towards increasing energy efficiency since 1980, and its record in energy efficiency improvement in the last two decade is encouraging. Reasoned judgements on trial runs of the model have been made for annual AEEI growth rates of 1, 1.2, 1.4 , 1.5 and 2 (paired with different annual TFPG rates), and on this basis annual AEEI growth rate of 1.5 percent per annum has been assumed in the Illustrative Scenario, being also typical of the AEEI growth rate assumed by other modelers.

Thus, the Illustrative Scenario is based on the assumption of 3 and 1.5 percent annual growth rates of TFPG and AEEI respectively. *It should, however, be noted that while these parameter values seem to reflect recent performance of the Indian economy, there is no reason to assume that they would hold for the entire simulation period, and accordingly, cannot be considered as either a "baseline" or "business-as-usual" scenario*.

Assumptions on Greenhouse Gas Emissions

Greenhouse gases (GHG) are emitted owing to burning of fossil fuel inputs. The major fossil fuels used in India are coal, natural gas, refined oil and crude petroleum. In addition to GHG (CO_2 and N_2O) emitted by fuel combustion, there may be GHG emanating from the very process of output generation. For example, the cement sector releases CO_2 in the limestone calcination process. Finally, GHG emissions also result from the final consumption of households and the government.

Fixed CO_2 and NO_2 emission coefficients have been used to calculate the sector-specific CO_2 emissions from each of the three sources of carbon emissions. For the total CO_2 emissions generated in the economy, the emissions from each of the sources over the 37 sectors is aggregated and subsequently the aggregate emissions across the three sources is summed.

2.3 Technical Description of the TERI-MoEF (MARKAL) Model

MARKAL (**Mar**ket **Al**location) is a generic model tailored by the input data to represent the evolution over a period of usually 30 to 50 years of a specific energy system at the global, national, regional, or state level. MARKAL was developed in a cooperative multinational project over a period of almost two decades by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA). Policy analysts in several developed and developing countries have used the MARKAL model to frame energy policy and evaluate options based on their projected financial and environmental effects (234 Institutions across 69 countries).

The MARKAL model is a bottom-up cost-minimization energy sector model with a potential to internalize environmental considerations and study the effects thereof. Figure 5 below depicts the simplified MARKAL building blocks, also called RES (Reference energy system). The RES is a convenient tool to map the flow of each energy resource over its entire fuel cycle. It provides a blueprint for each of the sectors in terms of the resources that they use or could use, and the end-use demands that are associated with the sector. It provides a flow chart of the basic building blocks of the overall model that can then be easily mapped on to the actual model without missing out any of the important components or links.

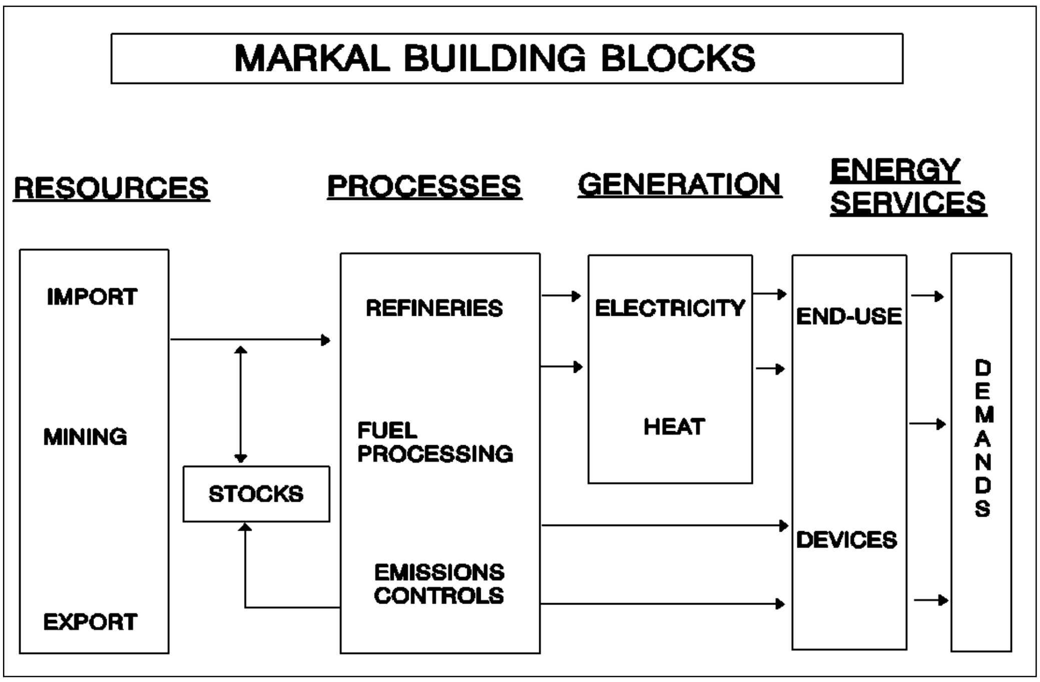

Figure 4: MARKAL Building Blocks

The MARKAL is a Linear Programming Model, comprising the objective function and a set of equations and inequalities, collectively referred to as the constraints.

2.3.1 MARKAL Objective Function

The MARKAL objective function is the minimization of the total energy system cost, time discounted over the planning horizon. Each year, the total cost includes the following elements:

Annualized investment costs of energy technologies

- Fixed and variable annual operation and maintenance costs (O & M) costs of technologies

- Costs of exogenous energy and material imports and domestic resource production (e.g. mining)
- Revenue from exogenous energy and material exports
- Fuel and material delivery costs
- Taxes and subsidies associated with energy sources, technologies and emissions

Mathematically:

The objective function is specified as follows:

$$\text{Minimize TDSC} = \sum_{t=1}^{t=NPER} (1+d)^{NYRS.(1-t)} .\text{Anncost}(r,t) .(1+(1-d)^{-1} + (1+d)^{1-NYRS})$$

where:

TDSC is the total discounted system cost

Anncost (t) is the annual cost for period t

NPER is the number of periods in the planning horizon

NYRS is the number of years in each period t

d is the discount rate for each period

where, Anncost = Sum of + Import cost –Exports Revenue –Salvage value- Emission fees

Constraints

While minimizing the total discounted cost, the MARKAL model must obey a large number of constraints, which express the physical and logical relationships that must be satisfied in order to properly depict the associated energy system. MARKAL constraints are of several kinds:

(1) *Flow conservation constraint:* For each energy flow, the consumption must not exceed procurement:

$$\sum_k out_{k,f} . ACT(k,t) + \sum_s IMP(f,t) - + \sum_k inp_{k,f}. ACT(k,t) - \sum_d EXP(f,t) > 0$$

where, INV (k,t): The investment in technology k, at period t (in physical units)

CAP (k,t) The capacity of technology k, at period t (in the same physical units as the investment variables)

ACT (k, t): The activity of technology k, at period t (in the same physical units as the capacity variables). For all end-use devices, the activity is assumed equal to capacity

IMP (i, t) : The amount of energy form i imported at period t

EXP (I, t): The amount of energy form i exported at period t

k represents any technology in the model

f represents any energy form

$out_{k,f}$ and $inp_{k,f}$ are the amounts of energy form f produced and consumed respectively by one unit of activity of technology k

(2) *Electricity Peak Reserve Constraint*: Installed capacity of electricity producing technologies must meet peak season demand multiplied by a reserve factor. Each power plant's capacity may participate to the fulfillment of this constraint to some degree, from 0 to 100%, depending upon the fraction of the time the plant is to be up and run at peak hour.

(3) *Demand Satisfaction*: Demand for each energy service must be met at each period.

For each time period t, region r, demand d, the total activity of end-use technologies servicing that demand must be at least equal to the specified demand.

Mathematically:

$$\sum_k CAP\,(k,t) > dem_{d,i}$$

where, dem $_{d,i}$ is the demand for energy service d at period t, and the summation over all technologies k which produce energy service d

(4) *Capacity Transfer*: The capacity of each technology is the initial capacity plus previous investments which are still productive

$$CAP\,(k,t) - \sum INV\,(k,p) < resid_{k,t}$$

Where resid$_{k,t}$ is the residual capacity of technology k at period t, the summation extends over all the previous periods p such that t-p does not exceed the life of technology k

(5) *Capacity Utilization*: In each technology, k's activity must not exceed its installed capacity (except end-use technologies for which activity is equal to capacity)

$$ACT\,(k,t) - util_k .\, CAP\,(k,t) < 0$$

Where, utilk is the annual utilization factor of technology k

(6) *Source Capacity*: Use of a resource must not exceed the annual capacity of its source

$$\sum_k inp_{k,f} .\, ACT\,(k,t) < \sum_i scrap_{f,t,i}$$

where, scrap$_{f,t,I}$ is the annual availability of energy f from source i at period t and f is any energy form

(7) *Optional Constraints*: The user may include many other constraints that are optional such as capacity growth constraints.

