India's GHG emission scenarios: Aligning development and stabilization paths

P. R. Shukla

Indian Institute of Management, Ahmedabad 380 015, India

This paper presents emission scenarios for India, constructed following the IPCC SRES framework. Analysis spans 21st century and is centered on energy sector CO_2 emission. Scenario stories presume no explicit climate intervention; however differences in endogenous profiles of key drivers like technologies have profound indirect impact on GHG emissions. Across scenarios, aggregate emission trajectories vary significantly, thus proving that endogenous development choices are key determinants of emission paths. The paper therefore argues that development policies and actions, which alter profiles of key drivers of development should be essential elements of climate mitigation strategies.

Scenario results show that India's per capita emission during the century would rank amongst the lowest. Stabilization at a 550 ppmv CO_2 concentration would induce significant changes in energy and technology mix and economic losses in India. Stabilization burden would be lower in scenarios where underlying development paths are sustainable. The near-term energy choices, given their path dependence, could deliver sustained development and climate benefits. Aligning development and climate actions, therefore, is advisable and feasible. The regime instruments, the paper concludes, should aim to first support endogenous climate-friendly actions and then to induce climate centric actions in addition.

Keywords: Emission scenario, GHG, methane, nitrous oxide, energy choices.

Emission scenarios are eminent constructs to analyse alternate futures and useful tools for communications among scientists and with policymakers. Scenarios assessments are not predictive, but provide the projections of alternate futures constructed to represent interactions among key-driving forces underlying socio-economic development. Across scenarios, aggregate emission trajectories vary significantly, thus proving that endogenous development choices are key determinants of emission paths. Global scenario studies[1] have shown that the stabilization of greenhouse gases (GHG) concentration, even in case of low emissions scenarios, would require substantial mitigation from the endogenous emissions baselines. These studies also show that mitigation from high emissions pathways would be very costly. The endogenous emissions pathways matter, as the determinant of the mitigation burden. The near-term development choices that create long-term lock-ins, such as the type of energy infrastructure to invest in, could have vital bearing on the future emissions trajectory. Development policies and actions, which alter profiles of key drivers of development, therefore, are the essential elements of climate mitigation strategies.

In 2004, India's annual per capita carbon dioxide emission of 0.3 tonne carbon (1.1 tonne of CO_2 equivalent) ranked among the lowest in the world, below a third of the global and tenth of the OECD averages. Often, questions are posed about the country's future emissions trends and apprehensions are expressed that India with its immense population, rising economic growth and vast coal resources would emit alarming amounts of GHG. This paper addresses these questions using the scenario framework similar to the IPCC Special Report on Emissions Scenarios[2]. The paper then examines India's emissions scenarios *vis-à-vis* the global GHG stabilization regime and delineates the extent of mitigation that India can supply under different scenarios in a cost-effective global regime aiming at 550 ppmv CO_2 concentration stabilization target and discusses stabilization-induced technological change. The analysis spans 21st century and is centered on the energy sector CO_2 emissions for which medium (30 years) and long-term (100 years) scenarios are presented. For non-CO_2 gases, the medium-term scenarios are presented. The emissions from land-use, land-use change and forests are excluded from the present analysis.

Indian emissions scenarios – Paradigm, storylines and drivers

Emissions scenario paradigm

The scenario paradigm views 'future' as multiple worlds; each can unfold depending on how their driving forces get shaped by accidental and/or planned actions. Scenarios are neither predictions nor forecasts. They are projections of alternate futures representing different interactions between key-driving forces. Scenarios are useful tools for scientific assessments, for learning about complex systems behaviour and for policy making. They provide baselines

e-mail: shukla@iimahd.ernet.in

for comparative assessment of policies that could alter the course of future, desirably. Scenario making is the craft of delineating internally consistent and reproducible set of assumptions about the key relationships and driving forces of change, which are derived from an understanding of both history and current situation.

The advantage of scenario paradigm *vis-à-vis* prediction is its practicality to accommodate inherent uncertainties shaping the drivers, diversity of perspectives amongst stakeholders and possibility to identify ranges of critical parameters so as to discern robust responses. The 'development' scenarios are shaped by the unfolding of key drivers of socio-economic development, like the population profile, institutional character and resource endowments. The emissions scenarios are consequential to the development scenarios, each generating own emissions profile. Thus, there are multiple emissions profiles to be viewed for addressing the questions such as those posed in the previous section.

Scenario storylines

The most prominent emissions scenario exercise reported in the literature is the IPCC SRES (Special Report on Emissions Scenarios). IPCC scenarios are conceptualized at global level and span hundred years. These scenarios posit the future global dynamics in a 2×2 matrix that classify the relative orientation of scenarios toward economic or environmental concerns on one dimension and global or regional development patterns on second dimension. Storylines provide consistent narration of complex interplay among driving forces, within and across alternative scenarios. Storylines, for instance, vary in description of how demographic structure changes with socio-economic conditions, how technological developments and market integration with global economy would drive economic growth, how decentralized economic development could evolve, and how policies for protecting local and regional environments would be implemented. Such dynamics cannot be expressed in strict quantitative terms. However, for quantitative assessments the modellers interpret the storyline, quantify the key drivers and assign numerical values to model parameters.

Indian emissions scenarios are constructed using the IPCC SRES methodology[3]. Four scenario families are classified by 2×2 matrix; one dimension of which is governance (A: centralization or B: decentralization) and second dimension is market integration (i.e. integration with global markets; 1: high and 2: fragmented). Four Indian (referred with prefix I) scenarios are named IA1, IA2, IB1 and IB2 to follow IPCC scenarios (Figure 1). The dimensions for Indian scenarios are different, though if 'centralization' is interpreted as top-down governance and 'decentralization' as in the classic 'sustainable development' approach, the dimensions are similar to IPCC.

Scenario drivers and quantification

The key driving forces of Indian scenarios are similar to IPCC scenarios, namely the economic growth, demographic profile, technological change, energy resource endowments, geographic integration of markets, institutions and policies. The quantification of drivers follows two stages. The range of projections of a driver, for instance population, is available from known data sources. The qualitative storyline description is then used to select a specific driver trajectory from the available range. As for modelling inputs, the numerical values of key drivers are used to quantify the model parameters. The quantification is a judgmental process. Different modelling exercises arrive at varied quantification of the same scenario story. Therefore their emissions projections for the same scenario differ even when they use same or similar models. Notwithstanding such variability, the usefulness of scenario modelling derives from consistency of trends and ranges of quantified results for same scenario, which are generally secular across modelling studies. Hence, the conclusions from the comparative results among and across scenarios are reliable and robust.

The quantification process uses results of such studies as benchmarks. In case of India, the medium-term (up to 2030) projections are often available from agency or Government Reports, e.g. United Nations World Population Statistics[4], India Vision 2020[5]. The drivers like GDP growth rates (Figure 2) and population (Figure 3) are quantifies using data from such official exercises. In this paper, we report the four medium-term emissions scenarios for India for CO_2, methane and N_2O, and the long-term emission scenarios for CO_2. The mitigation analysis assumes 550 ppmv CO_2 concentration as long-term stabilization benchmark. The stabilization analysis is done only for IA2 scenario[6].

Market integration

Integrated	Fragmented
IA1 **Globalization High Growth**	IA2 **Mixed Economy**
IB1 **Sustainable Development**	IB2 **Self Reliance**

Figure 1. Classification of India's emissions scenario families.

