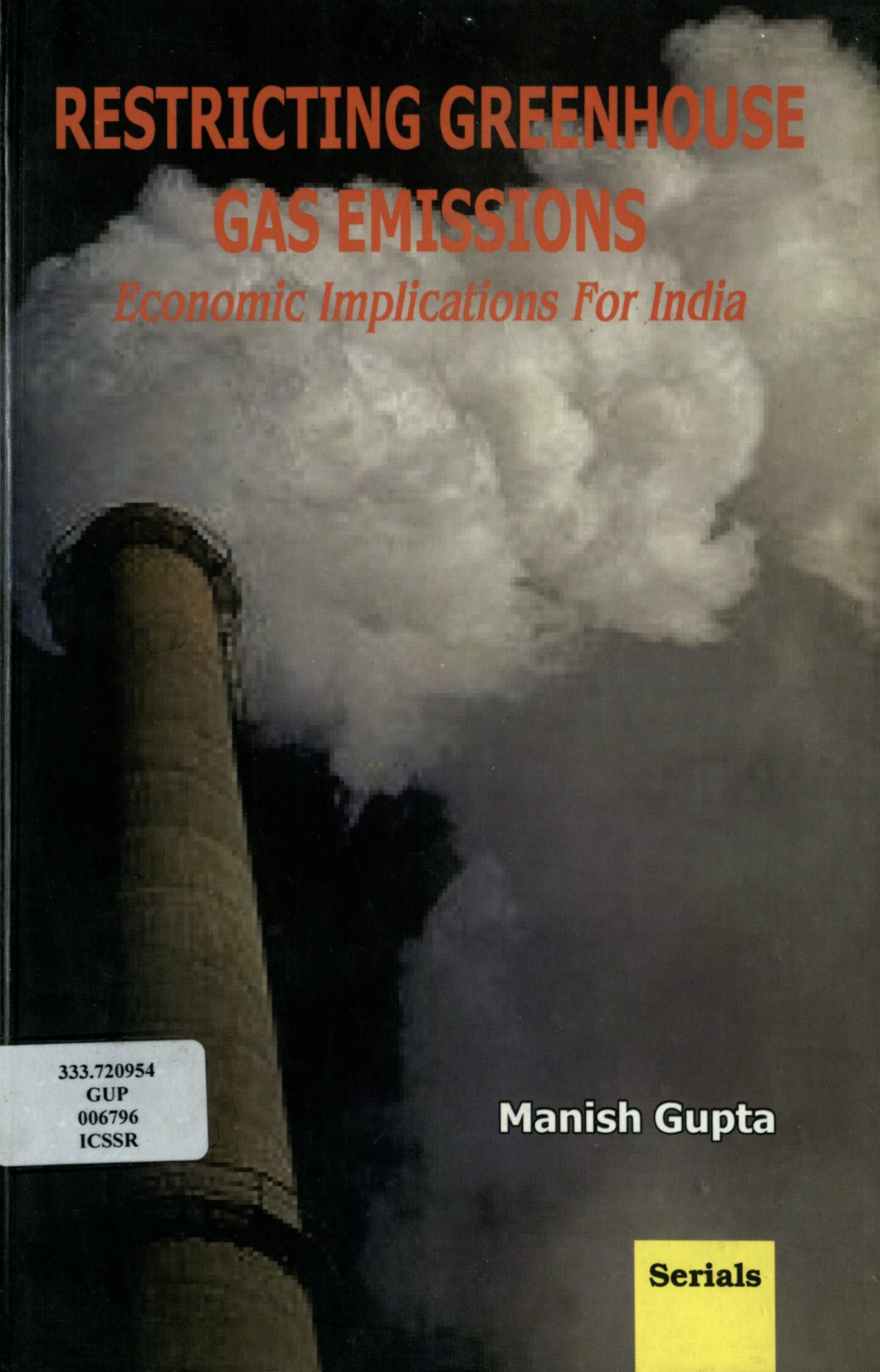
RESTRICTING GREENHOUSE GAS EMISSIONS

Economic Implications For India



Manish Gupta

Serials

With a population of more than one billion, and an economy that is undergoing substantial restructuring and greatly increased economic growth, India has an exceptional stake in the debate about climate change policy. In this context the current volume looks into the economic implications of restricting carbon dioxide emissions for India. It provides an estimate of the economic costs expressed in terms of loss of output, changes in the level of consumption and investment, impact on the level of poverty associated with the reduction in carbon dioxide emissions for a developing country like India. It is hoped that this book would be very useful to the researchers, teachers, and students of resource economics.