2.3.2 MARKAL's Inputs and Outputs

Inputs: the MARKAL Database

The MARKAL database is divided into four main sets as follows:
1) Demand
2) Technology
3) Energy
4) Emissions

The *Demand* set consists of all demand categories. It contains a few subclasses namely the Agriculture, Industry, Residential, Transport and Commercial demands. The exogenous demands for all energy services for these sectors at all periods are specified in this class.

End-use demands are projected in each of these five sectors by using a combination of analytical techniques such as end-use demand estimation methods, process models, as well as econometric techniques. Population and GDP projections are considered as the two main drivers for determining future levels of energy use.

The *Technology* set contains all technologies. This set is further classified into various subclasses such as electricity production, other energy production and transformation, and end-use demand technologies. Each of these classes in turn may have subclasses, for instance, electricity production technologies consist of base and non-base power plants. The techno-economic information of each technology such as residual capacity at each time-period, date of first availability, life, duration and the four types of cost namely the Investment, Fixed O & M, Variable O & M and fuel delivery costs are specified in the model.

The *Energy* set contains all the energy carriers and sources of these energy carriers. The energy carriers are further sub-divided into various subclasses such as nuclear energy, fossil energy, electricity and renewables. The acquisition cost per unit of imported, exported, or locally extracted energy forms, as well as the maximum amounts of the energy forms that could be imported, domestically produced, and exported are the parameters associated with this set.

The *Environmental set* contains the emissions coefficients of all energy forms and technologies.

Fuel choices, including new and emerging sources of fuel, are dictated by prices, investment requirements in new capacities, technological changes (changes in conversion efficiencies), flow logistics, etc. Besides the availability of fuels and the related fuel prices, assumptions on the development of clean energy technologies play a crucial role in the analysis of future energy systems.

MARKAL Outputs

The MARKAL Model's outputs include:

(1) A set of investments in all technologies selected by the model at each period
(2) A set of operating level of all technologies at each period
(3) The quantities of each fuel produced, imported, and/or exported at each period
(4) Sectoral energy consumption (aggregate), fuel-mix and emissions at each period
(5) The emissions of Green House Gases (GHG) and pollutants at each period
(6) The overall energy system's discounted cost.

2.3.3 Integration of the MARKAL Model within the overall Modeling Framework

In the MARKAL model, the Indian energy sector is disaggregated into five major energy consuming sectors, namely, agriculture, commercial, industry, residential and transport sectors. Each of these sectors is further disaggregated to reflect the sectoral end-use demands. For example, the industrial sector is disaggregated into eight energy-consuming industries namely: Chlor-Alkali (soda ash, and caustic soda), Aluminium, Iron & Steel, Cement, Textile, Fertilizer, Pulp and Paper, Other manufacturing units grouped as other industries. Similarly in the residential sector, the demand is projected for lighting, space-conditioning, cooking and refrigeration, etc. separately for urban and rural households to account for the differences in lifestyles and choice of fuel and technology options.

The end-use demands in each sub-sector are exogenously provided based on the outputs of the CGE model. For the sectors that were not mapped with the national level CGE model, socio-economic and demographic projections were considered as per the Government of the India's estimates, and the end-use demands were projected using a combination of econometric techniques such as regression analysis, process models, and end-use methods.

On the supply side, the model considers various energy resources that are available both domestically and abroad for meeting various end-use demands. These include both the conventional energy sources such as coal, oil, natural gas, hydro, nuclear as well as the renewable energy sources such as wind, solar, biomass. The availability of each of these fuels is restricted based on the expected growth in domestic production and plans of the Government of India. Further, various conversion and process technologies characterized by their respective investment costs, operating and maintenance costs, technical efficiency, life, etc. to meet the sectoral end-use demands are also incorporated in the model.

The technology characterization is largely based on the database developed by TERI for the *National Energy Map for India: Technology Vision 2030 – a study* undertaken by TERI for the *Office of the Principal Scientific Advisor (PSA) to the Government of India (TERI, 2006).* As part of the National Energy Map for India study, several sectoral workshops were conducted, which involved discussions and focused deliberations with researchers, stakeholders and experts from each of the individual consuming and supplying sectors for integrating India specific issues. This database has been updated to consider the enhanced technological developments over the past few years and assumes the continuation of growth in autonomous energy efficiency across technologies and processes over the modeling time period. However, the projected gains in energy efficiency have been restricted to technical feasibility limits on the basis of international literature and expert judgment.

Total factor productivity growth rate and labour wage rate indices from CGE model were used to adjust capital cost, and operation and maintenance cost of various technologies.

The relative energy prices of various forms and source of fuels dictate the choice of fuels that play an integral role in capturing inter-fuel and inter-factor substitution within the model. In this exercise model runs have been conducted for both economic and financial prices. In the economic price scenario, border prices of fuels have been used. For future international fuel prices IEA's projections as published in World Energy Outlook 2007 were used. In case of financial price scenario, market prices of fuels including taxes and subsidies were used. For indigenously produced fuels, price indices as generated from the CGE model were used for future projection. While in the case of economic price scenario, discount rate of 10% is considered, a discount rate of 15% is considered for the financial price scenario.

2.3.4 Data Sources used in the MARKAL Model

Data from following sources were used in the development of reference energy system and data based for MARKAL model for India

- National Energy Map for India: Technology Vision 2030 (TERI, 2006)
- Office of Registrar General & Census Commissioner, Government of India
- Planning Commission, Government of India
- Central Electricity Authority
- International Energy Agency
- Annual Reports and Yearbooks of the Ministries that handle the energy sector as well as other related Ministries such as Agriculture, Transport, Industry, Rural Development and Environment and Forests.
- National Accounts Statistics published by the Ministry of Statistics and Programme Implementation.
- Documents produced by research organizations such as the NCAER (National Council for Applied Economic Research), CMIE (Centre for Monitoring Indian Economy) and TERI (The Energy and Resources Institute).
- Annual Reports and industry updates published by various industrial associations such as Cement

Manufacture Association

- Year-wise GDP, and sector decomposition, sectoral output, price indices, wage rates etc as determined by the National CGE model developed by NCAER

2.4 Technical Description of the IRADE-Activity Analysis Model

2.4.1 Methodology

The Activity Analysis model uses the activity analysis framework to model the linkages between the national economy and environment. The programming model is multi-sectoral and inter-temporal and maximizes an objective function, which is the discounted sum of total consumption streams given the resources available to economy and the various technological possibilities for using them. The dynamic framework permits examinations of optimal inter-temporal choices. The model has endogenous income distribution. It traces well-being effects for the low-income groups by examining the incidence of absolute poverty in the population. Secondly, there are large differences in consumption patterns among different income classes in a developing country, which are represented in this model by the use of a Linear Expenditure System (LES) of equations for each consumer class. The model has a endogenous income distribution change which impacts on the structure of consumption demand in the economy, as population in a lower income class today will move to a higher income class in the future as income growth takes place. Empirical models work with a finite time horizon of length, say, *T* time periods only as it is computationally impossible to work with an infinite number of time periods. Instead, they account for the post-horizon periods in other ways. In this model there are terminal conditions on stock variables in model. With the inclusion of natural resources among the stock variables, the terminal conditions can be interpreted as sustainability constraints. The input output matrix used is the recently available 2003-04 Social accounting matrix.

2.4.2 Description of model equations

The Activity Analysis model is a linear programming model based on input-output framework. The input-output matrix used in the model is based on the updated SAM of 2003-04 prices. This structure is linked with a growth model on one hand and a detailed analysis of the energy sector on the other hand. The model maximizes the present discounted value of private consumption over the planning period (in our case 30 years (2003-33)) subject to various demand and supply constraints.

Objective function:

Where POP_t and PC_t are the total population and total per capita consumption at time t. T is the planning horizon.

The consumption side of the economy is divided into rural and urban sectors. The model assumes an income parity of 2.34 between rural and urban areas i.e. urban income, and hence consumption is 2.34 times rural income. Total population is exogenously assumed for urban and rural areas and is obtained from the data of the Registrar General of India. Five consumer expenditure based classes are assumed each in rural and urban sector. The per capita consumption of each household class is represented using a set of equations of Linear Expenditure System (LES) estimated based on the data of various NSS rounds of household consumption survey for rural and urban areas separately. These equations as shown below are introduced into the model as constrains.

$$C_{iht} = C_{iho} + \beta_{ih}(E_{ht} - \sum_i C_{iht})$$

C_{iht} = per capita consumption of the i^{th} commodity, h^{th} household group in t^{th} time period,

C_{ih0} = minimum per capita consumption of the i^{th} commodity, h^{th} household.

β_{ih} = share of i^{th} commodity in total per capita consumption of the h^{th} household.

