Chapter 3
Low Carbon Pathways for Growth in India: Assessment of Climate Models

Saon Ray and Kuntala Bandyopadhyay

Abstract Modelling the monetary impacts of climate change globally requires quantitative analysis of a very broad range of environmental, economic and social issues. Integrated Assessment Models (IAMs) provide a useful tool in this regard. Their estimates provide an important foundation for later work, and their results are valuable for informing policy. This chapter provides an overview of the existing models including the Mendelsohn, Dietz and Stern models. In addition it reviews the Indian models which include the NCEAR, TERI, IRADe and the McKinsey model. It also discusses the co-benefits approach proposed by Dubash (Econ Polit Weekly 48(22):47–62, 2013) in the Indian context.

3.1 Introduction

The world energy consumption is expected to grow by 56% between 2010 and 2040. Much of the growth in the energy consumption is expected from countries such as China and India, and will be driven by strong, long-term economic growth. For the past two decades, both these countries have been among the world's fastest growing economies; they have led the economic recovery from the recession has been led by these countries. Since 1990, their combined energy consumption accounted for 10% of the total world energy consumption in 1990, and 24% in 2010.

This paper reviews the key factors that feed into existing models of climate change.

S. Ray (✉) · K. Bandyopadhyay
Indian Council for Research on International Economic Relations,
New Delhi, Delhi, India
e-mail: sray@icrier.res.in

K. Bandyopadhyay
e-mail: kbandyopadhyay@icrier.res.in

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3.2 Review of the Models

Modeling the monetary impacts of climate change globally is very challenging: it requires quantitative analysis of a very broad range of environmental, economic and social issues. Integrated Assessment Models (IAMs) provide a useful tool in this regard. Their estimates provide an important foundation for later work, and their results are valuable for informing policy. However, these models are limited to snapshots of climate change at temperatures now likely to be exceeded by the end of this century. Below are three important examples of models of this category.

The Mendelsohn model (Mendelsohn et al. 2000) estimates impacts only for five "market" sectors: agriculture, forestry, energy, water, and coastal zones. The Tol model (Tol 2002) estimates impacts for a wider range of market and nonmarket sectors: agriculture, forestry, water, energy, coastal zones, and ecosystems, as well as mortality from vector-borne diseases, heat stress, and cold stress. The Nordhaus model (Nordhaus and Boyer 2000) includes a range of market and nonmarket impact sectors: agriculture, forestry, energy, water, construction, fisheries, outdoor recreation, coastal zones, mortality from climate-related diseases and pollution, and ecosystems. It also includes, what were at that time, pioneering estimates of the economic cost of catastrophic climate impacts.

Most formal models use 2–3 °C warming as a starting point. In this temperature range, the cost of climate change could be equivalent to a loss of 0–3% in global GDP from what could have been achieved in a world without climate change. Models differ on whether low levels of global warming would have positive or negative global effects. But all agree that the effects of warming above 2–3 °C would reduce global welfare, and that even mild warming would harm poor countries. Their results depend on key modeling decisions, including how each model values the costs to poor regions and what it assumed about societies' ability to reduce costs by adapting to climate change.

The existing estimates of monetary costs of climate change also omit significant factors such as such as extreme weather events, social and political instability, and cross-sectoral impacts.

Stern (2008) points out that business-as-usual (BAU) temperature increases may exceed 2–3 °C by the end of this century. Using an Integrated Assessment Model, and with due caution about the ability to model, he estimated the total cost of BAU climate change to equate to an average reduction in global per capita consumption of 5%, at a minimum, now and forever. Stern uses the PAGE2002 IAM (Hope 2006), which can take account of the range of risks by allowing outcomes to vary probabilistically across many model runs, with the probabilities calibrated to the latest scientific quantitative evidence on particular risks. He runs the model under two different assumed levels of climatic response. The "baseline climate" scenario is designed to give outputs consistent with the IPCC's Third Assessment Report (TAR) (IPCC 2001). The "high climate" scenario adds the risk of amplifying natural feedbacks in the climate system. Preliminary estimates of average losses in global per capita GDP in 2200 range from 5.3 to 13.8%, depending on the size of climate system feedbacks and what estimates of "nonmarket impacts" are included. In all scenarios, the highest impacts are in Africa and the Middle East, and India and Southeast Asia. In all scenarios, the consequences of climate change become disproportionately more severe with increased warming. Stern finds that the welfare costs of BAU climate change are very high. Climate change is projected to reduce average global welfare by an amount equivalent to a permanent cut in per capita consumption of a minimum of 5%. The reductions are larger if nonmarket impacts, feedbacks and regional costs are included. Putting these three factors together would probably increase the cost of climate change to the equivalent of a 20% cut in per capita consumption, now and forever.