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INTRODUCTION

There is a growing scientific consensus that human beings are altering the global environment in potentially significant ways. Nature is used both as a source and as a sink for enhancing human consumption. With the help of science and technology and labour the resources of nature are transformed into products, which are either goods or services, and are used for either consumption or capital formation. After the consumption or capital use, the physical content of the product flows back to the nature as degraded waste. Production and consumption require continuous inflow of resources from nature and in turn release waste into the nature for absorption. If the flow of resources from nature were to stop the economic system would come to a halt. A small portion of solar energy as received in the form of electromagnetic waves is transformed into chemical bond energy through photosynthesis in the biosphere and thereby helps in regenerating some of the resources. If the economic system uses such natural resources at a higher rate than the rate of their regeneration, there will be depletion of stock of natural resources over time. It is essentially the finiteness of the solar energy flow per unit of time that sets a bound on the regenerative capacity of the nature. With the rapid growth of economic system more resources will be required thereby resulting in their scarcity. As people continue their endless quest for new materials, new energy forms, and new processes, the constraints imposed by the depletion of natural resources and the pollution caused by human activity have generated environmental degradation world-wide. Nature recycles all that is generated as wastes in the process of use of natural resources in the human social and economic system. But there is a limit to which it can perform this task of recycling per unit of time. For any ecosystem the upper bound on the rate of flow of solar energy per unit of time imposes a restriction or limit on the absorptive capacity of nature. If the rate of growth of disposal of waste exceeds the rate of its absorption by nature per unit of time, the remaining waste would be deposited in the ecosystem as pollutant. The stock of pollutant would, therefore, accumulate in the ecosystem thereby adversely affecting the productivity of the natural system, human health, and the regenerative function of nature. Greenhouse gas (GHG) emission is one such waste generated by the humans.

The amount of greenhouse gas remaining in the atmosphere (and thus the warming) is determined by the balance between emissions from natural and anthropogenic sources and the amount absorbed in natural and human engendered processes called the sinks. The ocean acts as a sink, mainly through physical and chemical absorption at the surface and also through phytoplanktons (algae) that may fall from the surface to carry carbon into ocean sediments. In fact, any place where photosynthesis results in a net increase in biomass will be classified as a sink. In addition to these, bogs where carbon is being buried, forests where fire causes carbon to be sequestered in soil as charcoal, places where soil carbon is growing and many other wide spread phenomena acts as sinks. There is a limit up to which these sinks can absorb carbon. If the rate of emission of these greenhouse gases exceeds the rate of absorption by these sinks, the net outcome would be an increase in the concentration of these gases (or their carbon equivalent) in the atmosphere thereby resulting in global warming.

The main greenhouse gases are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFC-11 and CFC-12) and ozone (O_3). These gases are generated by a mixed of natural events and anthropogenic factors, which are induced by humans. CO_2 is the most important anthropogenic greenhouse gas and is produced by the burning of fossil fuels particularly coal and deforestation. With development more and more of fossil fuels would be required thereby resulting in an increased emission of carbon dioxide. Photosynthesis fixes carbon dioxide from the atmosphere but there are upper bounds on the rate of flow of solar energy per unit of which imposes a restriction or limit on the absorptive capacity of nature. If the rate of emission of carbon dioxide exceeds the rate of recycling or absorption by nature per unit of time, the remaining CO_2 would accumulate in the ecosystem as pollutant resulting in a rise in global temperature.

This book looks into the economic implications of restricting carbon dioxide emissions, which is one of the major greenhouse gases, due to the consumption of fossil fuels in developing countries like India. If India were to impose an upper bound or restriction on the emission of CO_2 various problematic issues are bound to crop up. An in depth study of the economic costs in terms of the output foregone, changes in the level of consumption, changes in the poverty ratio associated with the reduction of CO_2 emissions has been carried out in the present study for India.

