Climate change, sustainable development and India: Global and national concerns

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Climate change is one of the most important global environmental challenges, with implications for food production, water supply, health, energy, etc. Addressing climate change requires a good scientific understanding as well as coordinated action at national and global level. This paper addresses these challenges. Historically, the responsibility for greenhouse gas emissions' increase lies largely with the industrialized world, though the developing countries are likely to be the source of an increasing proportion of future emissions. The projected climate change under various scenarios is likely to have implications on food production, water supply, coastal settlements, forest ecosystems, health, energy security, etc. The adaptive capacity of communities likely to be impacted by climate change is low in developing countries. The efforts made by the UNFCCC and the Kyoto Protocol provisions are clearly inadequate to address the climate change challenge. The most effective way to address climate change is to adopt a sustainable development pathway by shifting to environmentally sustainable technologies and promotion of energy efficiency, renewable energy, forest conservation, reforestation, water conservation, etc. The issue of highest importance to developing countries is reducing the vulnerability of their natural and socio-economic systems to the projected climate change. India and other developing countries will face the challenge of promoting mitigation and adaptation strategies, bearing the cost of such an effort, and its implications for economic development.

Keywords: Adaptation, costs, India, mitigation, vulnerability.

CLIMATE change is one of the most important global environmental challenges facing humanity with implications for food production, natural ecosystems, freshwater supply, health, etc. According to the latest scientific assessment, the earth's climate system has demonstrably changed on both global and regional scales since the pre-industrial era. Further evidence shows that most of the warming (of 0.1°C per decade) observed over the last 50 years, is attributable to human activities[1]. The Intergovernmental Panel on Climate Change (IPCC) projects that the global mean temperature may increase between 1.4 and 5.8 degrees Celsius (C) by 2100. This unprecedented increase is expected to have severe impacts on the global hydrological system, ecosystems, sea level, crop production and related processes. The impact would be particularly severe in the tropical areas, which mainly consist of developing countries, including India.

The climate change issue is part of the larger challenge of sustainable development. As a result, climate policies can be more effective when consistently embedded within broader strategies designed to make national and regional development paths more sustainable. The impact of climate variability and change, climate policy responses, and associated socio-economic development will affect the ability of countries to achieve sustainable development goals. The pursuit of these goals will in turn affect the opportunities for, and success of, climate policies. In particular, the socio-economic and technological characteristics of different development paths will strongly affect emissions, the rate and magnitude of climate change, climate change impacts, the capability to adapt, and the capacity to mitigate.

The UN Conference on Environment and Development (UNCED) in 1992 at Rio de Janeiro led to FCCC (Framework Convention on Climate Change), which laid the framework for the eventual stabilization of greenhouse gases in the atmosphere, recognizing the common but differentiated responsibilities and respective capabilities, and social and economic conditions. The Convention came into force in 1994. Subsequently, the 1997 Kyoto protocol, which came into force in 2005, reasserted the importance of stabilizing greenhouse gas concentrations in the atmosphere and adhering to sustainable development principles. The Protocol laid out guidelines and rules regarding the extent to which a participating industrialized country should reduce its emissions of six greenhouse gases – carbon dioxide, methane, nitrous oxide, chlorofluorocarbon, hydrofluorocarbons and perfluorocarbons. It requires industrialized countries (listed as Annex B countries in the Protocol) to reduce their greenhouse gas emissions by a weighted average of 5.2%, based on the 1990 greenhouse gas emissions. The reduction is to be achieved by the end of the five-year period, 2008 to 2012. The Kyoto Protocol does not require the developing countries to reduce their greenhouse gas emissions.

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Climate change problem and the controversy

The Kyoto reduction, by itself, is inadequate to achieve a stabilization of climate change by 2100. A continual and larger reduction, similar to that stipulated in the Kyoto Protocol for the 2008–2012 period, will be needed in the future in order to begin to stabilize long-term greenhouse gas emissions. Even if stabilization of greenhouse gases is achieved, global warming will still continue for several decades and sea levels will continue to rise for several centuries. IPCC studies make it abundantly clear, however, that industrialized countries alone cannot achieve this reduction. Even if their emissions were reduced to zero in the near future, the current trends of growing emissions from developing countries alone could force the atmospheric concentration to exceed stabilization levels of 550 ppm. The participation of all countries, including the developing countries such as India, is essential for a successful worldwide effort to arrest the growth of greenhouse gas emissions.

What is the best method to justly and equitably distribute the burden of stabilizing climate change among the countries? This issue lies at the heart of much of the ongoing negotiations under the auspices of the UNFCCC. India, the fifth largest emitter of greenhouse gases from fossil fuel in the 1990s, has suggested that the 'right' to pollute the atmosphere be apportioned to all countries on the basis of their population. Using this gauge, China and India, the only countries with populations in excess of a billion each, could legitimately emit greenhouse gases to a greater extent, than other countries with lesser population, for some decades. But, as their greenhouse gas emissions today are less than this proposed allocation, they could 'sell' some of the 'rights' to the industrialized countries. Countries usually propose burden-sharing formulae that favour their economies, and other countries have suggested schemes based on inherited and future emissions, a country's contribution to temperature change, GDP, and land area and other resource endowments.

In the global climate change debate, the issue of largest importance to developing countries is reducing the vulnerability of their natural and socio-economic systems to projected climate change. Their concerns include increasing food security, reducing freshwater scarcity, protecting the livelihoods of forest dwellers, dry land farmers and coastal settlements and reducing health risks. Though there is a visible shift in the global discussions towards adaptation at the Climate Convention-related meetings, the focus continues to be on mitigation of greenhouse gas emissions. Adaptation can complement mitigation as a cost-effective strategy to reduce climate change risks.