India's emissions scenarios

The emissions scenario assessment is based on results of various studies carried out using an integrated modelling framework comprising of three types of models: (i) national level top-down macro-economic models exclusive or embedded within global models, (ii) national level bottom-up energy system models, and (iii) local level bottom-up models[7,8]. The models are soft-linked through exchange of various parameters. For instance, the projections of GDP and energy prices for different scenarios are endogenous outputs of top-down models. These are used as exogenous inputs into the scenario assessments by bottom-up models. The bottom-up models, on their part, provide future energy balances that are used for tuning inputs of the top-down models. The bottom-up models also provide detailed technology and sector level emission projections that are used as inputs to the GIS-based energy and emissions mapping at local and national levels. The medium-term results reported in this paper use for analysis the top-down computable general equilibrium model, the Second Generation Model (SGM)[9,10], and a combination of bottom-up model applications[11,12,8] using MARKAL[13–15] and Asia-Pacific Integrated Model (AIM)[16–18,8]. The long-term analysis uses results from Edmonds–Reilly–Barns (ERB) model[19], a global top-down energy sector partial equilibrium model, wherein India is considered a separate region for the long-term analysis within the global framework and ANSWER–MARKAL model[7] set-up for India.

CO_2 emissions scenarios

Medium-term carbon emissions (Figure 4) show secular increase in emissions in all scenarios. The range of emissions varies significantly across scenarios in 2030; the IB1 scenario that follows classic sustainable development pattern with medium economic growth displays emission trajectory that is significantly below the high growth scenario IAI having higher growth and advanced technologies. Carbon emission in IA1 scenario in the year 2030 is nearly 30% higher than IB1 scenario, though the carbon intensity (i.e. emissions per unit of GDP) of both scenarios is nearly the same. The other scenarios IA2 and IB2 which assume medium and low economic growth rates respectively display high emissions intensities. In 2030, in comparison with IB1 scenario, the emissions intensity of IB2 scenario is twice and IA2 scenario nearly 60% higher. The quality of development thus matters – not only in determining the future emissions pathways but also the emissions intensities. Development along a sustainable pattern (e.g. IB1 scenario) is inherently more climate-friendly. The integrated market reforms scenario (e.g. IA1), which enhances the fuel and technology choices, has better emissions intensity than scenarios assuming fragmented market. Thus, lower emissions intensities are feasible through alternate development approaches, though the development patterns do matter to the absolute emissions. The IA1 scenario displays the classic development and climate conflict, akin to the historical development pathways followed by present industrialized nations where economic growth is accompanied by declining emissions intensity and rising absolute emissions.

In all Indian scenarios, domestic coal has high share in primary energy demand. Although India's CO_2 emissions rise in all scenarios, the per capita emissions in 2030 for all Indian scenarios remain much below the global average reported for comparable IPCC SRES non-climate intervention scenarios.

Methane and nitrous oxide emissions scenarios

In the year 2000, methane (CH_4) (18.63 Tg) and nitrous oxide (N_2O) (0.31 Tg) emissions contributed 27% and 7% respectively to the CO_2 equivalent GHG emissions from India[11,20]. The key driving forces of CH_4 and N_2O emissions are economic growth, population (livestock and human), urbanization patterns, land reforms, techno-

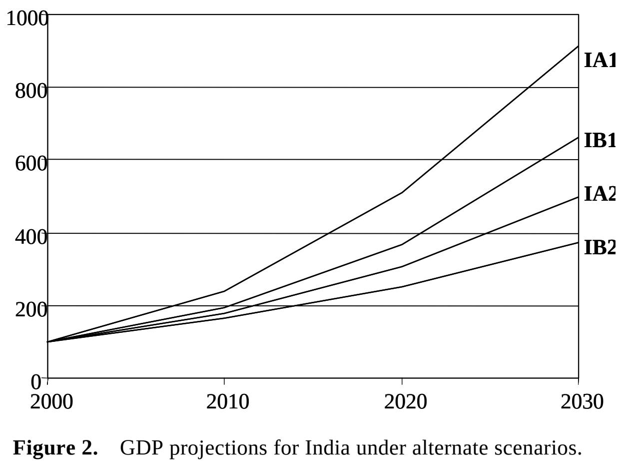

Figure 2. GDP projections for India under alternate scenarios.

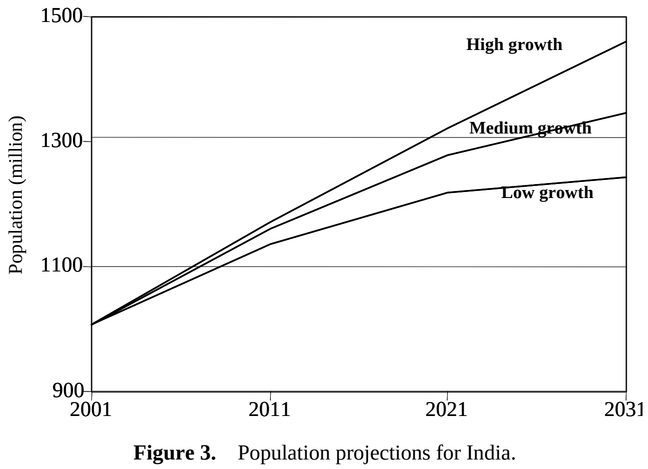

Figure 3. Population projections for India.

logical progress and global climate change regimes. The assessment of future emissions of methane and nitrous oxide for each scenario uses sector mix projected by top-down modelling exercise with SGM, together with detailed results of bottom-up energy modelling exercises.

Methane emissions (Figure 5) show rising trend in all scenarios, though the growth rate is lower compared to CO_2 emissions. The trend across scenarios is comparable to CO_2, with lowest emissions in 2030 in IB1 and highest in IA1 scenarios. In case of IB1 scenario, the emissions remain stable following the sustainable practices in paddy, livestock and municipal solid waste management. The rise in methane emissions in other scenarios is mainly from enhanced coal mining and ill-managed landfills in the rapidly growing urban centres.

Nitrous oxide emissions (Figure 6) grow at rates faster than methane emissions. Their comparative trend across scenarios is similar to those of CO_2 emissions. Main source that enhances N_2O emissions is the rising use of nitrogenous fertilizer by modernizing agriculture. Two other sectors where N_2O emissions increase rapidly are: (i) the manufacture of nitric acid as feedstock for other industrial products and (ii) the emissions from fuel combustion.

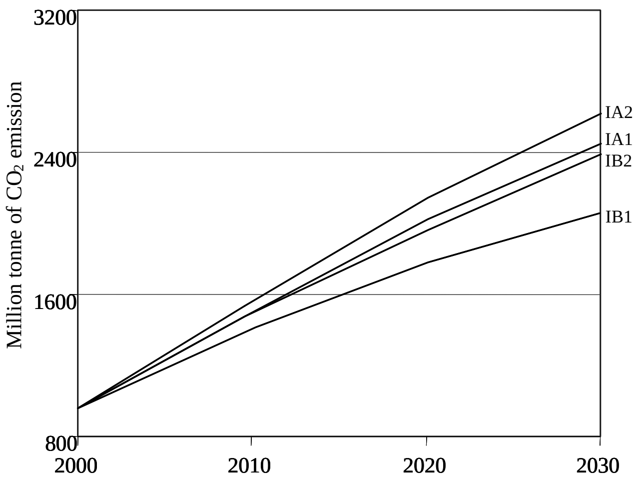

Figure 4. Carbon dioxide emissions scenarios for India.