GLOBAL WARMING AND GREENHOUSE GASES

We know that any body in space emits radiation and the wavelength of this radiation is inversely related to the temperature of the body. Sun's radiation reaching the earth is in shorter wavelengths (0.2 to 0.4 micrometers [μm]), whereas outbound radiations from earth are infrared longwave bands (4 to 100 μm). Clouds, water vapour and GHGs like carbon dioxide (CO_2), chlorofluorocarbons (CFCs), methane, nitrous oxide, and ozone being relatively transparent to the short wavebands permit about half of sun's radiation to reach the earth's surface, but they are more opaque to the longwave bands and hence trap 80-90 per cent of the outbound radiation from the earth's surface. This trapping influence is called the *"Greenhouse Effect"*. Without it, the average temperature of earth would have been -18° C instead of +15° C. Major part of this effect is natural, primarily from water vapour and non-anthropogenic emissions of carbon dioxide gas. However, with the growth of population and economic activity man-made emissions (i.e. anthropogenic emissions) have increased and are large enough and cannot be ignored. They have contributed significantly to the greenhouse effect in recent times. The most important anthropogenic gas is CO_2. The atmospheric concentration of all the GHGs have increased significantly after the Industrial Revolution as is evident from Table 1 given below. As evident from Table 1 the atmospheric concentration of CO_2, the most important GHG has increased from 280 ppm (parts per million by volume) in the pre-industrial times to 370 ppm in the year 2001 i.e., by about 32 per cent during this period.

Table 1
Atmospheric Concentration of Greenhouse Gases

	CO_2 *(ppm)*	CH_4 *(ppm)*	N_2O *(ppb)*	*CFC-11* *(ppt)*	*CFC-12* *(ppt)*
Pre-industrial	280	0.8	288	0	0
Current (2001)	370	1.84	315	263	544
Current annual rate of Change (%)	1.4	0.02	0.8	10	17
Lifetime (years)	120	12	114	50	102

Note: ppm: parts per million by volume; ppb: parts per billion by volume and ppt: parts per trillion by volume.

Source: Reproduced from A.R. Solow, "Is There a Global Warming Problem", in R. Dornbusch and J. Poterba edited Global Warming: Economic Policy Responses, MIT Press and IPCC Secretariat, 1992.

Consider now the earth's Radiative Budget. Earth's Radiative Budget measured in watts per square meter (wm^{-2}) is as follows: Incoming solar radiation is 340 wm^{-2} of which 100 wm^{-2} is radiated back to space by the reflective parts of the earth's surface (like snow, ice) and the atmosphere (consisting of clouds, aerosols, etc.). The remaining 240 wm^{-2} warms the earth's atmosphere and surface from absolute zero (i.e. 0 degrees Kelvin [K] or -273^0 C) to -18^{0}C. The earth's surface in turn emits 420 wm^{-2} of infrared radiation, of which 180 wm^{-2} is reradiated back to the earth thereby warming it by another 33^{0}C. As a result the earth's average temperature is maintained at about +15^{0}C. The remainder of the outbound radiation (420-180 = 240 wm^{-2}) is exactly matched by the net incoming radiation (340-100 = 240 wm^{-2}).

It is known that these greenhouse gases make the earth's temperature conducive to support life. Then, why should greenhouse effect be thought of as a problem? Actually it is the additional warming which is the major cause of worry. Over the years these greenhouse gases, which trap the outgoing infrared longwave radiation, are increasing at an alarming rate, thereby further reducing the ability of the longwave radiation to escape from the atmosphere and hence adding to the warming effect. This increased warming may have a telling effect upon earth. The main greenhouse gases are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFC-11 and CFC-12) and ozone (O_3). These gases are a mixed of natural events and anthropogenic factors, which are induced by humans. Water vapour is by far the most important of these gases with an atmospheric concentration of 1 per cent. With the exception of water vapour all the other greenhouse gases have significant anthropogenic sources. The following Table 2 shows the major sources of these greenhouse gases.