The impact of climate change is projected to have different effects within and between countries. Developing countries have to carefully evaluate the need for, and the roles of global and national institutions in promoting both mitigation and adaptation programmes. Mitigation and adaptation actions can, if appropriately designed, advance sustainable development and equity both within and across countries and between generations. The pervasiveness of inertia and the possibility of irreversibility in the consequences of the interactions among climate, ecological and socio-economic systems are major reasons why anticipatory adaptation and mitigation actions are beneficial. Thus, the inertia and uncertainty imply that targets and timetables must be fixed for avoiding dangerous levels of interference in the climate system. A number of opportunities to exercise adaptation and mitigation options may be lost if action is delayed[1].

Factors contributing to climate change – GHG emissions

The global carbon cycle involves interaction among the atmosphere, oceans, soils and vegetation and fossil fuel deposits. The oceans contain 39,000 giga tonnes of carbon (GtC), fossil fuel deposits about 16,000 GtC, soils and vegetation about 2500 GtC, and the atmosphere about 760 GtC[2]. Since 1850, land-use change is estimated to have released about 136 GtC and fossil fuel combustion, about 270 GtC. Of this, 180 GtC has ended up in the atmosphere, while 110 GtC has been absorbed by growing vegetation and the remainder by the oceans. It is the increasing concentration of atmospheric CO_2 that is the cause for concern about global climate change.

The combustion of fossil fuels and other human activities are the primary reasons for increased concentrations of CO_2 and other greenhouse gases. Between 1990 and 1999, an estimated 6.3 GtC/year was released due to the combustion of fossil fuels, and another 1.6 GtC/year was released due to the burning of forest vegetation. This was offset by the absorption of 2.3 GtC/year each by growing vegetation and the oceans. This left a balance of 3.3 GtC/year in the atmosphere[3]. Controlling the release of greenhouse gases from fossil fuel combustion, land-use change and the burning of vegetation are therefore obvious opportunities for reducing greenhouse gas emissions. Reducing greenhouse gas emissions can lessen the projected rate and magnitude of warming and sea level rise. The greater the reductions in emissions and the earlier they are introduced, the smaller and slower the projected warming and the rise in sea levels. Future climate change is thus determined by historic, current and future emissions.

Of the six aforementioned GHGs, CO_2 accounted for 63%, methane 24%, nitrous oxide 10%, and the other gases the remaining 3% of the carbon equivalent emissions in 2000. Thus in addition to CO_2, global mitigation efforts need to focus on the two largest and rapidly increasing GHGs.

Contribution of industrialized and developing countries

Historically, the industrialized countries have been the primary contributors to emissions of CO_2. According to one estimate, industrialized countries are responsible for about 83% of the rise in cumulative fossil fuel related CO_2 emissions[4] since 1800. In the 1990s, they accounted for about 53% of the 6.3 GtC/year, which was released as CO_2 from fossil fuel combustion. These countries have contributed little to the release of CO_2 from the burning of vegetation, which is largely due to tropical deforestation during this period. According to another estimate, developing countries accounted for only 37% of cumulative CO_2 emissions from industrial sources and land-use change during the period 1900 to 1999 (Figure 1), whereas industrialized countries accounted[5] for 63%, but because of their higher population and economic growth rates, the fossil-fuel CO_2 emissions from developing countries are likely to soon match or exceed those from the industrialized countries. Large countries, such as China and India, could match the USA's year 2000 greenhouse gas emissions within two to three decades. Figure 2 shows that when fossil fuel CO_2 emissions alone are considered, due to population and economic growth in the coming decades, the contribution of developing countries as a group will soon overtake the industrialized countries. Historically, the responsibility for emissions increase lies largely with the industrialized world, though the developing countries are likely to be the source of an increasing proportion of future increases.

Impacts of climate change: Implications for developing countries

Developing countries are faced with immediate concerns that relate to forest and land degradation, freshwater shortage, food security and air and water pollution. Climate change will exacerbate the impacts of deforestation and other economic pressures, leading to further water shortages, land degradation and desertification. Increasing global temperatures will result in rising sea levels. Populations that inhabit small islands and/or low-lying coastal areas are at particular risk of severe social and economic disruptions from sea-level rise and storm surges that could destroy cities and disrupt large coastal livelihoods.

The widespread retreat of glaciers and icecaps in the 21st century will also lead to higher surface temperatures on land and increasing water stress. By 2025, as much as two-thirds of the world population, much of it in the developing world, may be subjected to moderate to high water stress. Estimates of the effects of climate change on crop yields are predominantly negative for the tropics, even when adaptation and direct effects of CO_2 on plant processes are taken into consideration. Ecological productivity and biodiversity will be altered by climate change and sea-level rise, with an increased risk of extinction of some vulnerable species.

Even though the ability to project regional differences in impact is still emerging, the consequences of climate change are projected to be more drastic in the tropical regions. This is true for all sectors that are likely to bear the brunt of climate change – sea level, water resources, ecosystems, crop production, fisheries, and human health. The populations of the developing world are more vulnerable as their infrastructure is not strong and extensive enough to withstand a deleterious impact.