The emissions of three greenhouse gases increase in all four scenarios, though at different growth rates. There are no endogenous greenhouse emissions mitigation interventions presumed in any of these scenarios. The development choices embedded in each scenario lead to different greenhouse gas emissions trajectories. For instance, in IB1 scenario, the methane emissions are lower due to practices like waste recycling in urban areas and micro-irrigation in agriculture. In the same scenario, N_2O emissions are lower by sustainable agriculture practices due to lower and efficient use of nitrogenous fertilizers. Despite higher economic growth in IA1 scenario compared to IA2 scenario, the CO_2 emissions intensity is lower in IA1 scenario due to enhanced supply of clean fuels and technologies and efficient energy use due to enhanced competition. However, methane and N_2O emissions in IA1 scenarios are higher due to water and chemical inputs intensive agriculture. Thus, the conditions and choices, on demand and supply-side, that are endogenous to a scenario, are the key determinant of emissions pathways.

CO_2 equivalent emissions for reference (IA2) scenario

The growth rate of emission of each gas differs across scenarios; however the trend is comparable across gases. The CO_2 equivalent emissions are presented here for one benchmark scenario, namely IA2 scenario. For this scenario, the CO_2 equivalent GHG emissions grow nearly 2.6 times during the period from 2000 to 2030 (Table 1). Chief contributors of growth are CO_2 and N_2O as discussed earlier. The differing growth rates of each gas leads to altered shares of each in the global warming potential. The share of CO_2 which was 66% in 2000 would increase to 73% in 2030. The share of methane which

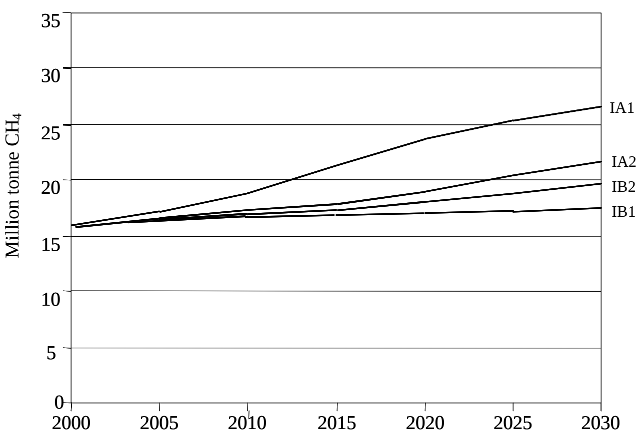

Figure 5. Methane emissions scenarios for India.

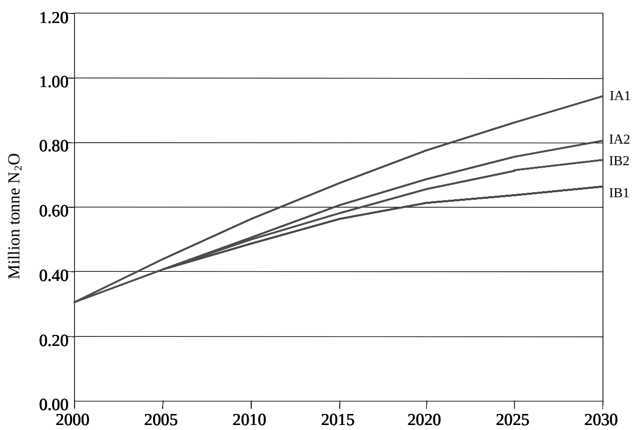

Figure 6. Nitrous oxide emissions scenarios for India.

was 27% in 2000 would be reduced to 15% in 2030. And, the share of N_2O will remain stagnant at about 7%.

Emissions intensity in scenarios

In rapidly growing developing economies, like India, the increasing trend of emissions across scenarios is normal. What is vital here is not the growth of emissions, but the change in emissions intensities, i.e. the emissions per unit of GDP. In all Indian scenarios, the CO_2 equivalent emissions intensity show sustained improvement over a period of three decades. In fact, the reduction in intensity in A1 and B1 scenarios is exceptionally high, more than 3% annual improvement, a rate rarely observed for a sustained period during the development phase of the current industrialized nations. The 2.2% annual improvement in intensity in case of IA2 scenario is also better than the historical long-term rates. Only in IB2 scenario, the rate of intensity improvement is low due to slow technological progress presumed in the storyline. However, this scenario has the lowest economic growth rate and therefore overall emissions growth is moderate. In general, it is comforting that although the economic growth across scenarios exhibit a wide range (4.5–7.5%), the growth rates of CO_2 equivalent emissions (2.6–3.9%) are confined to a lower band and narrower range. This notwithstanding, the secularly rising trend of emissions in the medium-term calls for extending the scenario analysis to a longer period, like 100 years, during which the global climate change regime would aim to achieve the stabilization of greenhouse gas concentration to meet the ultimate objective of the United Nations Framework Convention on Climate Change[25].

Long-term CO_2 emissions scenarios for India

The high growth rate of CO_2 emission is driven by fossil fuel demand, especially coal including the increased supply of domestic coal. In the long-run, spanning 21st century, the share of methane emissions in India's global warming potential declines in all scenarios[21] since the activities producing methane grow at much slower pace compared to fossil energy consuming activities. Thus, in the long-run, it is the CO_2 emissions from energy use that would overwhelm the CO_2 equivalent emissions scenarios for India. The analysis, next, is therefore focused on the long-term CO_2 emissions scenarios for India spanning 100 years. Following the IPCC SRES, one more scenario IA1T is added in the long-term analysis. The IA1T scenario is a variant of the IA1 scenario, with stronger assumptions about the supply of advanced technologies. The Indian long-term scenarios, like the IPCC scenarios, do not presume any explicit measures to address climate change.

Table 1. Emissions trend for IA2 scenario

Emissions (Tg or million tonne)	2000	2010	2020	2030
CO_2	956	1507	2080	2572
CH_4	18.63	20.08	21.73	24.36
N_2O	0.308	0.505	0.689	0.807
CO_2 equivalent GHG[a]	1454	2115	2839	3507

[a]Global warming potentials used for conversion to CO_2 equivalent GHG emissions are: CO_2 (1), CH_4 (21) and N_2O (310).

CO_2 emissions scenarios

The long-term CO_2 emissions scenarios for India (Figure 7) show sustained rising emissions trend throughout the century in all scenarios. The scenario storylines presume significant endogenous technological change in all scenarios, including improvements in current technologies and introduction of new and clean energy technologies and resources. The scenario results for 2100 show a large range of emissions across scenarios (Figure 7). The conclusions evident from Figure 7 are: a) long-term emissions pathways vary significantly across scenarios, thus reinforcing the conclusion that the endogenous development choices matter significantly in shaping emissions pathway for each scenario, b) all scenarios display rising emissions trends reaching to the year 2100, thus raising alarm *vis-à-vis* the ultimate objective of the UNFCCC to stabilize concentration of greenhouse gases, c) advanced technologies, especially the alternate energy technologies, can reshape the emissions profiles as is evident from IA1T emissions scenario, d) the advanced energy technologies shall not be adequate to stabilize emissions in absence of policies to address climate change, and e) the sustainable development choices, as in IB1 scenario, would deliver low emissions profiles even in absence of explicit climate policies.