Dietz and Stern (2014) assessed the series of Dynamic Integrated Climate-Economy (DICE) models (Nordhaus 1991). These models have inbuilt assumptions on growth, damages, and risk, which together result in gross underassessment of the overall scale of the risks from unmanaged climate change. The authors show that if the analysis is extended to take into account three essential elements of the climate problem—the endogeneity of growth, the convexity of damages, and climate risk—optimal policy comprises stronger controls. With the extended models, BAU trajectories of greenhouse gas emissions give rise to potentially large impacts on growth and prosperity in the future, especially after 2100. These impacts are large enough to feed back into future emissions via reduced activity, but the feedback is too small and too late for the system to self-regulate. As a guide, the authors find that the extended DICE models suggest the carbon price in a setting of globally coordinated policy, such as a cap-and-trade regime or a system of harmonized domestic carbon taxes, should be in the range \$32–103/tCO_2 (2012 prices) in 2015.

3.3 Results from the Indian Modeling Exercises[1]

India is one of the lowest emitters of greenhouse gases (GHGs) in the world on a per capita basis. At 1.4 tCO_2/person in 2010, India's emissions were less than one-third of the world average of 4.5 tCO_2/person, less than one-fourth that of China's, and one-twelfth that of the US's. But India is still threatened by the impact of global warming and climate change. Enthusiastic about its global responsibility, in December 2009, it announced that it would reduce the emissions intensity of its GDP by 20–25%, over the 2005 levels, by the year 2020. India is resolute about ensuring sustainable growth based on low carbon principles.

But this is not an easy task. The Low Carbon Society Vision 2050 India (2009) states that India faces challenges in economic development which have to be met with limited resources, minimal externalities, and in the presence of large uncertainties with respect to climate.

[1]Appendix 3.1 A–3.4 A lists the various assumptions and results obtained from the various models.

The Expert Group on Low Carbon Strategies for Inclusive Growth (2014) has evolved a macro-model to fully elucidate the inter-sectoral implications of different mitigation measures and ensure that the low carbon strategies being recommended are mutually consistent.

The model's output is summarized in two end-point scenarios: the BIG (Baseline, Inclusive Growth), and the LCIG (Low Carbon, Inclusive Growth). While inclusive actions remain unchanged between the two scenarios, low carbon strategies span the vector space between them. Pursuit of Low Carbon Strategies brings down the average GDP growth rate by 0.15 percentage points, while per capita CO_2 emissions (in 2030) fall from 3.6 tons in the BIG scenario to 2.6 tons in the LCIG scenario. However, in both scenarios, the total carbon emissions continue to rise up to the year 2030.

The cumulative costs of low carbon strategies have been estimated to be 834 billion US dollars at 2011 prices, over the two decades between 2010 and 2030. While total power demand remains unchanged between the two scenarios, emission intensity of GDP declines by 22%, over 2007 levels (by 2030) in the BIG scenario, as compared to 42%, over 2007 levels (by 2030) in the LCIG scenario. Further, due to a massive change in the energy mix by 2030, demand for coal comes down from 1568 Mt in the BIG to 1278 Mt in the LCIG scenario, demand for crude oil comes down from 406 Mt in the BIG to 330 Mt in the LCIG scenario, while demand for gas marginally rises from 187 bcm in the BIG to 208 bcm in the LCIG scenario. At the same time, the installed wind and solar power capacities need to be increased to 118 and 110 GW respectively, by the year 2030, in the LCIG scenario.