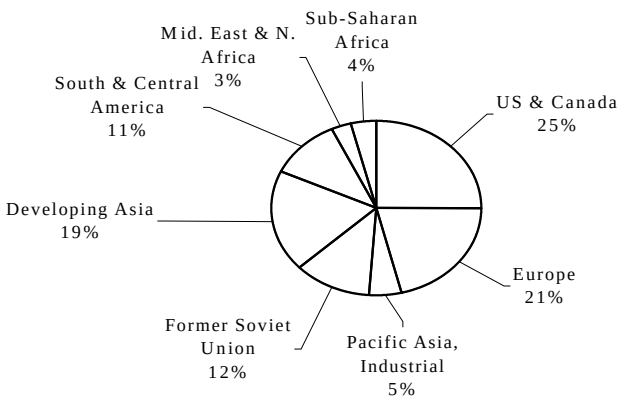

Figure 1. Per cent cumulative global CO_2 emissions from industrial sources and land-use change during 1900–1999.

Role of developing and industrialized countries in addressing climate change: Mitigation and adaptation

In the global climate change debate, the issue of largest importance to developing countries is reducing the vulnerability of their natural and socio-economic systems to projected climate change. Over time, there has been a visible shift in the global climate change discussions towards adaptation. Adaptation can complement mitigation as a cost-effective strategy to reduce climate change risks. The impact of climate change is projected to have different effects within and between countries. Mitigation and adaptation actions can, if appropriately designed, advance sustainable development and equity both within and across countries and between generations.

One approach to balancing the attention on adaptation and mitigation strategies is to compare the costs and benefits of both the strategies. If adaptation of climate change could be carried out at negligible cost then it may be less expensive, at least in the short-term, than any alternate strategy. Of course, there are complications in establishing the benefits of adaptation policies and consequent avoided damages[6]. Further, there are significant co-benefits of many mitigation and adaptation measures, which need to be estimated. The co-benefits could play a critical role in making decisions regarding the adoption of any mitigation or adaptation strategy.

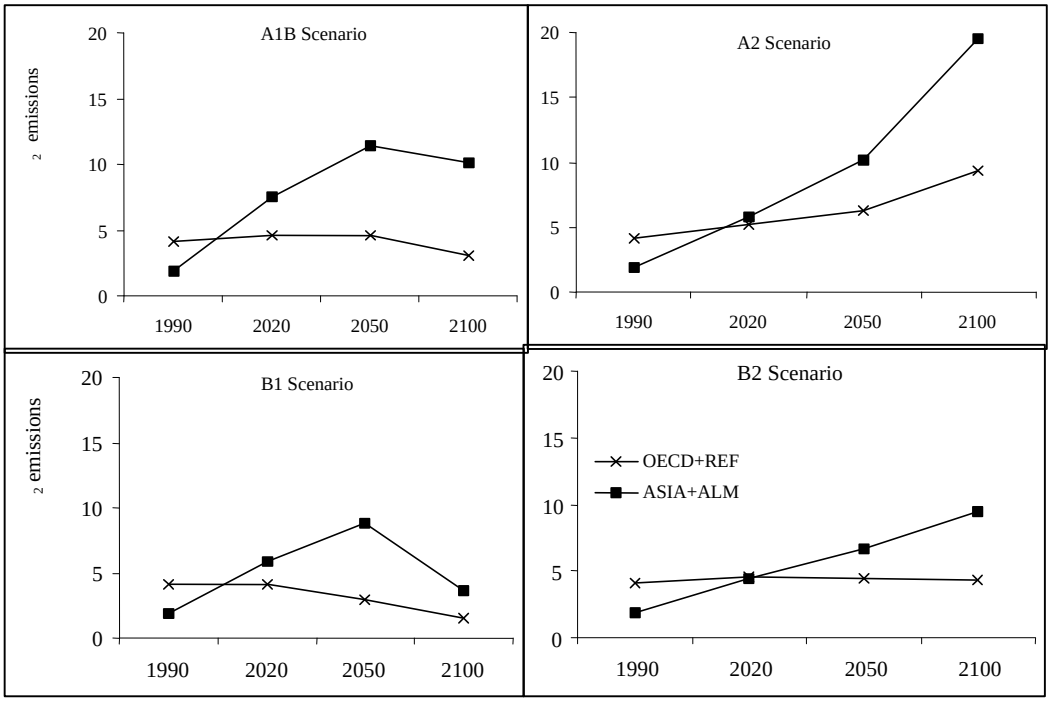

Figure 2. Fossil fuel CO_2 emissions (GtC) in industrialized and developing regions under four SRES marker scenarios. OECD90 region includes countries of the Organization for Economic Co-operation and Development as of 1990. REF region consists of countries undergoing economic reform and groups together in the East and Central European countries and the newly independent states of the former Soviet Union. ASIA region includes all developing countries in Asia (excluding the Middle East). ALM region stands for the rest of the world and corresponds to developing countries in Africa, Latin America and Middle East. Scenarios A1B, A2, B1 and B2 (ref. 29)

The impact of mitigation will only be felt in the long run by the future generations. However, the impacts or benefits of adaptation measures are immediate and felt by the implementers of the measures. The regions implementing the mitigation measures could be different from the regions experiencing its impacts. The current generation of industrialized countries may invest in mitigation measures and the main beneficiaries may be the next generation largely in the developing countries. The choice between mitigation and adaptation strategies has spatial (geographic) and temporal (different generations) dimensions. An optimal mix of mitigation and adaptation strategies may elude the climate negotiations due to the spatial and temporal dimensions, as well as the differing perceptions of industrialized and developing countries. Under the Kyoto Protocol and UNFCCC, developing countries have insisted that Annex-I countries demonstrate commitment by promoting mitigation measures domestically and provide resources for adaptation measures in developing countries[7]. However, over emphasis on adaptation might inhibit concerted mitigation actions by the Annex I governments, as adaptation measures are implemented and rewarded locally. Consequently, there is no incentive to participate in international negotiations, if a country considers itself to be able to fully adapt to climate change[8].