Global scenario assessments have shown that stabilization of GHG concentrations would require explicit mitiga-

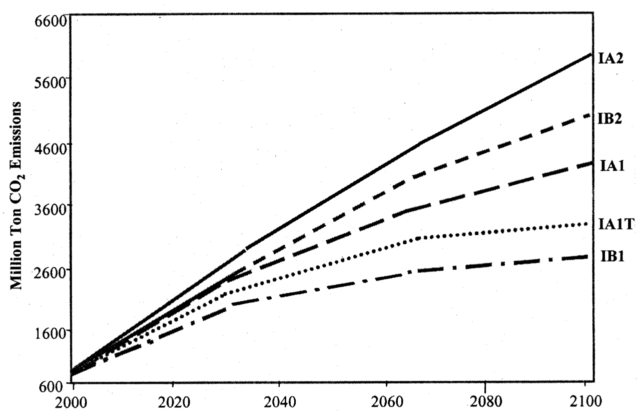

Figure 7. Long-term (100 years) CO_2 emissions scenarios for India.

tion interventions. However, for scenarios where endogenous development choices are climate-friendly, the mitigation costs are substantially lower[1].

Indian scenarios and the global stabilization regime

This analysis presumes, as a benchmark, the stabilization at 550 ppmv CO_2 concentration. To caution, the 550 ppmv CO_2 concentration stabilization target is chosen just as one benchmark, for the analysis, from a range of concentration benchmarks that may be chosen. It is neither preferred nor advocated as the ideal stabilization level. Figure 8 shows Indian CO_2 emissions scenarios, together with an optimal emissions trajectory for India, if a 550 ppmv CO_2 concentration stabilization regime is opted globally with tradable emissions rights. The stabilization analysis uses results from global modelling studies[22–24] and introduces these signals into Indian emissions scenario modelling exercise. As can be seen from Figure 8, the emission trajectories of all Indian scenarios are higher than the trajectory required for the cost-effective 550 ppmv CO_2 concentration stabilization[22]. Whereas the low emission scenarios like IB1 and IA1T would require moderate mitigation efforts and costs, the alarming fact is that the mitigation needs for the rest of the scenarios could be very high and would cause high economic damages.

The fact that IB1 scenario already includes significant sustainable development measures and IA1T scenario includes advanced energy technologies is not comforting since further mitigation in these scenarios could be expensive. Given the stringent mitigation needs of stabilization, India would face continued pressure for mitigation commitments. Whereas in a cost-effective mitigation regime for stabilizing the concentration at level equivalent to or stringent than 550 ppmv CO_2 concentration, India would have to mitigate; how much the mitigation burden on India shall be is an independent issue and will be decided by allocation of emissions rights or financial incentives within the climate regime. The understanding of mitigation burden on India is therefore of interest, regardless of the nature of burden sharing regime. Next, the high emission IA_2 case is analysed to examine the evolution of emission indicators like per capita emissions implications of stabilization on the Indian energy system and the extent of technological change induced by the participation in the stabilization regime.

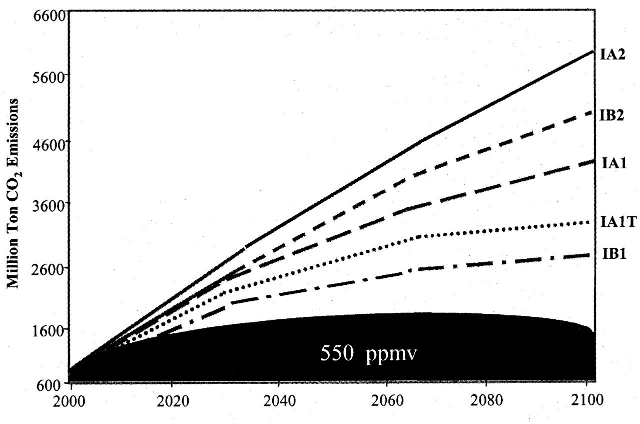

Figure 8. Endogenous and 550 ppmv CO_2 emissions stabilization scenarios for India.

Per capita emissions and income in IA2 scenario and implications

The CO_2 emissions in IA2 scenario increase during the century by about six times, from nearly a billion tonne in 2000 to over 6 billion tonne in 2100. In this scenario, most emissions are from coal used in the power and industry sectors and continued use of fossil fuels throughout the economy. The global stabilization at 550 ppmv CO_2 concentration would require the India's emissions trajectory to end in 2100 at 5.8 billion tonne emission level (Figure 8). Even in a high emission scenario like IA2, the per capita emissions of CO_2 from India shall be very low (Figure 9). The per capita emission CO_2 emission increases from a very low 1 tonne in 2000 to 3.6

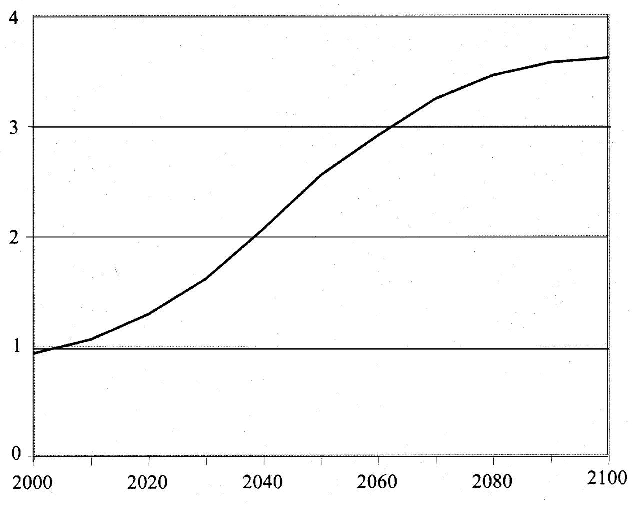

Figure 9. Per capita CO_2 emissions in IA2 scenario (tonne of CO_2/person/year).

Table 2. Annual growth rate of GDP, CO_2 equivalent and improvement of emissions intensity (from 2000 to 2030)

Scenario	GDP	CO_2 equivalent	Improvement of emissions intensity[b]
IA1	7.5%	3.9%	3.6%
IA2	5.5%	3.3%	2.2%
IB1	6.5%	2.6%	3.9%
IB2	4.5%	3.1%	1.4%

[b]Intensity refers to CO_2 emissions per unit of GDP.

tonne in 2100, which is what the global per capita average emission was in the year 2000. Thus, even in the high emission scenario, India's per capita CO_2 emission during next 100 years would never exceed the current global per capita emissions and would remain below the per capita emissions of industrialized nations under the equivalent IPCC scenario.

Stabilization-induced technological changes in IA2 scenario

Participation by a country in global CO_2 concentration stabilization regime would cause economy-wide structural changes, mainly in the energy systems. In case of IA2 scenario, the mitigation responses in India induced by the 550 ppmv CO_2 global stabilization regime are shown in Figure 10. The top line in Figure 10 is the baseline CO_2 emission trajectory of IA2 scenario. The topline of the lowest dark area is the optimal stabilization trajectory for India in IA2 scenario. It is constructed by using marginal mitigation cost for each period that is identical to the global permit prices imported from the modelling run of MiniCAM model[25,26] set-up to achieve the 550 ppmv stabilization *vis-à-vis* the global SRES A2 scenario. The shaded areas show the mitigation contribution contributed by different technologies due to their additional penetration beyond the baseline IA2 scenario, in order to reach the stabilization baseline.