Table 2
Sources of Greenhouse gases

Gas	*Sources*
Carbon dioxide (CO_2)	Fossil fuels, deforestation
Methane (CH_4)	Rice cultivation, ruminants, biomass burning, coal mining, natural gas venting
Nitrous Oxide (N_2O)	Fossil fuels, biomass burning, agricultural practices
CFC-11, CFC-12	Refrigerants, propellants, solvents

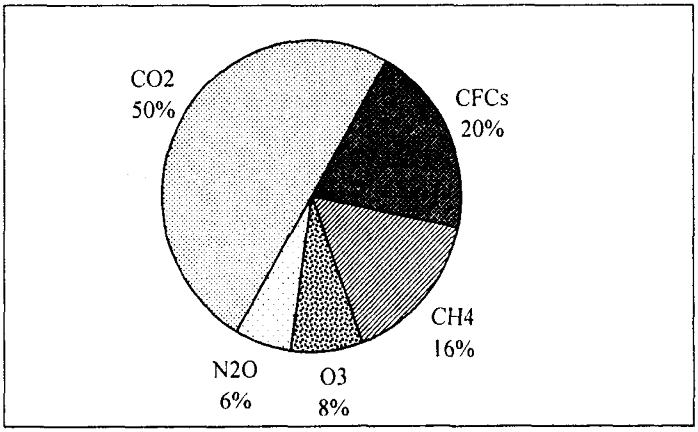
Source: Reproduced from A.R. Solow, "Is There a Global Warming Problem", in R. Dornbusch and J. Poterba (eds.), Global Warming: Economic Policy Responses, MIT Press and IPCC Secretariat, 1992.

CO_2 is the most important anthropogenic greenhouse gas with an atmospheric concentration of around 0.04 per cent (Solow, A.R., 1992). It is produced by the burning of fossil fuels (particularly coal) and by deforestation. It also occurs naturally in the atmosphere. Methane (CH_4) is produced through bacterial activity in bugs and paddy fields and in the digestive tracts of ruminant animals and insects such as termites. Most atmospheric methane comes from biological sources. Chlorofluorocarbons (CFCs) are a group of synthetic compounds used in refrigeration, insulation and other industrial processes.

CFC-11 and CFC-12 are the two most prevalent forms of CFCs. CFCs, apart from acting as GHG, also release free chlorine, which then catalyses the breakdown of ozone (in the stratosphere). Nitrous oxide (N_2O) is also produced naturally through microbial activities in the soil, decaying of crop residues, and the combustion of fossil fuels. N_2O has very long residence time in the atmosphere. It would stay in the atmosphere for more than 200 years, even if its emissions were to freeze today. Ozone (O_3) acts as a protective layer against ultra violet rays of the sun in the troposphere. But, below it, it acts as a greenhouse gas trapping radiation from the earth. It is produced through the combustion of fossil fuels used by automobiles and the industry.

Estimation to the relative contribution to global warming by different greenhouse gases between 1980 and 2030 as shown in Figure 1 points to the fact that CO_2 emissions would alone contribute about half of the global warming over the next thirty years, and thus are a major cause of the greenhouse gas effect. CFCs, as shown in Figure 1 are the other important source of GHG emission. CFCs, however, due to the protection of the stratospheric ozone layer, are subject to control and thus are gradually being phased out. Despite being phased out their effect will persist for a considerable time as the molecules of these CFCs take a longer time to disintegrate and are converted into other compound forms. This implies that the contribution of CO_2 to global warming is likely to rise over the next decades with the phasing out of the CFCs (Nordhaus, 1991).

Figure 1: Estimated Contributions to Global Warming by GHGs between 1980-2030



Source: World Resources Institute (1990), World Resources 1990-91, Oxford University Press, New York

Emissions of GHGs and the consequent global warming are a major environmental problem. Historically the earth's average annual temperature has not varied by more than 2°C in the past 10,000 years. Numerous studies indicate how a small change in average annual temperature leads to a substantial global climate change. Even though the functional relationship between emissions and temperature, and hence climate change, involves a great degree of uncertainty, there is no controversy as to the warming effects caused by the GHGs. We know that the release of greenhouse gases result in increased warming because of radiative forcing[1] of these gases in the atmosphere. The radiative forcings are the measure of heat trapping or radiating ability of the greenhouse gas molecules. The measure differs for molecules of different greenhouse gases. Various greenhouse gas molecules act in quite varying degrees to make the atmosphere retain additional amounts of solar energy re-radiated from the earth's surface thereby leading to warming. In order to consider policy options for controlling greenhouse gas emissions, it is important to have a measure of the radiative abilities of each of the greenhouse gases to change the radiative properties of the atmosphere. Relative to CO_2, a methane molecule has radiative forcing about 21 times higher and a molecule of CFC-12, 16,000 times higher forcing. But by weight they are respectively 58 times and 5,700 times effective. It is the stock of greenhouse gases and not the flow of emissions that matter so far as the warming up effect is concerned. Hence one cannot depend only on the radiative forcing alone. Atmosphere residence time should also be taken into account. Some greenhouse gases are removed from the atmosphere in a few years, while others take hundreds of years to be degraded. The equivalence relation of an emission of CO_2 and another gas in respect of global warming potential would depend upon both the radiative forcings value as well as the life or residence period of residence of two molecules in the atmosphere.