Low Carbon Society Vision 2050 India (2009) assesses two paradigms for transiting to low carbon future in India. The first pathway assumes a conventional development pattern together with a carbon price that aligns India's emissions to an optimal 450 ppmv CO_2e stabilization global response. The second emissions pathway assumes an underlying sustainable development pattern characterized by diverse response measures typical of "sustainability" paradigm. An integrated modeling framework is used for delineating and assessing the alternate development pathways having equal cumulative CO_2 emissions during the first half of the twenty-first century.

The base case scenario assumes future economic development along a conventional path. In the case of a developing country, such as India, the scenario assumes that future socioeconomic development will mimic the resource-intensive development path followed by the developed countries. Two paths are considered as part of Low Carbon Scenarios: the Conventional Path, Carbon Tax (CT) Scenario, and the Sustainable Society (SS) Scenario.

The CT scenario presumes a stringent carbon tax (or permit price) trajectory compared to a milder carbon regime assumed under the base case while sustainability is the rationale for the ST scenario. The perspective is a long-term one, aiming to deliver intergenerational justice by decoupling economic growth from the highly resource-intensive and environmentally unsound conventional path. In the SS scenario, mitigation choices are more diverse and include measures that are designed to influence several development indicators simultaneously. It pays greater attention to public investment decisions, such as infrastructure which lead to modal shifts in the transport sector; and institutional interventions that alter the

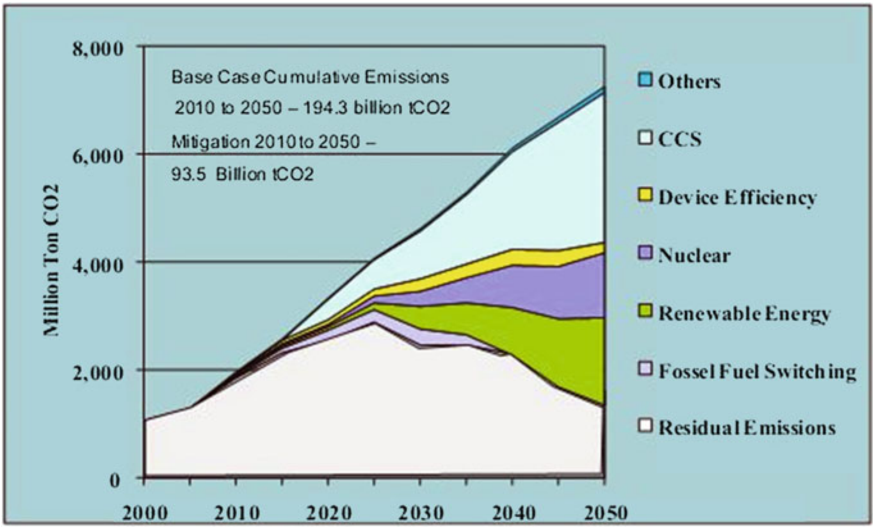

Fig. 3.1 Mitigation options in carbon tax scenario. *Source* Low carbon society vision 2050 India (2009)