Evidently, the global stabilization regime would induce significant technological changes in India, especially in the energy sector. Coal, which is otherwise the main fuel, will have to be replaced substantially and throughout the century in the stabilization scenario by gas, nuclear and renewable energy. The demand for energy will reduce due to enhanced penetration of energy efficiency technologies. These low or no carbon intensive technologies are among the endogenous technology stock in IA2 scenario, though their shares would be lower in IA2 scenario compared to those under stabilization. The technologies

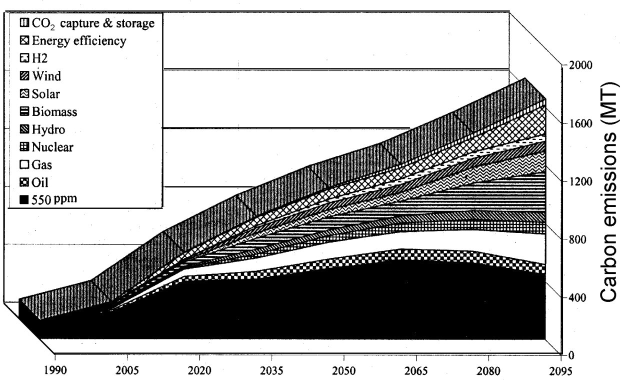

Figure 10. Stabilization (550 ppmv CO_2) induced technological change – IA2 scenario.

like carbon capture and storage would never penetrate in the non-climate intervention scenarios since their outputs are singularly aimed to reduce externalities from greenhouse gas emissions. Such technologies, including those that remove carbon from energy use or others like soil carbon fixation or biomass sequestration, would penetrate in stabilization scenario. These technological changes, induced by exogenous stabilization signals, would cause economic losses *vis-à-vis* the endogenous economy. The global agreements would need such information and also insights from global, regional and national scenario assessments, for addressing the complex equity and efficiency concerns.

Equity, efficiency and the stabilization

The scenario analysis for India shows that for several distant decades the per capita greenhouse emissions and income in India would be low enough not to invite any additional mitigation burden on the equity grounds of '*responsibility*' or '*capacity to pay*'[27–32]. '*Common but differentiated responsibilities*' and leadership of developed countries (Article 3.1, UNFCCC) apart, the scenario results convey that the global climate agreements would have no fair grounds to impose mitigation burden on India for next several decades. But at the same time, the principles of *cost-effectiveness to ensure global benefits* (Article 3.2, UNFCCC), *utility maximization*[33] and *wide participation*[34] exhort India's participation.

The analysis of India's emissions scenarios suggest that this classic conflict between '*equity and efficiency*' will persist into the distant future. The Kyoto Protocol[35] recognizes this, albeit weakly. The Clean Development Mechanism (CDM) (Article 12, Kyoto Protocol) facilitates voluntary participation of developing countries in the mitigation, with no commitment to mitigation but also no allocation of emissions rights. A cost-effective stabilization regime would require universal participation and would benefit from low cost supply of mitigation from India, and in general from all developing countries, much beyond what could be induced by CDM operating as an instrument at the margin of the endogenous baseline. The scenario studies have shown that global mitigation needs to achieve stabilization shall be stringent and these would require pervasive, and not marginal changes, that could alter the structure of economic activities in general and energy system in particular. Thus, the mitigation (and also adaptation) burden could be minimized by mainstreaming climate goals within the endogenous development choices rather than devising actions that operate marginally over a climate-unfriendly baseline. The resolution of the equity and efficiency conflict in climate regime could best lie, not in the climate centric programmes, but in the international mechanisms that could align global sustainable development and climate goals.

Mainstreaming climate interests in development choices

Post-facto mitigation actions, induced at the margin of the emission baselines, are inadequate or too expensive to meet the mitigation needs of stabilization. The question then to be addressed in future climate agreements is: 'how climate change is mainstreamed into development choices to create pathways having lower emissions and higher mitigative and adaptive capacities?'. A study[36] argues the case for mainstreaming by an inclusive strategy that promotes the climate cause through innumerable economic development actions that happen daily and everywhere, rather than following the current climate strategy that marginalizes the climate cause by pursuing exclusive climate-centric actions.

Climate-friendly development actions in India

In India, various programmes such as those supporting renewable and energy efficiency technologies, led to nearly 111 million tonnes of emissions mitigation in the decade of 1990s[37]. India's Initial National Communication (India's INC) to the UNFCCC[38] enumerates numerous initiatives undertaken for sustainable development reasons and which have accrued climate benefits in addition. The notable programmes among these are: population control measures, investments in enhancing road quality, metro railway in large cities, conversion of fleet of public vehicles to CNG in Delhi, support to energy conservation and efficiency programmes, advanced coal technology, incentives for renewable energy technologies, investment in water conservation practices, resource recycling and afforestation and land restoration. India's INC also notes the climate-friendly contribution of legal, institutional and financial reforms like the enactment of Energy Conservation Act, 2001 and Electricity Act 2003; establishment of regulatory authorities; and rationalization of tariff and reduction of subsidies to fossil energy and electricity.

Sustainable development, stabilization and energy choices

Among the most important development choices with relevance to climate change are those made in the energy sector. Increased access to safe energy and energy services can have several consequences for climate change, dependent on the pathway. Specifically in the field of energy, the policies for promoting energy efficiency and renewable energy are common to sustainable development and stabilization agendas. Despite the needs for expanding their energy consumption for sustained economic growth, most developing nations have instituted policies to ensure cleaner and more sustainable energy future. These policy choices have a significant impact on energy trends, social progress and environmental quality in developing countries[39]. Energy security is a precondition for sustainable economic growth. In India, so as in China and South Africa, coal is a major domestic energy resource. Instability in global energy market like energy supply disruptions or high prices of oil could make the energy system of these countries more coal, and hence carbon, intensive. Energy security in developing countries can be enhanced on the demand-side by improving energy efficiency and on the supply-side by enlarging the portfolio of domestic energy resources as well as access to regional energy resources. The proposed bio-fuel programme in India[40] is an excellent example where multiple dividends can accrue in terms of energy security, sustainable local development and climate benefits of mitigation and adaptation.

In early phases of development, countries make investments in back-bone assets, i.e. the infrastructure on which additional investments are made for manufacturing and delivering goods and services. Infrastructure choices create lock-ins[41,42] for how human, technological and physical capital is deployed. The lock-ins creates path dependence, which is not apparent in the near-term. In longer term the bifurcation is more evident, however it is then too late and expensive to shift from the path[43]. For instance, the transportation infrastructure in industrialized countries developed without explicit attention to energy security or climate change concerns. The past infrastructure decisions have created lock-ins into energy and emissions intensive pathway. Climate-friendly infrastructure choices are feasible in developing countries that are presently creating the back-bones. A couple of decades of delay, in rapidly growing economies like China and India, to align the infrastructure choices towards low energy intensity and climate-friendly pathway could create adverse lock-ins.