E_{ht} = Total per capita consumption expenditure of the h^{th} household.

As incomes rise, per capita consumptions rises, this results in a people moving from lower expenditure classes to higher classes. Such changes would have impact on the demand structure of the economy. The model has an endogenous income distribution separately for rural and urban areas to incorporate such change in number of people in different classes over time. The LES and endogenous income distribution together provide a dynamically changing commodity wise non-linear demand structure of the economy. The original I-O table consisting of 115 sectors was aggregated to 25 commodities being produced by 34 production activities. The model has each commodity being produced by one production activity, except electricity. To produce power the model employs renewable (wind, solar thermal, solar photo voltaic, wood gasification) and nuclear-based technologies apart from the traditional technologies of thermal, hydro and gas. Coal, Crude, Natural gas and electricity are energy inputs into the model. The model ensures commodity wise equilibrium between demand and supply in the optimal path.

$$C_{it} + G_{it} + I_{it} + IO_{it} + E_{it} \leq Y_{it} + M_{it}$$

(Private consumption demand + government consumption demand+ investment demand + intermediate input demand+ export demand) = (domestic production + imports)

Government consumption ($G_{i,t}$) is exogenous and specified to grow at a growth rate of 9%. Intermediate demand ($IO_{i,t}$) is determined endogenously by the input output coefficients. Total private consumption ($C_{i,t}$) is obtained from the LES demand systems and endogenous income distribution. Exports ($E_{i,t}$) and Imports ($M_{i,t}$) are determined endogenously from the trade side equations of balance of payments and other constraints explained later.

Domestic availability of commodities is assumed to come from domestic output ($Y_{i,t}$) and imports ($M_{i,t}$). Domestic production is constrained by capacity constraint (maximum output that can be produced at the given capital stock).

$$(X_{j,t} - X_{j,t-1}) \leq (K_{j,t} - K_{j,t-1}) / ICOR_j$$

(Incremental output is related to incremental capital).

$X_{j,t}$ = domestic output of the j^{th} sector at time t, $K_{j,t}$ = capital of the j^{th} sector at time t and $ICOR_j$ is the Incremental Capital Output Ratio of the j^{th} sector which is exogenously specified in the model.

Capital stock in sector j depends upon the rate of depreciation and investment and is modeled using the relation,

$$K_{j,t} = DEL(J) * K_{j,t-1} + I_{j,t}$$

Where *DEL(J)* is the rate of depreciation in sector j, which is exogenous and $I_{j,t}$ is the investment in sector j.

Aggregate Investment demand is assumed to depend upon aggregate domestic investible resources (domestic savings determined by marginal savings rate) and foreign investment available. Investment goods, reflecting the structure of capital goods in the sectors, are identified separately and are allocated to different sectors as fixed proportion ($P_{i,j}$) of total investment ($I_{i,j}$) in each sector.

$$\sum_i Z_{it} \leq Z_o + S*(VA_t - VA_0) + (FT_t - FT_0)$$

$$FT_t = (a - b*t)*VA_t$$

Where $Z_{i,t}$ = investment demand of commodity i at time t, VA_t = value added at time t, FT_t = Foreign investment at time t, S is the exogenously specified maximum marginal savings ratio, Z_0 is the investment in the base year (2003-04), $P_{i,j}$ and a & b are pre specified constants.

For exploring alternative scenarios to change GHG emissions – renewable technologies will play a vital role. Renewables generally require land. In India, there are other pressing demands on land. Thus the opportunity costs of growing fuelwood or of bio-fuel plantations may be foregone food production. These tradeoffs have been carefully evaluated in this framework where impact on small farmers and the poor is captured.

Trade is endogenous to the model. Foreign capital inflow (*FT*) is a changing proportion of value added. Though exports and imports are endogenous to the model, upper and lower limits are exogenously specified on growth rate of exports and imports. The model has a balance of payment constraint for exports and imports to grow in a balanced and realistic manner.

$$\sum_i (M_{i,t} * MTT_i) = \sum_i E_{i,t} + FT_t$$

$$M_{i,t} \geq (1 + MGRU_i) * M_{i,t-1}$$

$$M_{i,t} \leq (1 + MGRL_i) * M_{i,t-1}$$

$$E_{i,t} \leq (1 + EXGRU_i) * E_{i,t-1}$$

Where, MTT_i is the trade and transport margins for commodity i, and $MGRU_i$, $MGRL_i$ are upper and lower bounds for imports growth rates of commodity i. $EXGRU_i$ is the upper bound for exports growth rate of commodity i. Equations (8)- (11) form the complete specifications of the trade side of the model.

Equation (2)-(12) form a set of constraints based on economic criteria for the model solution to be meaningful.

Further, to smoothen the growth path of the model, monotonicity constraints have been added for per-capita total consumption, sectoral output, and sectoral investments. The monotonicity constraint for consumption imposes a minimum growth rate of 5% on per capita consumption. The model has been primarily structured for Energy and real sector interactions. Among the 25 commodity sectors in the model coal, crude oil, natural gas and power are the energy sectors. The use of input-output framework allows the interaction of these sectors with the other sectors of the economy through intermediate input demand and also final consumption demand by household of output of sectors like coal and power.

The model outcome accounts for the behavioral responses of economic agents (such as consumers and producers) to changes in policy. The model ensures among physical flows of commodities, and in the financial account for each type of economic agent :

a) Quantities produced, demanded and traded balance at the national level.
b) For consumers, expenditures, savings and incomes balance.
c) Income earned is consistent with income generated by production and trade.
d) Prices for producers, consumers and government taxes are consistent with the prices.
e) Government expenditure balances inflows.
f) Balance of trade is realized accounting for capital flows

These various consistencies ensure that all the feedbacks are taken into account and that there are no unaccounted supply sources or demand sinks in the system.

A distinguishing feature is that as far as possible the parameters are estimated from data and not bench-marked to one year's data.

The model permits exploration of alternative technologies and CO_2 strategies from a long-term dynamic perspective and permits substitution of various kinds.

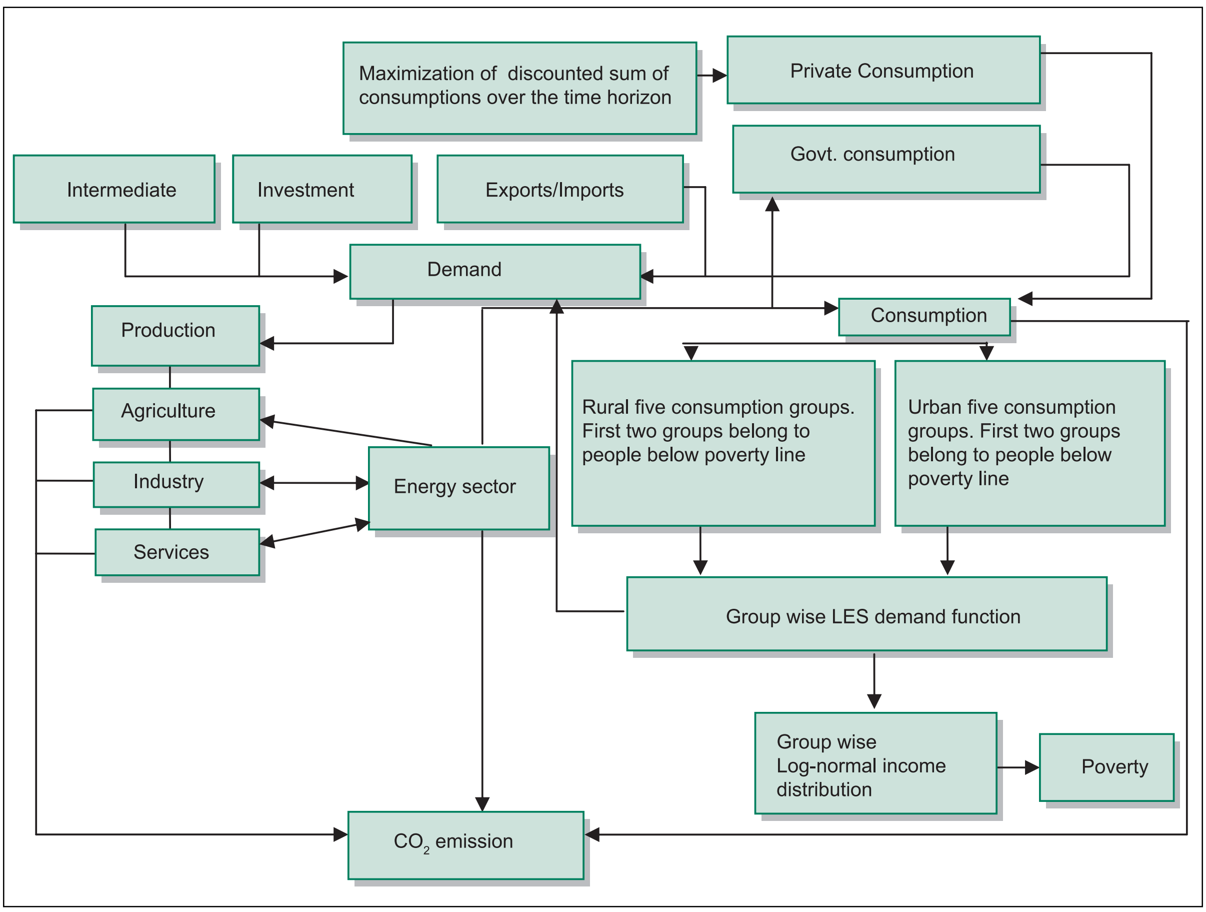

Figure 5: Activity Analysis Model Graphical Representation of Structure

2.4.3 Major features of the model

The major features of the model and sub-models are discussed below:

Sectors and Activities

The input-output table, provided by CSO consists of information on 115 sectors/activities. These have been aggregated to 34 sectors for better interpretation of results, 7 new activities like Bio fuels, Wind, Solar Photo Voltaic, Solar Thermal, low emission coal based technologies, nuclear and diesel have been added to the initial 27 sectors/activities. Aggregation has been by choosing sectors that are climate sensitive – either in terms of mitigation (e.g., energy, transportation, construction) or vulnerability and adaptation (e.g., agriculture, fishery, forestry etc.). Four broad groups consisting of 34 production sectors have been constructed as follows:

- Agriculture and allied activities (Cereal, Pulses, Sugarcane, Other crops, Animal husbandry, Forestry and Fishing)
- Energy sectors (Coal and lignite, Crude oil, Electricity and Gas, Electricity Hydro, Electricity from Bio Fuel, Wind, Solar Photo voltaic, Solar Thermal, Electricity from Wood, Electricity from low emission coal based technology)
- Services sector consisting of Transportation (Railway and Other), and other services. This sector is the largest chunk of the economy.
- Industry consisting of sectors like, Agro processing, textiles, petroleum products, Fertilizer, cement, steel, manufacturing, water supply & gas, mining and quarrying, non-metallic minerals and construction.

The main focus has been on agriculture, energy and Industrial sector since these are the important sources of CO_2 emissions are common. The activities related to these sectors in our model are as follows.

Direct and Indirect Emissions:

The Model captures both direct as well as indirect CO_2 emission. Such distinction arises because both production and consumption activities result in CO2 emissions. For example, the construction sector does not use much fossil-fuel-based energy at the site, e.g., roads or buildings, but it uses many energy intensive materials such as bricks, cements, iron and steel, aluminum, glass etc. In this case, the emissions from the construction activities at the site of construction are known as direct emission where as the emission during making the materials used in construction are known to be indirect emission.

Such an analysis gives deeper understanding of carbon emission from final consumption along with the production activities. The model does not consider other GHGs like CH_4 .

Consumption and Savings:

GHG emissions result from production as well as consumption. To model consumption, data of the latest NSS 55th round consumption survey has been used. LES Demand systems have been estimated for 10 consumer classes, 5 in rural sector and 5 in urban sector, programmed as a sub model and embedded in the system. LES demand functions have been introduced as constraints and the group wise per-capita consumptions satisfy LES demand system.

An urban-rural income parity of 2.34 has been exogenously specified in the model. Ideally income distribution should be linked to production structure and techniques. However, empirically income distribution as reflected in consumption expenditure has remained very stable with slow and miniscule changes in the Lorenz ratio. National Sample Survey (NSS) data show that over many years it varied with minor fluctuations [Panda (1999)]. Thus an assumption of a constant Lorenz ratio over a long period of time is justified for India and has been made.

A savings constraint has been imposed to restrict marginal savings rate. Programming models often give high investments and implied savings rate. Such rates are not realistic as governments in a democratic developing poor country are not able to force savings rate beyond a limit. Finally, though the model has been run for a period of 30 years, the post-terminal future has to be taken care of. This is done by assuming that a stationary state would prevail in the future with the composition of output, consumption, investment etc. fixed and growing at a prescribed rate. This translates into a larger weight for the terminal year consumption in the objective function.

Trade

On the trade side, a balance of payments constraint with capital flows is imposed. There is also a wedge between export price and import price to reflect international trade and transport margins. Some restrictions are imposed on exports and import growth rates by sectors to keep the model realistic. Thus, import of agricultural commodities is restricted to reflect a self-sufficiency requirement. Import of services is also restricted as not all services can be imported. Generous export bounds are introduced to account for fall in export price and profitability consequent to large exports by India. Higher imports have been allowed for Crude Oil, Coal and Natural gas compared to other items of import on account of their importance as basic inputs to production. Domestic savings are endogenous, but foreign financial inflows are permitted. These inflows are endogenous and depend on profitability of investment in India compared to the rest of the world, which are projected from past trends. Alternative carbon credit regimes and their impact have been examined.

Model Inputs:

The major instrumental variables and inputs in the Activity Analysis model are as follows

- A minimum growth rate constraint for total per-capita consumption which ensures that in the optimal path per-capita consumption grows at some minimum growth rate has been included.
- The model has Sector wise Total Factor Productivity Growth (TFPG) and Autonomous Energy Efficiency Improvement (AEEI).
- Autonomous Energy Efficiency Improvement (AEEI)
- Restrictions on the growth of power generation capacities on renewable technologies like hydro, natural gas, nuclear and wood introduced to make the model solution more realistic.

To make the model more realistic, resource constraints have also been introduced particularly for primary energy sources like coal, crude and natural gas. Apart from these, constraints have also been imposed on power generation capacities of newer technologies like nuclear, wind, wood and also on hydro and gas based power. These constraints are based on realistic beliefs about India's energy resources and production. A list of resource and capacity constraints has been listed in Table 2 below.

Table 2: Resource and capacity constraints

Resource	Constraint
Coal	Specified to grow by at the most 8 times the base year output
Crude oil	Specified to grow by at the most 2 times the base year output
Natural Gas	Specified to grow by at the most 3 times the base year output
Wood gasification	At max 2% of forestry output can be used for power generation
Hydro	Maximum output of power from hydro is 440 billion KWh
Wind	Maximum output from wind power is 175 billion KWh
Nuclear	Maximum output from nuclear power is 375 billion KWh (optimistic IEP scenario)
Natural gas	At max 40% of domestic availability can be used for power generation

Table 3: Import constraints on Energy inputs

Commodity	Import constraints
Coal	2%-25% of total availability
Crude Oil	80% to 90% of total availability
Natural Gas	5%-15% of total availability in Illustrative Scenario

Assumptions about important control parameters in the model:

AEEI: The AEEI assumptions in the model is given in the Table below, accumulated to 2030.

Maximum savings rate (S): The model imposes a limitation on maximum domestic savings available for investments. In the model it has been assumed to be 40% of GDP.

Minimum consumption rate: The minimum consumption growth rate of 4% is used in the monotonicity constraint on per-capita total consumption.

Government consumption rate: The Government consumption growth rate is assumed to be a uniform 9% for all commodities and over all time periods.

Table 4: Assumptions of Exogenous parameters:

Parameter		Value
AEEI	Coal	36.5% reduction in input use between 2003-30
	Petroleum products	36.5% reduction in input use between 2003-30
	Natural gas	36.5% reduction in input use between 2003-30
	Electricity	36.5 reduction in input use between 2003-30
Maximum savings rate (S)	35% of GDP	
Government consumption growth rate	9% per annum	
Minimum per capita private consumption growth rate	4% per annum	
Discount rate	10% per annum	
Total factor productivity growth	3.0% per annum	

Model Outputs

- The model forecasts total as well as Activity-wise emissions and ten household class wise emissions.
- The model provides sectoral output in value terms as well as quantity terms. Presently output in quantity terms is projected only for coal & Lignite, Crude petroleum, Petroleum products, fertilizer, cement industry, steel and electricity. However the model can be easily extended to forecast the quantity output of other sectors as well.
- The model computes values for shadow prices of commodities, gross domestic product, total private consumption, total aggregate investment, sector-wise investment, class-wise per capita consumption, sector-wise gross fixed capital formation, change in stock, emission from private consumption, emission from government consumption, levels of domestic production by different activities, export / import levels
- Apart from the power generation from traditional power generation techniques based on coal, hydro and natural gas, power generation from other new renewable based technologies like solar, wind, nuclear, bio fuels and polluting technologies like diesel and newer costlier but lower carbon emitting coal based technologies also included are also computed..

2.4.4 Data and Approach

Recent data for India has been used to estimate the various parameters and initial values of different variables to be included in the model. Input-output coefficients and production functions for various activities form an important element of the model (The latest I-O table (1998-99), published by the CSO and updated by Prof. M. R. Saluja to 2003-04 prices, has been used).