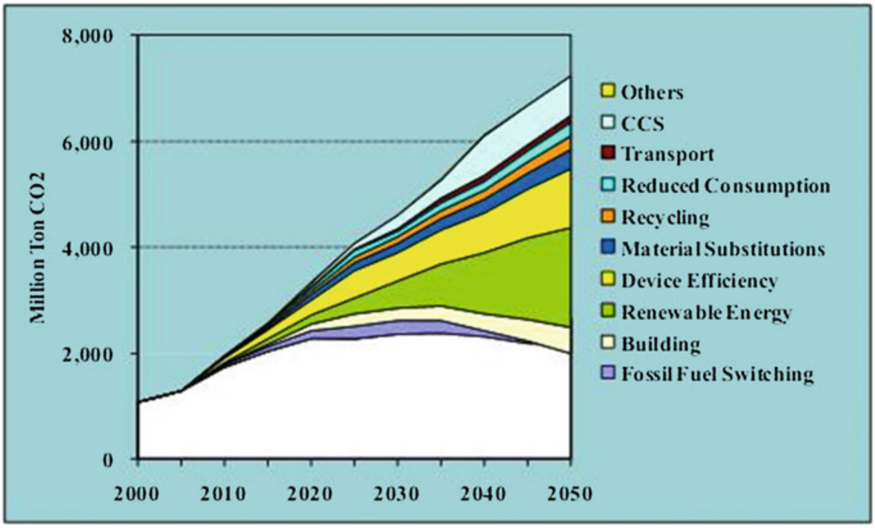

Fig. 3.2 Mitigations options in sustainability scenario. *Source* Low carbon society vision 2050 India (2009)

quality of development. In the CT scenario, the mitigation measures are more direct and have a greater influence on private investments (Figs. 3.1 and 3.2).

For realizing the vision of a Low Carbon Society for India, the study listed policy actions required to implement mitigation measures such as sustainable transport, low carbon electricity, fuel switching, building design, material

Table 3.1 Results for Illustrative Scenarios[a]

	NCAER CGE model	TERI MoEF model	IRADe AA model	TERI Poznan model	McKinsey India model
GHG emissions in 2030–31 (CO_2 or CO2e) (billion tons)	4.00 billion tons of CO2e	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 capita GHG emissions in 2030–31 (CO_2 or CO2e)	2.77 tons CO2e per capita	3.4 tons CO2e per capita (in 2031–32)	2.9 tons CO2e per capita	5.0 tons CO2e per capita (in 2031–32)	3.9 tons CO2e per capita (2030), all GHGs
CAGR of GDP till 2030–2031, %	8.84%	8.84% (Exogenous–taken from CGE)	7.66% (Endogenous, 2010–11 to 2030–31)	8.2% 2030–2031 (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 CO2e) intensity	From 0.37 kg CO_2e to 0.15 kg CO2e 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)

[a]Tables prepared by Gayatri Khedhkar
Source India's GHG Emissions Profile: Results of Five Climate Modelling Studies

Table 3.2 Assumptions and data sources for Illustrative Scenarios

	NCAER CGE model	TERI MoEF model	IRADe AA model	TERI Poznam 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 assumptions 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 = 3.5% 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 (WEO 2007) 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

(continued)

Table 3.2 (continued)

	NCAER CGE model	TERI MoEF model	IRADe AA model	TERI Poznam model	McKinsey India model
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 NCAER (2009)	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 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 values, capex and cost
GHG emissions coefficients	National Communications	National Communications	National Communications	National Communications	National Communications + IPCC (2001) + 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

Source India's GHG Emissions Profile: Results of Five Climate Modelling Studies

Table 3.3 Shukla-AIM model comparison with MoEF models (Shukla et al. 2015)

GHG emissions in 2050	7.2 billion tons
Per capita emissions in 2050	4.5 tons
CAGR of GDP till 2032	8%
Commercial energy use in 2050, mtoe	2825 mtoe
Fall in energy intensity	3% per annum
Fall in CO_2 intensity	
Assumptions	
Population	UN population medium scenario version 2004
Global/domestic energy price projections	Global prices by IEA
GDP growth rates	Exogenous
Foreign savings projections	
Specific energy technologies data	Technologies in power, transport
Model/methodology descriptions	
Model/methodology type	AIM CGE/GCAM model
Key features of model/ methodology	Top down—bottom up integrated model soft linking of AIM CGE model with ANSWER- MARKAL model
Key inputs	Population, energy prices, GDP growth rate,
Key outputs	CO_2 emissions, energy intensity, CO_2 intensity, energy demand, mitigation choices
Number of sectors	13 sectors, industry divided into 11 subsectors
Greenhouse gases included	CO_2 (energy and industry only)
Primary energy forms	Coal, oil, gas, nuclear, hydro, biomass, renewable

Source India's GHG Emissions Profile: Results of Five Climate Modelling Studies

Table 3.4 Difference between IRADe–MoEF model and expert group macro-model

Parameter	IRADe MoEF model	Expert group macro-model
Results	Results till 2030 with 3-year interval	Results till 2030 for each year
TFPG assumptions	3%	1%- agriculture, 1.5%—non-agriculture sector
AEEI	1.5%	0.5% for BAU
Development indicators	No	Basic development indicators included which makes BAU scenario a BIG—baseline inclusive growth scenario

Source: India's GHG Emissions Profile: Results of Five Climate Modelling Studies substitution and recycling, reduced consumption and device efficiency, urban planning, resource management, governance, and financing.