Table 3
Radiative Forcing and Global Warming Potential (GWP)

Trace Gases	*Radiative forcing relative to CO_2 (ratios by molecules)*	*Estimated atmospheric residence (years)*	*Global Warming Potential (GWP)*					
			Direct Effects Integration Time Horizon (years)			*Indirect & Direct Effects Integration Time Horizon (years)*		
			20	*100*	*500*	*20*	*100*	*500*
CO_2	1	120	1	1	1	1	1	1
CH_4	21	10.5	13	4	1.5	22	7.5	3.2
CFC-11	12000	55	13500	10200	4200	-	-	-
CFC-12	16000	116	20000	20000	11500	-	-	-
N_2O	210	132	260	270	170	-	-	-

Source: Reproduced from–K.R. Smith, "The basics of Greenhouse gas indices", in P. Hayes and K. Smith (eds.) The Global Greenhouse Regime: Who Pays?, United Nations University Press, 1993.

Table 3 shows the parameters for some important GHGs. A major change in the perception of the global warming is the recognition that, the combined effect on climate of increases in the concentrations of a large number of trace gases, having different residence times, could rival or even exceed the global warming effect of CO_2. According to Lashof and Ahuja (1990), the trace gases were responsible for 43 per cent of the increase in radiative forcing between 1980 and 1990. These observations regarding the radiative forcings and residence time of trace gases motivated the construction of an index in order to estimate the relative contributions to additional greenhouse gas forcings during a particular period. The index estimates the radiative impact of given emissions over time. The fact that different GHGs have different residence times so the cumulative impact of each gas may be quite different from its initial radiative forcing. Global Warming Potential (GWP) of a gas is such an index that combines its radiative forcing of a unit molecule in the atmosphere with its atmospheric residence time. Thus, global warming potential may be defined as the estimated ratio of total warming produced by each gas over a particular period compared to an equal amount of CO_2 released at the same time. This enables the impacts of various GHGs to be aggregated or compared in the units of CO_2 equivalent. Lashof and Ahuja (1990) defined the index as:

$$GWP_i = \frac{\int_{t=0}^{t=\infty} a_i(t)\, c_i(t)\, dt}{\int_{t=0}^{t=\infty} a_c(t)\, c_c(t)\, dt}$$

where, $a_i(t)$ = instantaneous radiative forcing due to a unit increase in concentration of gas i.

$c_i(t)$ = fraction of gas i remaining in the atmosphere at time t.

$a_c(t)$ = instantaneous radiative forcing due to a unit increase in concentration of CO_2.

$c_c(t)$ = fraction of CO_2 remaining in the atmosphere, equivalent to that of gas i, at time t.

However, this formulation weights all future forcings equally, contrary to the case of instantaneous forcing, which neglects all future impacts[2].

In addition to the direct effects of each GHG compared to CO_2, there are indirect effects of the gases on global warming that needs to be considered and incorporated in the construction of GWPs of gases. Indirect effects on global warming arise out of complex atmospheric chemical interaction among gas molecules, which complicate the determination of GWPs. The chemical reaction might take place between GHGs and non-GHGs or between GHGs themselves[3]. Unfortunately, the atmospheric chemistry involved is not very well understood. Highest degree of confidence is placed on radiative forcings to be followed by residence times and finally indirect effects. The levels of concentration of gases affect indirect effects and cause GWPs to change over time. It is really the complexities of the reaction process that assigns a degree of uncertainty in the evaluation of the indirect effects.