UNFCCC and Kyoto Protocol

In the 1980s, the scientific evidence linking GHG emissions from human activities with the risk of global climate change started to arouse public concern. The United Nations General Assembly responded in 1990 by establishing the Intergovernmental Negotiating Committee for Framework Convention on Climate Change. The UNFCCC held in 1992 at Rio de Janeiro adopted the framework for addressing climate change concerns. The key goal of the Convention is 'stabilization of GHG concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development in a sustainable manner'[9]. Acknowledging the global nature of climate change, the Climate Convention calls for the widest possible cooperation by all countries and their participation in an effective and appropriate international response, in accordance with 'their common but differentiated responsibilities and respective capabilities and their social and economic conditions'.

The UN Conference of Parties held in Kyoto in 1997 adopted the Kyoto Protocol as the first step towards address-

ing climate change. The Protocol shares the Convention's objective, principles and institutions, but significantly strengthens the Convention by committing Annex I Parties to individual, legally-binding targets to limit or reduce their GHG emissions. To achieve the goals of the Climate Convention, the Kyoto Protocol broke new ground by defining three innovative 'flexibility mechanisms' to lower the overall costs of achieving its emissions targets. These mechanisms enable Parties to access cost-effective opportunities to reduce emissions or to remove carbon from the atmosphere in other countries. While the cost of limiting emissions varies considerably from region to region, the benefit for the atmosphere is the same, wherever the action is taken. Much of the negotiations on the mechanisms have been concerned with ensuring their integrity. The three Kyoto mechanisms are as follows:

- *Joint Implementation (JI)* under Article 6 provides for Annex I Parties to implement projects that reduce emissions, or remove carbon from the atmosphere, in other Annex I Parties, in return for emission reduction units (ERUs).
- *Clean Development Mechanism (CDM)* defined in Article 12 provides for Annex I Parties to implement projects that reduce emissions in non-Annex I Parties, or absorb carbon through afforestation or reforestation activities, in return for certified emission reductions (CERs) and assist the host Parties in achieving sustainable development and contributing to the ultimate objective of the Convention.
- *Emissions Trading (ET)*, as set out in Article 17, provides for Annex I Parties to acquire certified emission reduction units from other Annex I Parties.

Among the above three mechanisms, only CDM is relevant to developing countries such as India. Developing countries could view CDM as an opportunity not only to attract investment capital and Environmentally Sustainable Technologies (ESTs) but also to implement innovative technical, institutional and financial interventions to promote energy efficiency, renewable energy and forestry activities that contribute to sustainable development. Projects specially designed and implemented in developing countries under CDM, leading to carbon emission reduction or sequestration will receive payments from institutions and agencies in Annex B (Annex I countries with commitment to reduce GHG emissions) countries for every tonne of carbon emission avoided or sequestered. CDM has been a contentious issue with diverse perceptions[10]. According to one perception, it provides an opportunity for developing countries to access modern ESTs and receive financial incentives to overcome the barriers. According to another perception, developing countries may lose the low cost mitigation options to industrialized countries, while leaving behind only more expensive ones to pursue, should they take on commitments in the future to limit their GHG emissions. Further, countries using CDM, to the extent of their dependence on this mechanism, need not reduce fossil fuel CO_2 emissions domestically and their national GHG emissions, instead of declining, may remain stable or even increase.

Why should India be concerned about climate change?

India is a large developing country with nearly 700 million rural population directly depending on climate-sensitive sectors (agriculture, forests and fisheries) and natural resources (such as water, biodiversity, mangroves, coastal zones, grasslands) for their subsistence and livelihoods. Further, the adaptive capacity of dry land farmers, forest dwellers, fisher folk, and nomadic shepherds is very low[10]. Climate change is likely to impact all the natural ecosystems as well as socio-economic systems as shown by the National Communications Report of India to the UNFCCC[11].

The latest high resolution climate change scenarios and projections for India, based on Regional Climate Modelling (RCM) system, known as PRECIS developed by Hadley Center and applied for India using IPCC scenarios A2 and B2[12] shows the following:

- An annual mean surface temperature rise by the end of century, ranging from 3 to 5°C under A2 scenario and 2.5 to 4°C under B2 scenario, with warming more pronounced in the northern parts of India.
- A 20% rise in all India summer monsoon rainfall and further rise in rainfall is projected over all states except Punjab, Rajasthan and Tamil Nadu, which show a slight decrease.
- Extremes in maximum and minimum temperatures are also expected to increase and similarly extreme precipitation also shows substantial increases, particularly over the west coast of India and west central India.

Some of the projected impacts of climate change in India[11] are as follows:

Water resources

The hydrological cycle is likely to be altered and the severity of droughts and intensity of floods in various parts of India is likely to increase. Further, a general reduction in the quantity of available run-off is predicted.

Agriculture

Simulations using dynamic crop models indicate a decrease in yield of crops as temperature increases in different

parts of India. However, this is offset by an increase in CO_2 at moderate rise in temperature and at higher warming, negative impact on crop productivity is projected due to reduced crop durations.