The Census and NSS data has been used for rural and urban population and consumption by expenditure classes.

The model is solved using GAMS programming tool developed by Brooke et al. (1988). For endogenous income distribution consistency, iterations over optimal solutions changing distribution parameters are carried out till they converge.

2.5 The TERI-Poznan Study:

The TERI-Poznan study uses the same MARKAL modeling framework as the TERI-MOEF study (see above), but with several differences in assumptions and database. First, it assumes a GDP growth rate of 8.2% per annum during 2001-2031, as compared to CAGR of GDP of 8.84% between 2003-2030 in the TERI-MoEF model, consistent with the GDP projections by the NCAER-CGE. Second, energy prices in TERI-Poznan were considered to evolve over the model simulation period as per expert judgment, whereas in TERI-MoEF international energy prices were obtained from IEAs WEO, 2007, and domestic energy prices were based on price indexes projected by the NCAER-CGE. Third, it was assumed that there would be no improvements in factor productivity, while TERI-MoEF, in line with NCAER-CGE, in the Illustrative Scenario, assumed a total factor productivity growth of 3.0% per annum. Finally, TERI-Poznan considered only limited improvements in energy efficiency based on past trends and expert judgment, whereas TERI-MoEF in the Illustrative Scenario assumed an autonomous energy efficiency improvement of 1.5% per annum, in line with NCAER-CGE, but subject to technical feasibility limits determined through expert judgment.

2.6 The McKinsey Study:

The McKinsey India Cost Curve study estimates greenhouse gas (GHG) emissions from 10 of the largest emitting sectors till 2030 based on assumptions of growth and technology deployment in these sectors.

The methodology is consistent with climate change abatement cost curve research that McKinsey has conducted in 18 countries over the past three years. The McKinsey Cost Curve is a bottom up analysis of emission projections in sectors based on technology deployment.

The Illustrative Scenario: Building on McKinsey's extensive study of a range of Indian industries and the research findings of leading Indian institutes and experts, the Illustrative Scenario is a bottom-up analysis of GHG emissions sector by sector for 10 sectors: power, cement, steel, chemicals, refining, buildings, transportation, agriculture, forestry, and waste. The Illustrative Scenario assumes reasonable technological development across all these industries and includes a range of mature, proven technologies, since product quality and the efficiency of industrial processes will continue to increase in India in the coming decades.

The findings are not meant to be an exhaustive estimate of the GHG emissions inventory of India. It is not intended to serve in any way as a forecast or baseline or target for reducing greenhouse gas emissions. *The results of the work have many underlying assumptions, and realisation of such assumptions depends on many external factors*.

The analysis limits itself to:
- A focus on emissions produced and energy consumed by human activity within the borders of India, without a detailed analysis of the impact of "imported" or "exported" GHG/energy
- A focus on technical levers, without assessing the impact of abatement options on energy prices and consumer behaviour, or of energy price changes on abatement options considered
- Conservative assessments of future technologies. The analysis does not include the "disruptive" effects of technology change.

3. PART II: PRELIMINARY RESULTS OF STUDIES FOR ILLUSTRATIVE SCENARIOS:

3.1 Preliminary Results of NCAER-CGE Simulations

The CGE model may be employed to run various simulations of policy interest.

Scenario Definition: Scenario 1: *Illustrative scenario*: The Illustrative Scenario is chosen on the basis of TFPG = 3.0%, and AEEI = 1.5%, which from the available literature seem to reflect the rates of these types of technological change in the Indian economy in recent years. In different model runs the TFPG and AEEI values are varied over a plausible range. It involves no specific new policy for GHG mitigation, The time period of analysis is 2003-04 to 2030-31. The outputs of the Illustrative Scenario simulation include:

- GDP growth rates over the period
- Per capita income over the period
- Per capita CO_2 emissions over the period
- CO_2 emission intensity of economy over the period
- Energy intensity of the economy over the period

Simulation Results:

The GDP growth rate over the period as given in the Illustrative Scenario as follows:

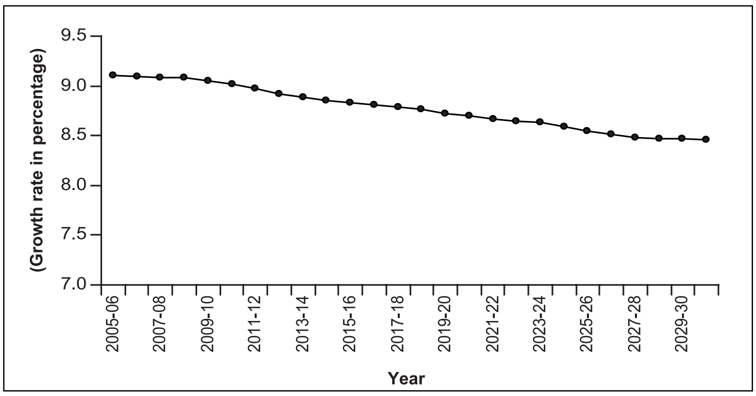

Figure 6: GDP Growth Rate in the Illustrative Scenario

Over the period, the GDP growth rate declines slightly, but remains above 8.5%. It may be noted that this is a trend rate, and the CGE model cannot account for year-to-year perturbations either due to unanticipated exogenous shocks or the business cycle.

The CO2e emissions of the economy increase to 4.0 GT in 2030, as shown below:

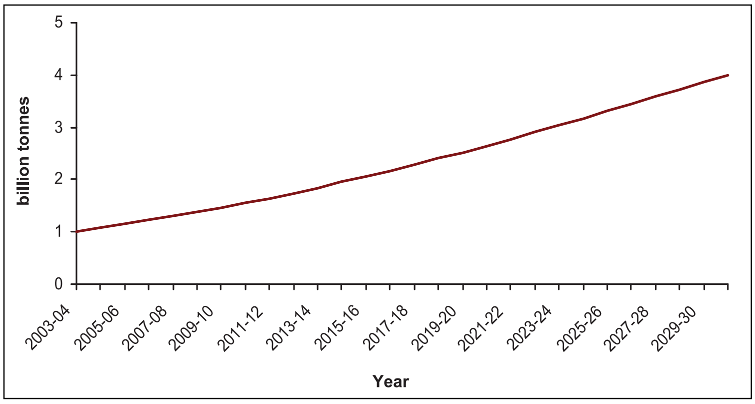

Figure 7: Growth in aggregate CO2e emissions till 2030 in the Illustrative Scenario

The growth in per-capita CO_2e emissions under the Illustrative Scenario was also provided by the model, and is 2.77 tons CO2e per capita in 2030, as given below:

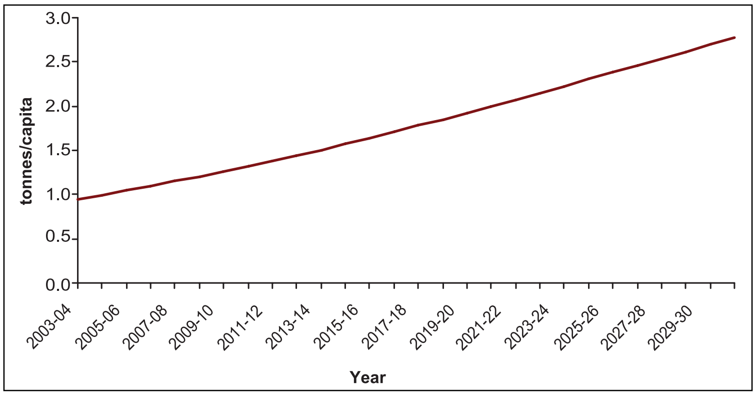

Figure 8: Growth in Per-Capita CO_2e Emissions in the Illustrative Scenario

There is continuous decline in the energy intensity of the GDP, at a CAGR of -3.85 percent during 2003-04 to 2030-31:

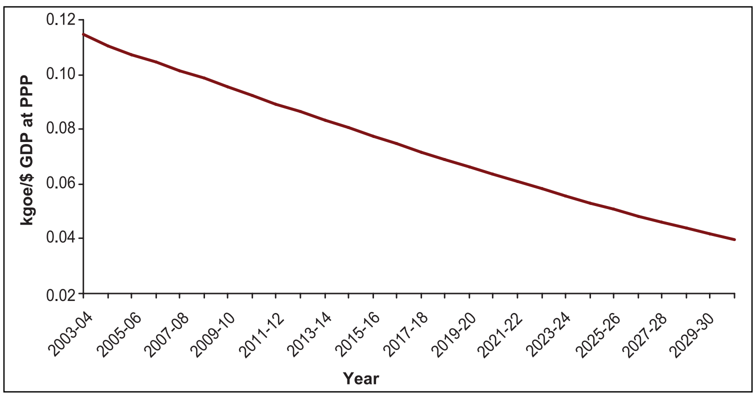

Figure 9: Change in energy intensity of the GDP during 2003-2030 in Illustrative Scenario