The theory of greenhouse warming caused by man-made emissions of CO_2 has been known for more than a century. Sevante Arrhenius, a Swedish scientist was the first person to estimate that a doubling of carbon dioxide (CO_2) would raise global mean temperature by 4 to 6°C. For most of the 20th century, however, the greenhouse effect was not considered a priority problem. Not much attention was paid as the scientists familiar with the issue assumed that the oceans would absorb these man-made CO_2 but later it was shown by Revelle and Suess that the upper layers of the oceans would not absorb these emissions rapidly.

By the mid 1960s the greenhouse issue was well established, but it did not emerge into prominence among the public until late 1980s. The decade of 1980s was the warmest on record. This coupled with increased awareness among the scientists that the other greenhouse gasses (especially CFCs and methane) were adding substantially to the impact of CO_2 and by the late 1980s the results of the General Circulation Models (GCMs) had become available which provided more insight on and support for the concept of global warming, resulted in tremendous concern about the greenhouse effect.

EMPIRICAL EVIDENCES

One hundred years of theory and the simulation of modern computer models are the foundations of greenhouse science. Empirical support to date is weak. However, there is an unambiguous evidence of the buildup of CO_2 and other trace gases in the atmosphere. The present atmospheric concentration of CO_2 is about 370 parts per million (ppm), which is about 32 per cent above the pre-industrial level (the pre-industrial concentration of CO_2 was 280 ppm). Its concentration is currently increasing by about 0.4 per cent annually. Atmospheric concentration of methane is roughly around 1.7 ppm and is increasing at 1.1 per cent annually. Both CFC-11 and CFC-12 are increasing at a rate of about 5 per cent annually (the Montreal Protocol aims at slowing down this rate). Atmospheric concentration of N_2O on the other hand is growing at a rate of 0.25 per cent per year. It is believed by the scientists that by the year 2030 the N_2O levels would be 34 per cent more than the pre-industrial levels.

Evidence for the greenhouse effect has been derived from air trapped in ice core samples dating back over 160,000 years. These evidence show a relatively close correlation between the atmospheric concentration of greenhouse gases and temperature. In fact, Lorius et al[4] concludes that one half of the observed warming between the glacial and inter-glacial periods as evidenced in the ice-core samples was contributed by the greenhouse gases. Another important source, which acts as an evidence on warming and its effects, is the data on sea level rise. There is evidence to show that sea level over the past 100 years has been rising by 1 to 2 mm per year. This provides further evidence on global warming. However, it will take decades to provide highly reliable statistical evidence that fits the global warming theory. Nonetheless, there is general consensus that a rise in global mean temperature is almost a certainty: only the degree is debatable.

INTERNATIONAL INITIATIVES OF POLICY ANALYSES AND ACTION

Over the years, we know, there has been considerable build-up in atmospheric concentration of CO_2 and other greenhouse gases. As a result, some amount of warming is bound to occur even if all the present emissions (both man-made or otherwise) of all these greenhouse gases were to stop immediately. Under such a scenario the Inter Governmental Panel on Climate Change (IPCC) estimates the amount of warming as 1.7^0 C. Thus we see that if all the emissions of all the greenhouse gases were to stop immediately, we would still experience global warming to the range of 1.7^0 C. Matters would be worse if no aggressive action is taken now. If the emission of greenhouse gases is allowed to grow unhindered or are allowed to grow at the same rate as they are growing now, IPCC projects that under this scenario (also called the business as usual scenario), by the year 2100, the earth's temperature would increase by around 5.6^0 C. IPCC estimates that even an aggressive programme of accelerated policies to curb emission of GHGs would translate into a 2.5^0 C rise in temperature.

It is obvious that with the current level of economic activity the atmospheric concentration of greenhouse gases is bound to rise and hence result in a rise in earth's temperature. If left unchecked, the greenhouse gas emission will increase manifold, thereby adversely affecting the humans. Greenhouse gas mitigation is, therefore, crucial for the stabilization of atmospheric GHG concentrations. Hence, efforts must be made, both on an individual as well as on a global scale to curb or restrict the emission of these GHGs.