Forests

Climate impact assessments using BIOME-3 model and climate projections for the year 2085 show 77% and 68% of the forested grids in India are likely to experience shift in forest types under A2 and B2 scenario, respectively. Indications show a shift towards wetter forest types in the northeastern region and drier forest types in the northwestern region in the absence of human influence. Increasing atmospheric CO_2 concentration and climate warming could also result in a doubling of net primary productivity under the A2 scenario and nearly 70% increase under the B2 scenario[13].

Coastal zone

Simulation models show an increase in frequencies of tropical cyclones in the Bay of Bengal; particularly intense events are projected during the post-monsoon period. Sea level rise is projected to displace populations in coastal zones, increase flooding in low-lying coastal areas, loss of crop yields from inundation and salinization.

Human health

Malaria is likely to persist in many states and new regions may become malaria-prone and the duration of the malaria transmission windows is likely to widen in northern and western states and shorten in southern states.

Desertification

Globally, about 1900 Mha of land are affected by land degradation, of which 500 Mha each are in Africa and the Asia-Pacific and 300 Mha in Latin America. Climate change leading to warming and water stress could further exacerbate land degradation, leading to desertification. The United Nations Convention to Combat Desertification (UNCCD) aims to address the problem of land degradation, which is linked to climate change.

It is important to note that the climate-sensitive sectors (forests, agriculture, coastal zones) and the natural resources (groundwater, soil, biodiversity, etc.) are already under stress due to socio-economic pressures. Climate change is likely to exacerbate the degradation of resources and socio-economic pressures. Thus, countries such as India with a large population dependent on climate-sensitive sectors and low adaptive capacity have to develop and implement adaptation strategies.

Contribution of India to global GHG emissions and build up – Past, current and future

In recent years, the development planning in India has increasingly incorporated measurable goals for enhancement of human well being, beyond mere expansion of production of goods and services and the consequent growth of per capita income. Many developmental targets[14,15] are even more ambitious than the UN Millennium Development Goals[16]; several of which are directly or indirectly linked to energy and therefore to GHG emissions. India holds over 1 billion people, i.e. over 16% of global population. Endowed with coal, India's energy system has evolved around coal. India's share in global CO_2 emissions is still very small (Table 1).

The contribution of India to the cumulative global CO_2 emissions from 1980 to 2003 is only 3.11%. Thus historically and at present India's share in the carbon stock in the atmosphere is relatively very small when compared to the population. India's carbon emissions per person are twentieth of those of the US and a tenth of most Western Europe and Japan (Figure 3).

Table 1. Share in global CO_2 emissions (%)

	1990	2003
United States	23.04	23.06
China	10.41	14.07
Russia[1]	9.67	6.38
Japan	4.54	4.79
India	2.63	4.07
Germany[2]	4.24	3.35
Canada	2.19	2.39
United Kingdom	2.76	2.24
Italy	1.91	1.85
France	1.80	1.63
Rest of World	38.61	36.17

[1]Russia 1990 numbers are for 1992.
[2]Germany 1990 numbers are for 1991.
Source: Based on data from USDOE[27].

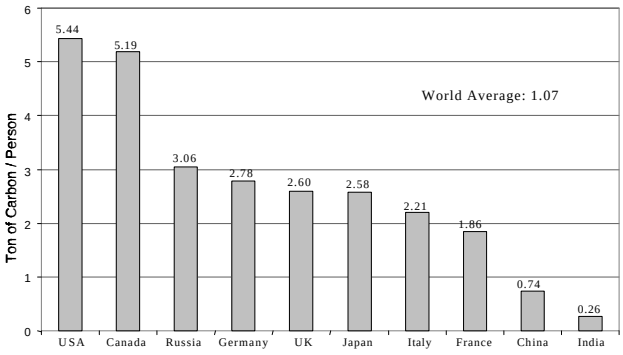

Figure 3. Per capita carbon emissions from energy for the year 2003 (ref. 27).

The endogenous responses generated to achieve the 'development goals' are the key factors shaping the economic growth, endogenous technological change and consumption preferences that drive the energy and emissions trends. The goal of providing universal access to electricity, for instance, from the present fifty-five per cent coverage, has vital implications for development and greenhouse gas emissions. The policies to achieve 'development goals' could deliver double dividends[17] for economies that are below the production frontier. In India's case the recent history and the trends show that the economic reforms are enlarging choices that are delivering double dividends, as is evident from the declining trend of energy, electricity and carbon intensities of the Indian economy (Figure 4).

Cost of addressing and not addressing climate change for India

India has potential to supply substantial mitigation at a relatively low price. Major opportunities exist both on the supply and demand side of energy, in case of carbon emissions. There are also low cost opportunities for mitigation of methane and nitrous oxide. As Table 2 shows, in the short-run, till the Kyoto Protocol period, substantial potential of mitigation of carbon, methane and nitrous oxides exist at costs below $30 per tonne of carbon equivalent (or $8 per tonne of carbon dioxide equivalent), which is below the prevailing price of traded carbon in European market. In the long run, the results of the modelling exercises show that India, between 2005 and 2035, could supply cumulative 5 billion tonne of carbon equivalent mitigation from the energy options at price below $10 per tonne of carbon equivalent (Figure 5). The low mitigation cost potential is also evident from the sizable CDM projects being proposed from India in recent times.

Together with mitigation, UNFCCC also emphasizes adaptation; its Article 4(4) exhorting to assist particularly vulnerable developing country parties in meeting the costs of adaptation to the adverse effects of climate change. The 'Marrakech Accords' have established the Adaptation Fund as an instrument for implementing this requirement in the future. The 'Buenos Aires Programme of Work on Adaptation and Response Measures' adopted by COP10 in 2004, aims to step up the implementation and funding of targeted adaptation activities, as well as activities to address the impact of the implementation of response measures, in developing country parties.