There is also continuous change in the CO_2e intensity of the economy under the Illustrative Scenario, from 0.37 Kg CO2e in 2003 to 0.15 Kg CO2e in 2030, as shown below:

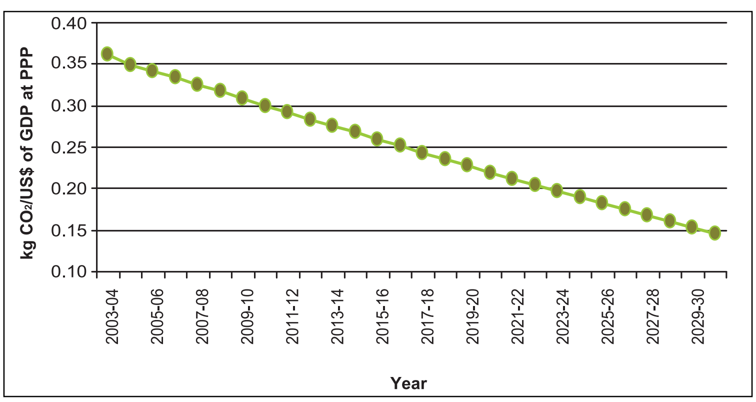

Figure 10: Change in CO_2e Intensity of the GDP in the Illustrative Scenario

The CO_2e emission intensity falls from 0.37 kg CO_2 /US$ of GDP at PPP in 2003-04 to 0.15 kg CO_2 /US$ of GDP at PPP in 2030-31.

In order to study the impacts of changing the assumed values of TFPG and AEEI, further simulations were made as follows:

Scenario Definition: Scenario 2: *Sensitivity Analyses over technology change parameters*: To study the impact of changing TFPG on GDP, the AEEI was fixed at 1.5%, while TFPG was varied from 0 to 4%. Similarly, to study the effect of changing AEEI on GDP, the TFPG was fixed at 3.0%, and the TFPG was varied from 0 to 2% per annum.

Simulation Results

The results are given below:

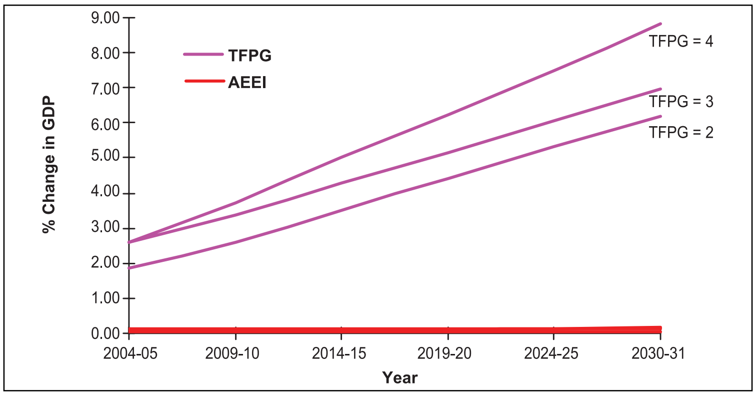

Figure 11: Effects of Varying TFPG and AEEI

Changes in TFPG have a significant impact on GDP, while changes in GDP arising from changes in AEEI are negligible.

The variation in the per-capita CO_2e emissions under different assumptions of AEEI were also studied, and are given below, holding TFPG constant at 3.0%:

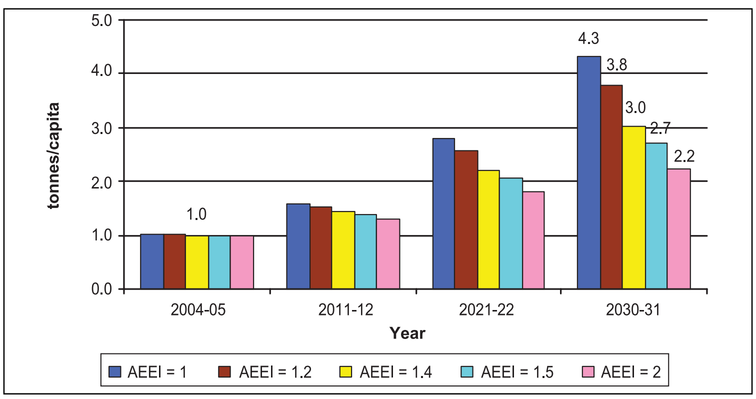

Figure 12: Variation in CO_2e Emissions Per-Capita with Change in AEEI

Holding TFPG constant and varying AEEI shows that CO_2 emissions fall dramatically with increase in AEEI above the base level (TFPG=3). Under the lowest AEEI assumption of 1.0%, India's per-capita CO_2e emissions are virtually equal to the current global average. *An important policy lesson from these simulations is that improvements in the specific energy consumption of different technologies is key to addressing GHG mitigation.*

3.2 Preliminary Results of TERI-MoEF Simulations

3.2.1 Scenario Definition:

Simulations of the MARKAL model were carried out for the *Illustrative scenario*, i.e. with no new GHG abatement policies, TFPG=3.0, and specific energy consumption improvement consistent with AEEI = 1.5, *subject to feasibility limits of specific energy consumption for each technology*.

Simulation Results: CO_2 emissions from energy sources in the Illustrative scenario are estimated at around 4.9 billion tonnes in 2031 (Figure 13):

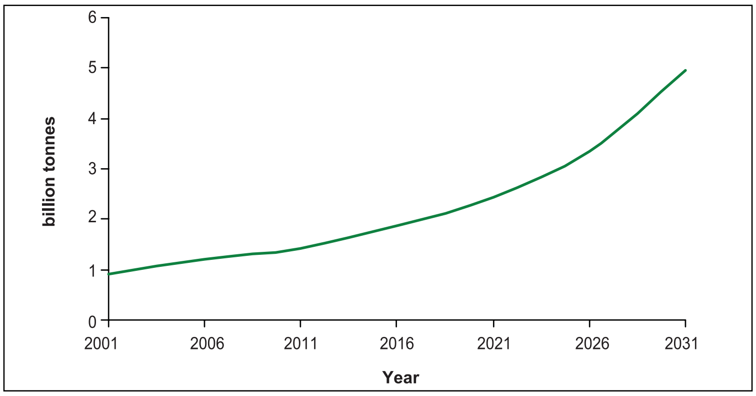

Figure 13: CO_2 emissions in the Illustrative Scenario

This is equivalent to 3.4 tonnes per capita CO_2 emission in 2031 (Figure 14).

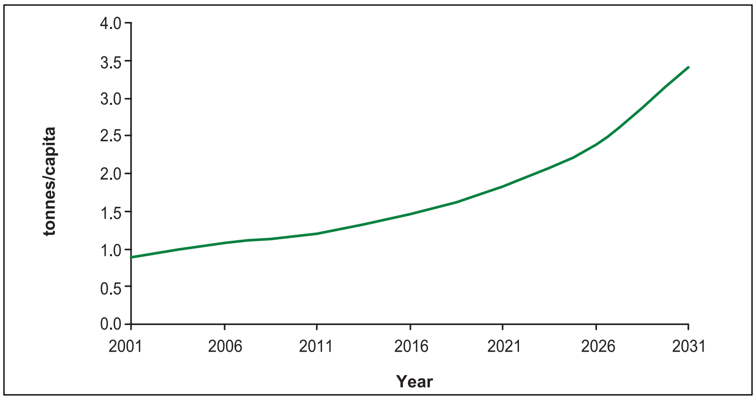

Figure 14: Trajectory of Per-capita CO_2 emissions till 2031 in Illustrative Scenario

Figure 15 shows the commercial energy requirements over the 30-year modeling time frame for the Illustrative Scenario. The total commercial energy requirement in 203'1 is 1567 mtoe, and coal remains the dominant primary energy source.

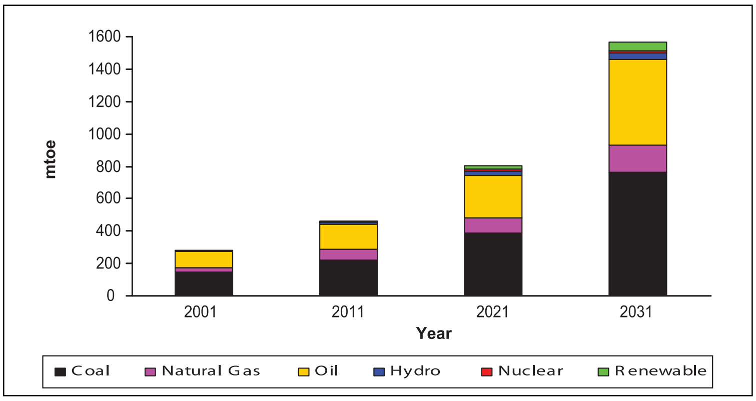

Figure 15: Commercial energy supply across scenarios

There is a continuous decline in energy intensity of the GDP, falling from 0.11 to 0.06 Kgoe per $ GDP at PPP (Figure 16).