Besides infrastructure choices, there are numerous other development policies and actions that could profoundly influence future energy use and associated emissions. The urban development is one key area. Differentiated structures of settlements generate widely differentiated emissions through transportation. Nivola[44] shows how divergent policies in Europe and the United States since 1945 have shaped widely different structures for cities, and in turn widely different demands for transport services, energy consumption[45] and CO_2 emissions. Financial policies, like differentiated taxes on gasoline, which are implemented for budgetary reasons and not for environment or climate change reasons have led, over the course of half a century, to higher energy efficiency of cars in Europe than in the United States, and therefore to lower emissions per passenger-km travelled. The 21st century will witness major urbanization in India. Urban development choices would offer opportunities, those if wisely harnessed would deliver profound sustainable development and stabilization benefits.

Aligning mitigation and adaptation actions

Global climate policies have traditionally focused on mitigation question. There is a growing recognition of significant role of developing countries in mitigation and adaptation policies[46]. Climate mitigation and adaptation policies are not addressed jointly due to common misconception that they belong to entirely different domains. Development though is common determinant of mitigative and adaptive capacities[47]. National communications from several countries[48,49,38] have acknowledged the co-benefits of linked mitigation and adaptation actions. Recent studies have highlighted co-benefits from investments in human development, technology cooperation and transfer and local initiatives and have proposed policy frameworks for harmonizing climate change mitigation and adaptation responses[50–53]. Some areas where sustained co-benefits from integrating mitigation and adaptation actions can accrue are: (i) biomass, land-use and unmanaged ecosystems, (ii) water management, iii) agriculture, (iv) energy for space heating and cooling, and (v) design of long-life assets, like infrastructures.

Biomass and land use policies have high synergies and substantial co-benefits for climate change mitigation and adaptation. For instance, the National Alcohol Program (PRO-ALCOOL) in Brazil[49] launched in 1975 promoted ethanol production to substitute gasoline and support domestic sugar industry. Over three decades, it delivered direct mitigation benefits and indirect benefits like local employment, energy security and conservation of foreign exchange. Biomass plantations in surplus and waste lands deliver several spillover benefits like income for forest-dependent communities, employment to surplus agriculture labour[5,40] and land conservation, besides enhancing adaptive capacity of local communities. In the forestry sector, opportunities for linking mitigation and adaptation exists in afforestation and reforestation projects like commercial bio-energy, agro-forestry, forest protection and forest conservation through sustainable management of native forests[54]. Numerous country-specific case studies emphasize these options[55,56].

An area where mitigation and adaptation are directly linked is the change in future energy consumption arising from incremental change in climate parameters like temperature and rainfall that could alter demand for space cooling and heating and water pumping. The projection of India's future energy demand under the changed climate shows higher demand for primary energy and electricity due to increased space cooling and irrigation needs[52]. The increase in aggregate energy demand would add to carbon emissions, creating a vicious circle of climate change. The national development policies such as instituting the building codes and water conservation can reduce energy demand, additional emissions and also benefit adaptation.

In most developing countries, incomes of farming communities derive from the rain-fed cultivation. Changing precipitation patterns and enhanced evaporation due to higher temperature could alter water demand for agriculture. The increased water stress due to the dual effects of unsustainable water consumption and climate change would make these communities more vulnerable. Water deficits increase greenhouse emissions from dual effects of increased energy demand for pumping and reduced electricity generation from hydroelectric projects[8]. Sustainable water management projects like rainwater-harvesting, watershed development, drip irrigation, zero tillage, bed planting, multiple-cropping system, crop diversification, agro-forestry and animal husbandry are win–win–win solutions that deliver development, mitigation and adaptation co-benefits. Policies for changing cropping practices and patterns, flood warning and crop insurance also deliver similar multiple benefits[38].

Mitigation and adaptation co-benefits from regional cooperation

Regional cooperation is among the key principles of sustainable development. Its compelling is the potential to sustain economic growth through rational deployment of region's human and natural resources. The South Asian region comprising of Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka holds quarter of the global population. The countries have diverse energy resource endowments – coal in India, gas in Bangladesh, hydro potential in Himalayan nations of Bhutan and Nepal and strategic location of Pakistan for the transit routes linking South-Asia with the vast gas and oil resources of Central Asia and the Middle East. Maldives and Sri Lanka, as small island nations face energy security and scale economy concerns. Despite diverse comparative advantages, there is little energy and electricity trade in the region.

The recent cooperation initiatives, like the recent South Asia Free Trade Agreement (SAFTA), entering into force from 1 January 2006, could deliver substantial direct, indirect and spill-over benefits via economic efficiency, energy security, water security and environment[7]. Efficient energy trade in South-Asia would yield direct economic benefits due to energy efficiency gains resulting from improved fuel and technology choices. An analysis of a stylized cooperative regime shows that the benefits of cooperation over the 20-year period from 2010 to 2030 could be US$319 billion; which would add 1% of growth each year to the region's GDP for these 20 years[57].

Besides direct economic benefits, the South-Asia regional cooperation would deliver significant climate and local air quality benefits. The cumulative carbon mitigation for the period 2010–2030 would be 1.4 billion-tonne of carbon (i.e. 5.1 billion-tonne of CO_2); the mitigation amount larger than what the Kyoto Protocol is expected to achieve. The altered energy mix would also reduce 2.5

million tonne of SO_2 emissions each year, i.e. 30% of total emissions from the region. The hydro development could yield spill-over benefits of enhanced water supply and floods control.

Conclusions

The following conclusions are evident from the emissions scenario analysis: (i) endogenous development paths are key determinants of long-term emissions profiles, (ii) India's long-term scenarios display a wide range of emission profiles, (iii) concentrations stabilization would require mitigation even in low emission scenarios, (iv) stabilization regime would induce significant mitigation, technological change and concomitant burden on India, (v) mitigation burden is substantially lower in scenarios that follow sustainable development pathways, and, (vi) sustained multiple dividends would accrue if development and stabilization actions are aligned.

The coincidence of the time-frame for addressing climate change and the development phase of developing countries is conventionally viewed as the 'what comes first?' question, as in the classic 'chicken and egg' dilemma. The analysis in this paper shows that this conventional perspective would lead to inferior policies, which would miss opportunities of accruing multiple benefits from synchronized development and climate actions. The 'Gordian knot' of 'development or climate' could be best cut by aligning development and stabilization goals, strategies and actions. Evidently, the policies to meet national sustainable development goals have important impacts on national greenhouse gas emissions and capacity to mitigate and adapt. The direction and magnitude of the changes vary depending on the policy and on national circumstances. Some general lessons that emerge are: (i) in a country, the sectors that are farther away from the production frontier offer opportunities for multiple dividends by freeing resources to meet sustainable development goals and in addition reduce GHG emissions and enhance mitigative and adaptive capacities, (ii) national circumstances, including endowments in primary energy resources and institutions[58] matter in deciding the extent to which development and climate benefits are ultimately realized, (iii) the win–win opportunities would diminish as markets and institutions get organized in time in developing countries; therefore global climate agreements in early periods should pay special attention to capture multiple dividends in the near-term and avoid lock-ins that cause path dependence towards high emission profiles in long-term.

Emissions pathways that can stabilize concentration, such as at 550 ppmv CO_2 concentration, are far under the endogenous emissions pathways. Therefore, mitigation instruments designed to alter endogenous emission pathway at the margin would be ineffective and would cause excessive distortions. It is advisable and feasible to mainstream climate concerns into evolving development perspective. The new political and economic framework can stimulate climate benign, non-climate actions that shape climate-friendly pathways. The opportunities can be taken up by existing businesses into innovative ventures, requiring the forging of coalitions between the mainstream policy agencies, civil society and private actors[57]. Within wider and inclusive contexts, in the near-term the marginal instruments like CDM can still play additional role as one of the instruments for aligning national sustainable development strategies with climate objectives. As is evident from India's emissions scenarios, different greenhouse gases have common as well as different drivers. This offers flexibility as well as opportunities of aligning mitigation actions across comprehensive basket of greenhouse gases and local emissions. Crafting policies and instruments that realize innumerable such opportunities would be key to aligning development and climate interests.