These measures notwithstanding, adaptation has received less attention than mitigation in the climate regime. Adaptation is a private or local public good, whereas mitigation is a global public good. The individuals or communities bear the risk wherever there is undersupply of adaptation measures. Adaptation costs are the insurance payments and the costs of not addressing adaptation are the damages from unmitigated climate risks.

India is a large developing country with diverse climatic zones. The livelihood of vast population depends on climate-sensitive economic sectors like agriculture, forestry and fisheries. The climate change vulnerability and impact studies in India[18] assume high degree of uncertainty in the assessment due to '… limited understanding of many critical processes in the climate system, existence of multiple climatic and non-climatic stresses, regional-scale variations and nonlinearity …'. The costs of not addressing climate change or to adapt to it are very uncertain, but their welfare consequences are enormous. Early actions on adaptation therefore are prudent and consistent from the viewpoint of 'precautionary principle'.

The future regime architecture can reduce the climate burden by giving greater emphasis to adaptation, e.g. via an Adaptation Protocol, whereby mandatory funding by industrialized countries could support adaptation activities in developing countries. Additional policy options like

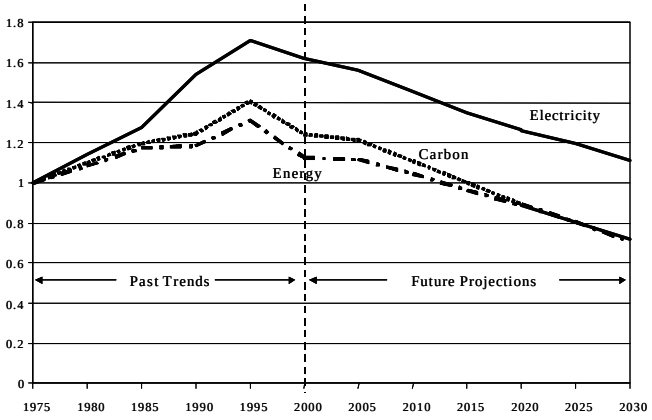

Figure 4. GDP intensities of energy, electricity and carbon for IA2 scenario (ref. 30).

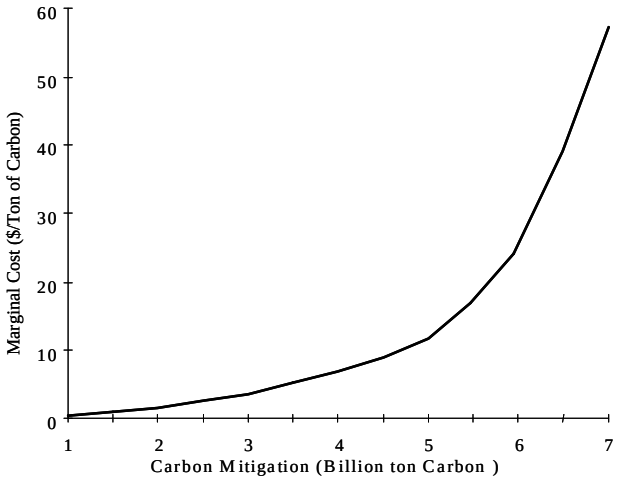

Figure 5. Carbon mitigation supply curve for India for the period 2005–2035 (based on modelling exercises reported in refs 30–32).

Table 2. Mitigation options, potential and costs

Greenhouse gas	Mitigation options	Mitigation potential 2002–2012 (million tonne)	Long-term marginal cost ($/tonne of carbon equivalent)
Carbon	Demand-side energy efficiency	45	0–15
	Supply-side energy efficiency	32	0–12
	Electricity T&D	12	5–30
	Renewable electricity technologies	23	3–15
	Fuel switching – gas for coal	8	5–20
	Forestry	18	5–10
Methane	Enhanced cattle feed	0.66	5–30
	Anaerobic manure digesters	0.38	3–10
	Low methane rice varieties	Marginal	5–20
	Cultivar practices	Marginal	0–20
Nitrous oxide	Improved fertilizer application	Marginal	0–20
	Nitrification inhibitors	Marginal	20–40

Source: Chandler *et al*.[28].

support for adaptation planning and implementation, creation of a public–private insurance mechanism and alignment of climate funds and development assistance can be deployed for gaining added benefits.

Addressing climate change and sustainable development

Sustainable development has become part of all climate change policy discussions at the global level, particularly due to adoption of Agenda 21 and the various Conventions resulting from the UNCED-1992. The generally accepted and used definition as given by the Brundtland Commission is 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'[19]. Sustainable development has become an integrating concept embracing economic, social and environmental issues. Sustainable development does not preclude the use of exhaustible natural resources but requires that any use be appropriately offset. This concept is not acceptable to many developing countries since it seems to disregard their aspirations for growth and development. Further, sustainable development cannot be achieved without significant economic growth in the developing countries[20].

Three critical components in promoting sustainable development are economic growth, social equity and environmental sustainability. The question often asked is, should the current economic growth (GNP, employment, etc.) be sacrificed for long-term environmental conservation? Policy makers in developing countries often perceive a trade-off between economic growth and environmental sustainability. However, there is a growing evidence to show that environmental conservation for sustainability of natural resources is not a luxury but a necessity when considering long-term economic growth and development, particularly in the least developed countries. The decline and degradation of natural resources such as land, soil, forests, biodiversity and groundwater, resulting from current unsustainable use patterns are likely to be aggravated due to climate change in the next 25 to 50 years. Africa, South Asia and some regions of Latin America are already experiencing severe land degradation and freshwater scarcity problems[21].