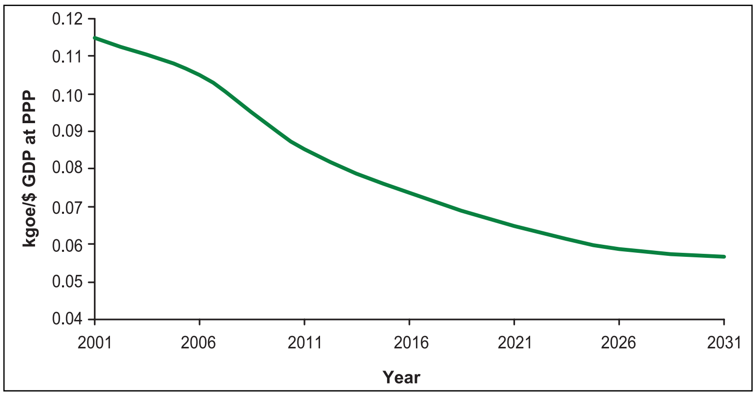

Figure 16: Trajectory of Energy Intensity of GDP in Illustrative Scenario

Similarly, there is also sharp decline in the CO2e intensity of the economy over the same period, from 0.37 to 0.18 Kg per $ GDP at PPP (Figure 17):

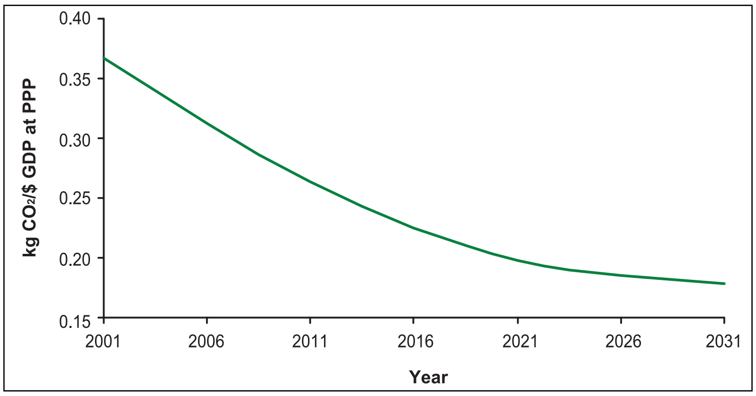

Figure: 17: Trajectory of CO_2 Intensity of GDP in Illustrative Scenario

3.3 Preliminary Results of IRADe-AA Model Simulations

3.3.1. Scenario Definition

Simulations were made with an *Illustrative Scenario*, defined as follows:

Illustrative scenario assumptions were the following:

- No new CO2 mitigation policy
- Max savings rate of 35%
- Aggregate govt. consumption growth rate of 9%
- Social discount rate for consumption one period ahead of 10%
- TFPG = 3.0, AEEI = 1.5

Simulation Results:

Under the Illustrative Scenario, CO2 emissions increase from c. 1.2 GT in 2003-04 to 4.23 GT in 2030-31 (Figure 18):

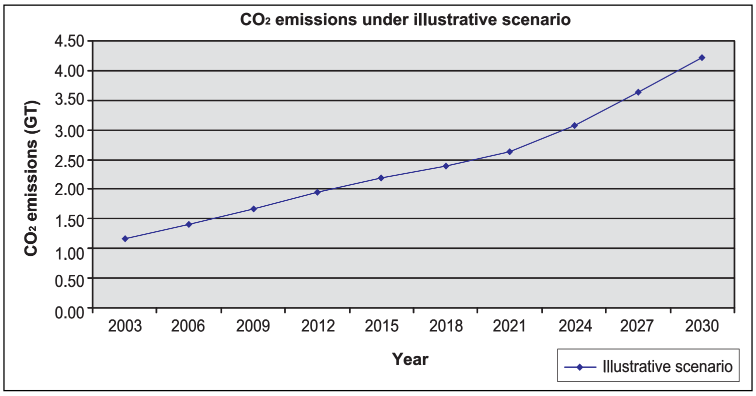

Figure 18: CO_2 emissions in Illustrative Scenario

During this period, per capita CO2 emissions rise from about 1.1 tons per capita to under 2.9 tonnes per capita. This is well below the 2005 global per-capita emissions of 4.22 tons per capita, (Figure 19):

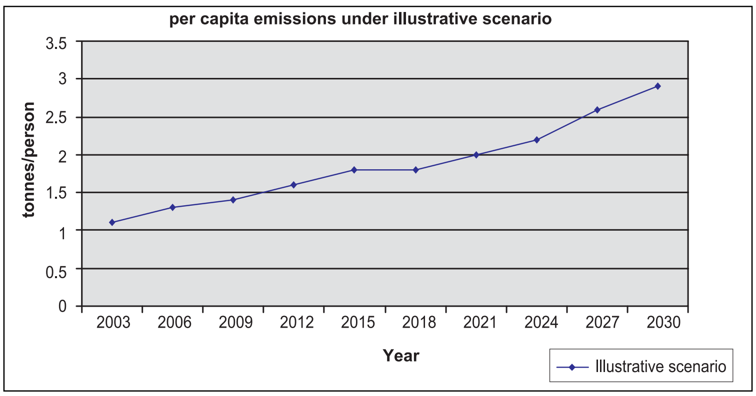

Figure 19: Trajectory of Per-capita CO2e Emissions during 2001 to 2031 in Illustrative Scenario

There is also continuous decline in energy intensity in the Illustrative Scenario, from just over 0.1 kgoe per $ GDP in PPP to c.0.04 kgoe per $ GDP in PPP.

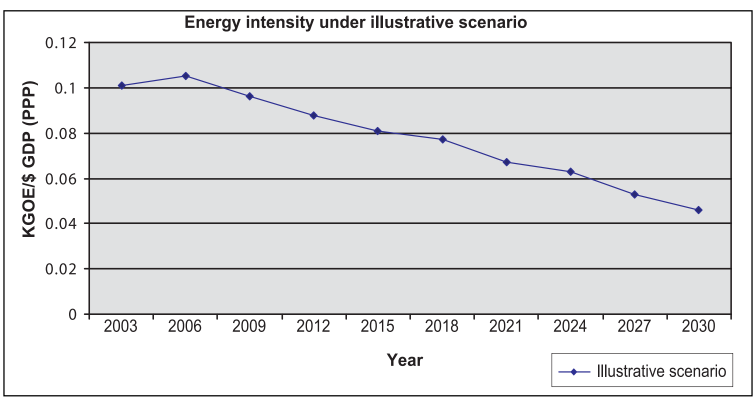

Figure 20: Energy Intensity in Illustrative Scenario

There is a similar decline in the CO2 intensity of the economy in the Illustrative Scenario, from about 0.37 million tons CO2 per billion $ GDP in PPP to less than one-half, i.e. 0.15 million tons CO2 per billion $ GDP at PPP.

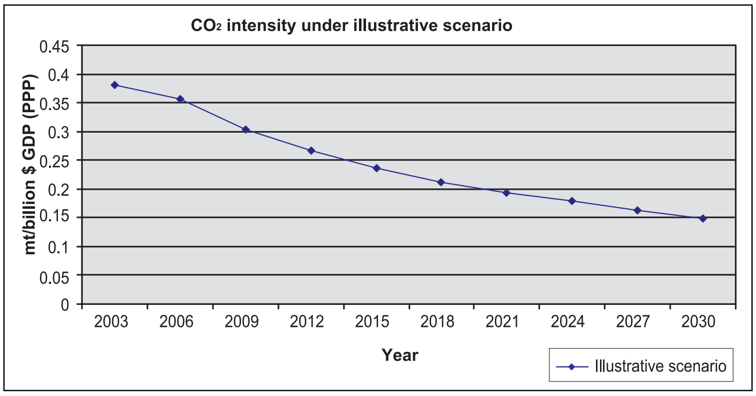

Figure 21: CO_2 Intensity under Illustrative Scenario

3.3.4: Results of TERI-Poznan (MARKAL) Study:

Scenario Definition: The TERI-Poznan study defines the *Illustrative Scenario* as comprising efficiency improvements as per past trend and expert opinion considering level of maturity of specific technologies in India. The discount rate is assumed at 10% per annum, and the model considers economic costs. There is no new policy which bears on GHG mitigation.