Dubash et al. (2013) propose and develop a methodology for operationalizing a co-benefits approach to climate policy formulation. They use the technique of multi-criteria analysis (MCA), which requires making choices between and examining trade-offs across multiple objectives of policy, such as growth, inclusion, and environment. MCA is the general term for a family of analytical techniques that are particularly relevant when assessing likely policy outcomes relative to multiple objectives, when values and consequent prioritization across those values may differ, and where it is important to assess both quantifiable monetary impacts and unquantifiable impacts. The authors argue that adopting an MCA-based co-benefits approach will likely bring gains to both domestic policymaking and India's international climate stance. Domestically, this approach would increase the coherence of policymaking early in the decision process. Internationally, a well-specified co-benefits approach will be a necessary first step to articulating India's policy approach based on the centrality of the principle of "common but differentiated responsibility and respective capabilities". In addition, the authors develop a framework for consideration of implementation issues (Tables 3.1, 3.2, 3.3 and 3.4).

References

Dietz S, Stern N (2014) Endogenous growth, convexity of damages and climate risk: how Nordhaus' framework supports deep cuts in carbon emissions. Centre for Climate Change Economics and Policy, Working Paper No. 180

Dubash N, Raghunandan D, Sant G, Sreenivas A (2013) Indian climate change policy. Econ Polit Weekly 48(22):47–62

Hope C (2006) The Marginal Impact of CO_2 from PAGE 2002: an Int grated assessment model incorporating the IPCC's five reasons for concern. Int Assess J 6(1):19–56

Indian Institute of Management Ahmedabad (IIMA), National Institute of Environmental Studies (NIES), Kyoto University (KU), Mizuho Information and Research Institute (MIZUHO) 2009 Low Carbon Society Vision 2050: India. Collaborative report prepared by Indian Institute of Management Ahmedabad, India, National Institute of Environmental Studies, Japan, Kyoto University, Japan, and Mizuho Information and Research Institute, Japan. (November 2009)

Intergovernmental Panel on Climate Change (2001) Synthesis Report. Cambridge University Press, Cambridge, UK

International Energy Agency (2007) World Energy Outlook. OECD/IEA, Paris, France

Mendelsohn R, Dinar A, Dalfelt A (2000) Climate change impacts on African agriculture. Preliminary analysis prepared for the World Bank, Washington, District of Columbia, p 25

MoEF (2009) India's GHG emissions profile: results of five climate modelling studies. Climate Modelling Forum, supported by Ministry of Environment and Forests, Government of India, New Delhi, India. http://www.moef.nic.in/downloads/home/GHG-report.pdf

National Council of Applied Economic Research (2009) Climate Change Impact on the Indian Economy—A CGE Modelling Approach. NCAER, New Delhi, India

Nordhaus WD (1991) To slow or not to slow: the economics of the greenhouse effect. Econ J 101 (407):920–937

Nordhaus WD, Boyer JG (2000) Warming the World: economic models of Global Warming. MIT Press, Cambridge, MA

Planning Commission (2014) The Final Report of the Expert Group on Low Carbon Strategies for Inclusive Growth. Planning Commission, Government of India, New Delhi, India. Available online at http://planningcommission.nic.in/reports/genrep/rep_carbon2005.pdf

Shukla PR, Garg A, Dholakia HH (2015) Energy-emissions trends and policy landscape for India. Allied Publishers

Stern N (2008) The American Economic Review, vol 98, No. 2. In: Papers and proceedings of the one hundred twentieth annual meeting of the American Economic Association

Tol RSJ (2002) Estimates of the damage costs of climate change, Part 1: benchmark estimates. Environ Resource Econ 21:47–73