There are many ways to pursue sustainable development strategies that contribute to mitigation of climate change. A few examples are presented below.

- Adoption of cost-effective energy-efficient technologies in electricity generation, transmission distribution, and end-use can reduce costs and local pollution in addition to reduction of greenhouse gas emissions.
- Shift to renewables, some of which are already cost-effective, can enhance sustainable energy supply, can reduce local pollution and greenhouse gas emissions.
- Adoption of forest conservation, reforestation, afforestation and sustainable forest management practices can contribute to conservation of biodiversity, watershed protection, rural employment generation, increased incomes to forest dwellers and carbon sink enhancement.
- Efficient, fast and reliable public transport systems such as metro-railways can reduce urban congestion, local pollution and greenhouse gas emissions.
- Adoption of participatory approach to forest management, rural energy, irrigation water management and rural development in general can promote sustained development activities and ensure long-term greenhouse gas emission reduction or carbon sink enhancement.
- Rational energy pricing based on long-run-marginal-cost principle can level the playing field for renewables, increase the spread of energy-efficient and renewable-energy technologies, and the economic viability of utility companies, ultimately leading to greenhouse gas emission reduction.

Several initiatives are being pursued to measure and report an entity's progress on sustainable development. An example is the Leadership in Energy and Environmental Design (LEED) – a US Green Building Council organization that uses 69-point criteria to award a certificate at platinum, gold and other levels to buildings. Criteria include sustainable sites, water efficiency, energy and atmosphere, materials and resource use, indoor environmental quality, and innovation and design process. As part of this international process, hundreds of buildings have received certification worldwide, including several in India some of which have received the platinum rating.

Another example is the Global Reporting Initiative (GRI), which is a multi-stakeholder process and an independent institution whose mission is to develop and disseminate globally applicable Sustainability Reporting Guidelines. These guidelines are for voluntary use by organizations for reporting on the economic, environmental and social dimensions of their activities, products, and services. Started in 1997, GRI is an official collaborating centre of the United Nations Environment Programme (UNEP) and works in cooperation with UN's Global Compact.

The motivation for using the above types of reporting criteria is diverse. In a recent evaluation of GRI, 85% of the reports addressed climate change, and 74% of respondents identified economic reasons and another 53% ethical reasons for reporting their company's performance to GRI. India's ITC Limited, for example, has won a platinum LEED rating for its Gurgaon building, and also reports its sustainable development performance to GRI as a carbon-positive corporation, i.e. it sequesters more carbon than it emits.

Over time, as indicators and measurement tools become available, the pursuit of sustainable development is moving out of academic discourses, and being put into practice increasingly by institutions and private industry. The trend is likely to strengthen globally as nations come to recognize the limits on access to and development of natural resources.

Future direction of addressing climate change at global level and implications for India

The first commitment period of the Kyoto Protocol ends in 2012. Given the relatively short period to its termination, participating countries have been engaged in several dialogues within the UNFCCC auspices and elsewhere about post-2012 commitments on emissions reductions and adaptation measures. The discussion at these dialogues ranges from mandatory economy-wide targets to sector-specific ones on all countries, to bilateral and/or multilateral agreements to voluntarily reduce GHG emissions. Industrialized countries, except notably US and Australia, already have agreed to adhere to economy-wide targets, and they are keen to continue such an approach post-2012. Others have proposed sector-based approaches that require adoption of voluntary carbon intensity targets for the energy and major industry sectors in all countries. Key questions include: how are sectors defined, how does the voluntary target setting process unfold, are there separate benchmark targets for new and existing facilities within a sector, when and how are reductions generated that can be sold, how will sectoral benchmarks be part of an Annex I country target? Studies[22,23] have tested the use of tools and voluntary approaches for benchmarking energy efficiency and carbon intensity in a variety of industrial sectors in both industrialized and developing countries, and these could form the basis for setting verifiable sectoral targets. A key to making a sector-based approach attractive to developing countries is to create financial incentives to adopt such a target. A combination of technology finance and CDM/trading revenues could serve as one basis for making such targets attractive to developing countries.

Addressing adaptation in a post-2012 international climate regime could be done through the use of insurance-based approaches, mainstreaming and innovative financing mechanisms. There is a growing interest in evaluating the role that innovative insurance mechanisms and other risk-spreading activities may offer in addressing adaptation needs[24]. These options can be structured so that they both help address impacts ex-post, and thereby expedite recovery efforts, and encourage participants to take anticipatory actions that help reduce their vulnerability. Insurance can spread the risk of potential climate change impacts through public–private risk transfer mechanisms, weather-derivatives, catastrophe bonds and micro-insurance. The implications for developing countries with nascent insurance industries, however, need to be better understood.

The ability to adapt to climate change is intertwined with sustainable development and poverty reduction in both a positive and negative sense. In the positive sense, enhancement of adaptive capacity entails a variety of similar actions to sustainable development and poverty reduction (e.g. improved access to resources and improved infrastructure). On the negative side, sustainable development and poverty reduction can be hampered by the impacts of climate change. Further, some sustainable development activities could make countries more susceptible to climate change (so-called maladaptation). Some climate policymakers and development policymakers have supported the need to 'mainstream adaptation' – where adaptation responses are considered and integrated into sustainable development and poverty reduction processes. While in general, most agree that this is an important aspect of adaptation response, its implications for on-the-ground actions need to be addressed.