Simulation Results: Under the Illustrative Scenario, GHG emissions increase to 7.3 billion tons in 2031. This is shown in Figure 22 below:

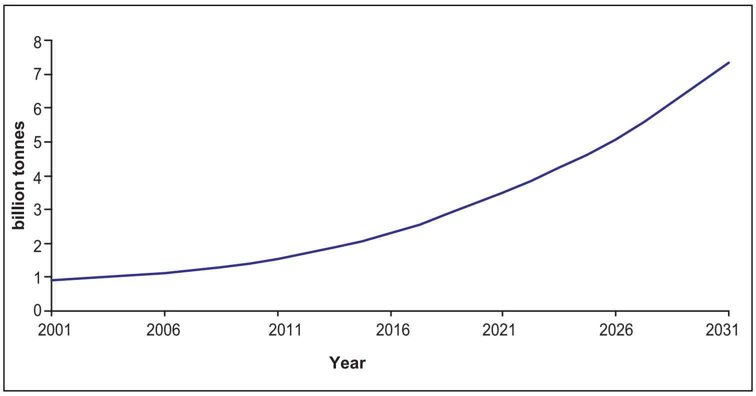

Figure 22: CO_2 emission in Illustrative scenario (2001-2031)

This works out to 5.0 tons per capita CO2 in 2031, Figure 23:

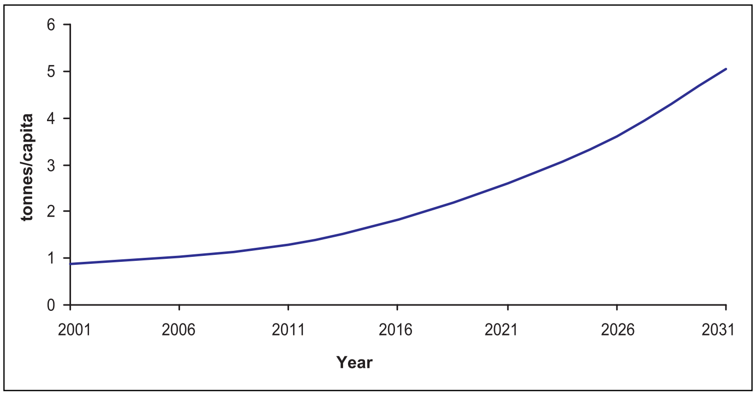

Figure 23: Per capita CO_2 emission in Illustrative scenario

The commercial energy supply in 2031 is 2149 mtoe, a nearly six fold increase since 2001, Figure 24:

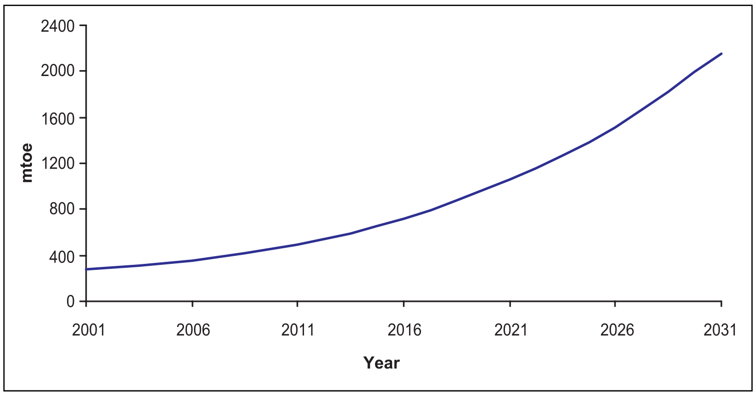

Figure 24: Commercial energy supply in Illustrative scenario

Nevertheless, there is a continuous decline in the energy intensity of the economy, from c. 0.11 to 0.08 Kgoe per $GDP at PPP, Figure 25:

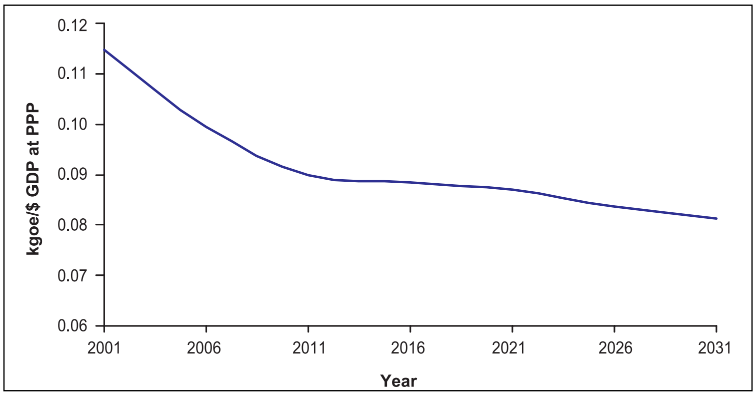

Figure 25: Commercial energy intensity of economy in Illustrative scenario

Finally, there is a continuous downward trend in the CO2 intensity of the economy, mirroring that of the decline in energy intensity, till 2031, Figure 26:

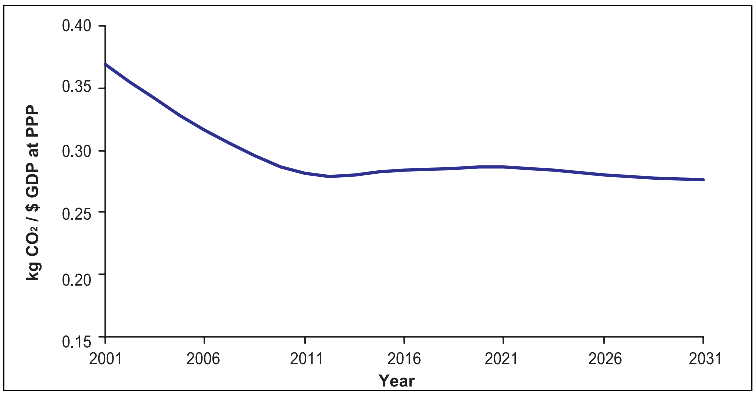

Figure 26: CO_2 emission intensity of economy in Illustrative scenario

3.3.5: Results of McKinsey Bottom-up Study:

The McKinsey Study makes the following assumptions with respect to the *Illustrative Scenario*:

Scenario Definition: The *Illustrative Scenario* is defined by the following assumptions:

Parameter	Illustrative Scenario assumption		
Total energy demand	1.7 billion toe		
Power demand	3870 TWh (including captive)		
Base and non-base power demand	60:40		
Power capacity mix (including captive and spinning reserves)	**In GW**	2005	2030
	Total	150	760
	Share of clean and renewable power[2]	25%	29%
Area under forests / degraded area by 2030	86 Mha/15 Mha		
Technical T&D losses and auxiliary consumption	12% and 6%		

Study Results:

The trajectory of aggregate GHG emission in the Illustrative Scenario till the year 2030-31 is presented below:

GHG emissions in year (GtCO2e)	2005	2020	2030
Illustrative Scenario	1.6	3.2	5.7

Note: All emissions in billion tonnes CO_2e. Emissions include CO_2, CH_4 and N_2O weighted by their respective GWPs.

The aggregate GHG emissions increase from 1.6 GT in 2005 to 5.7 GT in 2030. This works out to *3.9 tons/CO2e per capita in 2030.*

The changes in energy intensity and GHG intensity of the economy in the Illustrative Scenario from 2005 to 2030 are given below:

Model output	Illustrative Scenario
Change in energy intensity (CAGR) 2005-2030; implied	-2.6% p.a.
Change in GHG intensity (CAGR) 2005-2030; implied	-2.1% p.a.

There is a continuous decline in both energy intensity of the GDP, as well as of the GHG intensity of the economy, at CAGRs of -2.6% and -@.1% per annum respectively.

[2] *Includes nuclear, solar, hydro, biomass, geothermal and wind power*

3.4 Conclusions:

The results of 4 of the 5 studies, which vary in terms of model structure/methodology, assumptions, and data, besides differences in the definitions of the Illustrative Scenario, *whose common feature is that no new GHG mitigation policies are put in place*, show that India's per-capita CO2e emissions in 2030/31 would be between 2.77 and 3.9 tons per-capita, which is well below the 2005 global average of 4.22 tons per-capita. The fifth study projects the 2031 emissions at 5 tons per-capita, i.e. a little above the 2005 global average.

Further, both the energy intensity of the Indian economy, as well as the CO2e intensity of the Indian economy fall continuously till 2030-31 in the Illustrative Scenarios, as revealed by all 5 studies.

The results should set at rest any apprehensions that India's GHG emissions are poised for runaway increase over the next two decades. On the other hand, the structure of the economy, policy and regulatory regime, and energy endowments, together ensure that India's growth over the next two decades, while rapid, would remain inherently sustainable.

The fact that significant differences still arise between the results of the different studies show that it is not feasible to unambiguously define any "baseline" or "business-as-usual" GHGs trajectory for the country.

Thus, even without any new policies for GHG abatement and given the structure of the Indian economy, its current and projected GHG growth rates, and its energy endowments, there can be no apprehension that its GHG emissions will increase in a runaway manner over time. India's energy use patterns and GHG emissions profile will continue to be among the most sustainable in the world for the next generation.

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