The architecture of future climate regime should therefore aim for instruments that mainstream climate interests within development choices. A key lesson from scenario assessment is that climate agreements can deliver more if they view the climate problem from the development lense. Climate centric instruments are inferior to those, which first support endogenous climate-friendly actions and then induce exclusive climate centric actions. The benefits of aligning development and climate actions are not exclusive to developing countries, though their welfare gains are more apparent. The alignment should be embraced by developed countries too, so as to modify their unsustainable emissions pathways that are the primary cause of climate change.

1. Morita, T. *et al*., Greenhouse gas emission mitigation scenarios and implications. Climate Change 2001. In *Mitigation. Report of Working Group III of the Intergovernmental Panel on Climate* Change (eds Metz, B., Davidson, O., Swart, R. and Pan, J.), Cambridge University Press, Cambridge, 2001, pp. 115–166.
2. Nakicenovic, N. *et al*., Special report on emissions scenarios. *Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, 2000.
3. Shukla, P. R., Garg, A. and Kapshe, M., Greenhouse gas emissions scenarios. In *Climate Change and India: Vulnerability Assessment and Adaptation* (eds Shukla, P. R., Sharma, Subodh K., Ravindranath, N. H., Garg, A. and Bhattacharya, S.), Universities Press (India) Pvt Ltd, Hyderabad, 2003.
4. *World Population Prospects: The 2002 Revision*. United Nations Population Division (UNPD), 2003.
5. Indian Vision 2020, SP Gupta Committee Report, Planning Commission, Government of India, New Delhi, 2002.
6. Shukla, P. R., Rana, A., Garg, A., Kapshe, M. and Nair, R., *Climate Change Assessment for India: Applications of Asia Pacific Integrated Model (AIM)*, Universities Press, Hyderabad, 2004.
7. Nair, R., Shukla, P. R., Kapshe, M., Garg, A. and Rana, A., Analysis of long-term energy and carbon emission scenarios for India. *Mitigation and Adaptation Strategies for Global Change*, Kluwer Academic Publishers, Dordrecht, 2003, vol. 8(1), pp. 53–69.
8. Shukla, P. R., Heller, T. C., Victor, D. G., Biswas, D., Nag, T. and Yajnik, A., *Electricity Reforms in India: Firm Choices and Emerg-*

ing Generation Markets, Tata McGraw Hill Publishers, New Delhi, 2004.
9. Edmonds, J., Pitcher, H. M., Barns, D., Baron, R. and Wise, M. A., Modelling future greenhouse gases emissions: The second generation model description. In *Modelling Global Change*, United Nations University Press, Tokyo, 1993.
10. Fisher-Vanden, K. A., Shukla, P. R., Edmonds, J. A., Kim, S. H. and Pitcher, H. M., Carbon taxes and India, *Energy Economics*, 1997, **19**, 289–325.
11. Garg, A., Shukla, P. R., Ghosh, D., Kapshe, M. and Nair, R., Future GHG and local emissions for India: Policy links and disjoints. *Mitigation and Adaptation Strategies for Global Change*, Kluwer Academic Publishers, Dordrecht, 2003, vol. 8(1), pp. 71–92.
12. Rana, A. and Shukla, P. R., Energy economy model applications for India: Long-term GHG trends and mitigation costs. In *Climate Change Economics and Policy: Indian Perspectives* (ed. Toman, M.), Resources for the Future Publication, Washington DC, 2003.
13. Manne, A. S. and Wene, C. O., *MARKAL-MACRO: A Linked Model for Energy – Economy Analysis*, BNL-47161, Brookhaven National Laboratory, Upton, New York, 1992.
14. Loulou, R., Shukla, P. R. and Kanudia, A., *Energy and Environment Strategies for a Sustainable Future: Analysis with the Indian MARKAL Model*, Allied Publishers, New Delhi, 1997.
15. Kanudia, A. and Shukla, P. R., Modelling of uncertainties and price elastic demands in energy–environment planning for India, *OMEGA. Int. J. Manage. Sci.*, 1998, **26(3)**, 409–423.
16. Kainuma, M., Matsoka, Y. and Morita, T. (eds), *Climate Policy Assessment – Asia-Pacific Integrated Model (AIM) Applications*, Springer–Verlag, Tokyo, 2002.
17. Matsuoka, Y., Kainuma, M. and Morita, T., Scenario analysis of global warming using the Asian Pacific integrated model (AIM). *Energy Policy*, 1995, **23(4/5)**, 357–371.
18. Morita, T., Kainuma, M., Harasawa, H., Kai, K., Kun, L. D. and Matsuoka, Y., Asian-Pacific integrated model for evaluating policy options to reduce greenhouse gas emissions and global warming impacts. AIM Interim Paper, National Institute for Environmental Studies, Tsukuba, Japan, 1994.
19. Edmonds, J. and Reilly, J., *Global Energy: Assessing the Future*, Oxford University Press, New York, 1985.
20. Garg, A. and Shukla, P. R., *Emissions Inventory of India*, Tata McGraw-Hill, New Delhi, 2002.
21. Shukla, P. R., Garg, A., Kapshe, M. and Nair, R., India's non-CO_2 GHG emissions: Development pathways and mitigation flexibility. *Energy J.* (forthcoming), 2005.
22. Wigley, T., Edmonds, J. and Richels, R., Economic and environmental choices in the stabilization of atmospheric CO_2 concentrations. *Nature*, 1996, **379,** 240–243.
23. Edmonds, J. A., Clarke, J. F., Dooley, J. J., Kim, S. H. and Smith, S. J., Stabilization of CO_2 in a B2 World: Insights on the roles of carbon capture and storage, hydrogen, and transportation technologies. *Energy Economics*, 25, *Special Issue* (eds Weyant, J., and Tol, R.), 2003.
24. Global Energy Technology Strategy Project for Addressing Climate Change – An Initial Report of an International Public–Private Collaboration, Battelle Memorial Institute, Washington DC, 2001.
25. Brenkert, A. L., Smith, S. J., Kim, S. H., Pitcher, H. M.,. Model documentation for the MiniCAM, PNNL–14337, Pacific Northwest National Laboratory, Richland, WA, 2003 @ http://www.pnl.gov/gtsp/publications/pub_2003.stm
26. Edmonds, J. and Clarke, L., Endogeneous technological change in long-term emissions and stabilization scenarios, presented at the IPCC Expert Meeting on Emissions Scenarios, Washington DC, January 2005.
27. Rose, A., Reducing conflict in global warming policy: Equity as a unifying principle. *Energy Policy*, 1990, **18**, 927–935.
28. Hyder, T. O., *Climate Negotiations: The North/South Perspective* (ed Mintzer, I.), National Academy Press, Washington DC, 1992.
29. Hayes, P., North–south transfer. In *The Global Greenhouse Regime: Who Pays?* (eds Hayes, P. and Smith, K. R.), Earthscan Publishers, London, 1993, pp. 144–168.
30. Rose, A. and Stevens, B., The efficiency and equity of marketable permits for CO_2 emissions. *Resources Energy Econ.*, 1993, **15**, 117–146.
31. Banuri, T., Goran-Maler, K., Grubb, M., Jacobson, H. K. and Yamin, F., Equity and social considerations. In *Climate Change 1995: Economic and Social Dimensions of Climate Change* (eds Bruce, J. P., Lee, H. and Haites, E.), Cambridge University Press, Cambridge, 1996, pp. 79–124.
32. Shukla, P. R. (ed.), Justice, equity and efficiency in climate change: A developing country perspective. In *Fair Weather: Equity Concerns in Climate Change – Ference Toth*, Earthscan Publications, London, 1999.
33. Chichilinsky, G. and Hea, G., Who should abate carbon emissions? An international viewpoint. *Econ. Lett.*, 1994, **44**, 443–449.
34. Kverndokk, S., Tradable CO_2 emission permits: Initial distribution as a justice problem. *Environmental Values*, 1995, **4**, 129–48.
35. United Nations Framework Convention on Climate Change (UNFCCC), Kyoto Protocol to the United Nations Framework Convention on Climate Change. United Nations, 1997.
36. Heller, T. and Shukla, P. R., Development and climate – Engaging developing countries. In Beyond Kyoto – Advancing the international effort against climate change, Report, The Pew Center on Global Climate Change, Washington DC, December, 2003.
37. Chandler, W., Schaffer, R., Dadi, Z., Shukla, P. R., Tudela, F., Davidson, O. and Alpan-Atamar, S., Climate change mitigation in developing countries. Report, The Pew Center on Global Climate Change, Washington DC, October, 2002.
38. India's Initial National Communication to the United Nation's Framework Convention on Climate Change, Government of India Ministry of Environment and Forests, New Delhi, June, 2004.
39. Geller, H., Schaeffer, R., Szklo, A. and Tolmasquim, M., Policies for advancing energy efficiency and renewable energy use in Brazil. *Energy Policy*, 2004, **32**, 1437–1450.
40. Report of The Committee on Development of Bio-Fuel, Planning Commission, Government of India, New Delhi, 2003.
41. Arthur, W. B., Ermoliev, Y. M. and Kaniovski, Y. M., Path dependence processes and the emergence of macro-structure. *Eur. J. Op. Res.*, 1987, **30**, 294–303.
42. Ruttan, V. W., The new growth theory and development economics: A survey. *J. Dev. Studies*, 1998, **35**, 1–26.
43. Hourcade, J. C., Modelling long run scenarios – Methodology lessons from a perspective study on a low CO_2 intensity country. *Energy Policy*, 1993, **21(3)**, 309–325.
44. Nivola, P. S., *Laws of the Landscape: How Policies Shape Cities in Europe and America*, Brookings Institution Press, Washington, DC, USA, 1999, vol. 126, pp. 32
45. Newman, P. W. G. and Kenworthy, J. R., *Cities and Automobile Dependence – An International Sourcebook*, Avebury Technical Publishing, Aldershot, UK, 1991.
46. Müller, B., Equity in climate change – The great divide, *Climate Asia*, COP8 Special Issue, 2002.
47. Yohe, G., Mitigative capacity – the mirror image of adaptive capacity on the emissions side: An editorial. *Climatic Change*, 2001, **49**, 247–262.
48. Initial national communication under the United Nations Framework Convention on Climate Change, Government of Republic of South Africa, Department of Environmental Affairs and Tourism, Pretoria, October, 2000.
49. Secretaria de Políticas y Programas de Investigación y Desarrollo (SEPED), Brazil's Initial National Communication to the United