Since early 1990s, international efforts have created the climate change regime, the centre piece of which is

the UNFCCC and its instruments the Kyoto Protocol and the Marrakech Accords which details rules for the implementation of this protocol and the existing commitments under the UNFCCC relating to funding, capacity-building and technology transfer. These currently existing multilateral instruments by themselves are not adequate to meet the twin challenges of mitigation and adaptation. They do, however, provide a basis for further development of the multilateral regime, if advantage is taken of the political momentum generated by the entry into force of the Kyoto Protocol. The regime development has now reached a crucial stage where continued progress is necessary in order to consolidate the results achieved so far and reduce uncertainty as to the future direction of climate change policy.

In view of the considerable time and effort invested over the past fifteen years in developing a global climate policy regime, it is logical for international cooperation to build on the existing framework. Whereas the regime architecture has in-built flexibility to create efficient emissions mitigation markets, the current framework has remained mired in controversies; it is not universally accepted and has created fragmented mitigation markets that are not cost-effective. Robust and efficient regime architecture would require wider participation and more decisive progress towards achievement of the agreed ultimate objective.

A least resistant and operationally efficient approach is to find interfaces through which climate change needs are integrated with the routine policies, measures and activities which are undertaken daily and sizably by governments and different stakeholders. Countries and stakeholders craft strategies to achieve own goals and objectives, numerous elements of which are amenable to contribute climate goals at little or no cost and sometimes even with positive gains. For developing countries, the climate benign actions are best driven as a part of the sustainable development priorities derived from the Millennium Development Goals and concretized in national development goals and targets. This approach is well articulated in India's Initial National Communications[11]: '*Since the goals of sustainable national development are favorable to the issue of climate change, the achievement of these goals would accrue a double dividend in terms of added climate change benefits. The cascading effects of sustainable development would reduce emissions and moderate the adverse impacts of climate change, and thereby alleviate the resulting loss in welfare*'.

For developing countries, enhancing the economic well being of their citizens remains an urgent and pressing goal. To the extent the new climate architecture would be perceived as a barrier to this, it would be resisted and would fail to garner wide support so necessary for economic efficiency and co-ordination to derive multiple benefits. For coming decades, the GHG emissions per citizen from most developing countries would remain significantly below those in industrialized countries. For most developing countries, this is the century when majority of their citizens are likely to first experience economic prosperity. The next climate regime would succeed to the extent it would create instruments that align to sustainable development goals, activities and processes in these nations.

The science of climate change: role for Indian science

Climate change is a fast emerging science involving physical, biological and social sciences. There has been an explosion of literature on climate science and policy. There are three broad categories of scientific assessment as adopted by the IPCC:

- The science of climate change; climate modelling and projections (Working Group-I).
- Impacts, vulnerability and adaptation to climate change (Working Group-II).
- Mitigation and policies (Working Group-III).

Institutions in the industrialized countries largely dominate research on climate science and policy, particularly climate modelling and projections. Developing countries such as India should take leadership in all the above three types of assessments. The participation of scientific community from developing countries is still limited. For example, the total number of Indian experts participating in the Assessment Report-4 of the IPCC is 5 out of 142 in Working Group-I, 9 out of 178 in Working Group-II and 7 out of 160 in Working Group-III.

India has completed four nationally coordinated assessments of climate change projections, impacts and mitigation; the first being the climate change studies supported by the Asian Development Bank, the second being the ALGAS (Asian Least-Cost Greenhouse Gas Abatement Study) supported by the Global Environment Facility (GEF), the third being climate impact assessment study conducted under the Indo-UK collaborative project and the latest being the National Communications supported by the GEF. Interestingly, the Ministry of Environment and Forests coordinated all the collaborative efforts. The National Communications was one of the successful national level coordinated efforts involving 131 teams from research and educational institutions, covering all the three aspects of climate change; climate projections, impacts and adaptation, and mitigation[11]. The National Communications project has promoted a network of research teams and institutions in India, to address various aspects of climate change. Large developing countries such as India should have long-term Research and Development (R&D) groups working on various aspects of climate change science, particularly the modelling aspects of GHG emissions sce-

narios, climate projections, climate impacts, integrated assessments, adaptation and mitigation.

Some of the critical scientific issues that need to be addressed include the following:

- Many uncertainties continue to limit the ability to detect, attribute and understand the current climate change and to project what future climate changes may be, particularly at the regional level. Further, there is a need to link physical climate-biogeochemical models with models of the human system in order to provide better understanding of possible cause–effect–cause patterns linking human and non-human components of earth systems[3].
- Improved understanding of the exposure, sensitivity, adaptability and vulnerability of physical, ecological and social systems to climate change at regional and local level[25].
- Evaluation of climate mitigation options in the context of development, sustainability and equity at regional, national and global level in different sectors (energy and non-energy)[26].
- To develop sustainable and equitable international protocols, mechanisms and financial arrangements to promote mitigation and adaptation to achieve the goals of Article 2 of the UNFCCC.

India is a large developing country with nearly two-thirds of the population depending directly on the climate-sensitive sectors such as agriculture, fisheries and forests. The projected climate change under various scenarios is likely to have implications on food production, water supply, biodiversity and livelihoods. Thus, India has a significant stake in scientific advancement as well as an international understanding to promote mitigation and adaptation. This requires improved scientific understanding, capacity building, networking and broad consultation processes.

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