Nation's Framework Convention on Climate Change, Government of Brazil, Brasilia, November, 2004.
50. Burton, I., Huq, S. l, Lim, Bo, Pilisova, Olga, Schipper, and Emma L., From impacts assessment to adaptation priorities: the shaping of adaptation policy. *Climate Policy*, 2002, **2**, 145–159.
51. Dang, H. H., Michaelowa, A. and Tuan, D. D., Synergy of adaptation and mitigation strategies in the context of sustainable development: The case of Vietnam, *Climate Policy*, 2003, **3S1**, S81–S96.
52. Kapshe, M., Shukla, P. R. and Garg, A., Climate change impacts on infrastructure and energy systems. In *Climate Change and India: Vulnerability Assessment and Adaptation* (eds Shukla, P. R, Sharma, S. K, Ravindranath, N. H., Bhattacharyya, S. and Garg, A.), Universities Press, Hyderabad, 2003, pp. 291–325.
53. Shukla, P. R., Sharma, S. K., Ravindranath, N. H., Bhattacharyya, S. and Garg, A. (eds), *Climate Change and India: Vulnerability Assessment and Adaptation*, Universities Press, Hyderabad, 2003.
54. Masera, O., Ceron, A. D. and Ordonez, A., Forestry mitigation options for Mexico: Finding synergies between national sustainable development priorities and global concerns. In *Mitigation and Adaptation Strategies for Global Change* 6, Kluwer Academic Publishers, The Netherlands, 2001, pp. 291–312.
55. Ravindranath, N. H., Sudha, P. and Rao, S., Forestry for sustainable biomass production and carbon sequestration in India. *Mitigation and Adaptation Strategies for Global Change* 6, Kluwer Academic Publishers, The Netherlands, 2001, pp. 233–256.
56. Asquith, N. M., María Teresa Vargas Ríos and Smith, J., Can forest-protection carbon projects improve rural livelihoods? Analysis of the Noel Kempff Mercado Climate Action Project, Bolivia, *Mitigation and Adaptation Strategies For Global Change* 7, Kluwer Academic Publishers, The Netherlands, 2002, pp. 323–337.
57. Heller, T. and Shukla, P. R., Financing the climate-friendly development pathway: with illustrative case studies from India. Paper presented at Workshop on 'Development and Climate' organized by RIVM, The Netherlands and Indian Institute of Management, Ahmedabad (IIMA), New Delhi, September, 2004.
58. World Development Report 2003, Sustainable Development in a Dynamic World, Transforming Institutions, Growth and Quality of Life. World Bank, Washington DC, USA, 2003, pp. 250.

ACKNOWLEDGEMENTS. The author gratefully acknowledges APN CAPaALE project, AIM Project and UNEP, RISO Center's 'Development and Climate' project for support leading to this research. The paper benefited from the joint research and interactions with Asia–Pacific Integrated Model (AIM) team from NIES, Japan; Global Technology Strategy Project of Battelle, PNNL, USA; Program on Energy and Sustainable Development, at Institute of International Studies, Stanford University and Energy Modelling Forum, Stanford University. The author has benefited immensely from joint modelling work, discussions and insights on the theme, over the years, with Dr Jae Edmonds, Dr Kirsten Halsnaes, Prof. Thomas Heller, Dr Jean Charles Hourcade, Dr Mikino Kainuma, Dr. Nebosja Nakicenovic, Dr Richard Richels, Dr Ronald Sands, Prof. John Weyant, and several other eminent researchers, to whom the author is grateful. The paper draws from the work of numerous co-researchers with whom author had the privilege to work, especially Dr Amit Garg, Prof. Manmohan Kapshe, Dr Rajesh Nair and Dr Ashish Rana. Notwithstanding the benefits of association with these eminent researchers, the responsibility for the contents solely rests with the author.