Observed trends as well as projected increase in greenhouse gases generated by human activities that are disturbing atmospheric balances and affecting global climate in new and uncertain ways, all point towards the fact that the composition of the earth is changing. Global warming and its consequences are an instance of the severe consequence resultant on taking the environment for granted.

The issue of global warming (and climate change), due to its potential for enormous impact on the world economy, is extremely important. For the most of the twentieth century the issue of global warming was not considered a priority problem, although the temperatures in the northern hemisphere increased through the 1930s. Over the years, realizing the potential for possible adverse impact of global warming, some steps were taken to control the emission of GHGs. In June 1972, the Conference on Human Environment was held at Stockholm. This historical Conference was the first global recognition that the environment was endangered, and that a collective effort was required from both the government and the industry to curb the emission of GHGs. The Conference was a success in the sense that the developed nations realised that their development paths have completely ignored the impact of development on the environment and, therefore, rules and regulations were proposed to rectify the situation.

World Commission on Environment and Development (Brundtland Commission), set up in 1987, was intended to be a stock taking report on the achievements since the Stockholm Conference. Its report highlighted that the relentless pursuit for growth and development, with little care for the environment, the unabated increase in pollution and wastes would lead to a noticeable decline in the quality of life. It prescribed the adoption of a sustainable development path meeting the needs of the present generation without compromising the needs of the future generation[5]. Various other events that were taking place simultaneously in 1970s were related to understanding the implications of global warming.

In 1989 the Inter-governmental Panel on Climate Change (IPCC) was established to access the technical issues that were being raised. In its First Assessment Report published in 1990, it pointed to the fact that the possibility of global warming had to be taken seriously and efforts should be made to tackle the problem. Earlier, in 1987, the successful negotiations of the Montreal Protocol to protect the ozone layer had set a precedent for international action on environmental threat that transgressed national boundaries. The report of the Brundtland Commission, the success of the Montreal Protocol and the First Assessment Report of the IPCC set the ball rolling and in early 1991 negotiations began on a world treaty known as the United Nations Framework Convention on Climate Change (UNFCCC), which was signed at the Earth Summit in Rio. The ultimate objective of the UNFCCC is

> "...... *stabilization of greenhouse gas concentrations 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 to proceed in a sustainable manner* ......" *(Article 2)*

The UNFCCC committed the signatories to voluntarily curtail their emission of GHGs. It, however, soon became evident that such a voluntary action would not accomplish much in reducing the emission of GHGs, hence the political and scientific process continued. Many developed countries are of the opinion that since the developing countries will be the major contributors of GHGs in the future any unilateral action by the developed countries towards addressing the problem of global warming without active participation of the developing countries would be meaningless. Hence, the developing countries should also participate in efforts towards lowering the GHG emissions. The developing countries, on the other hand, hold the developed countries responsible for global warming and hence should, to begin with, alone take the initiative to address the problem. The FCCC recognizing both the historical responsibilities and the limited role that the developing countries could play in addressing the problem of global warming, called upon the developed countries to stabilize their GHG emissions to the 1990 level by 2000 and also to move towards Quantified Emission Limitations or Reduction Commitments. Recognizing the need for development, the developing countries were exempted from any commitments towards emission reductions, but were asked to abstain from GHG emissions, which were not necessary for their development. The Convention called for the parties to protect the climate system for the benefit of present and future generations, on the basis of equity and in accordance with their common albeit differentiated responsibilities and capabilities.

The parties to the UNFCCC reached an agreement on a historical protocol for reducing GHGs in December at the Third Conference of Parties (COP-3) held at Kyoto in Japan in 1997. This historical protocol, known as the Kyoto Protocol was a major milestone in international efforts to avert the threat of climate change. The central feature of the Protocol is an agreement on binding targets. In the Protocol the industrialized Annex B countries (known in the 1992 convention document as Annex I countries) agreed to reduce their annual emissions to a level, which was 5.2 per cent below the 1990 level in the first budget period 2008-12. The Kyoto Protocol includes several flexibility mechanisms (called the cooperative implementation mechanisms), which provides the developed nations the opportunity to reduce emissions beyond their national boundaries. The idea behind this was to enable GHG emission reduction to take place, presumably at a lower cost, beyond the geographical boundaries of the Annex B country (also known as the "Annex I" country[6] in the Framework Convention). The details of how these mechanisms would operate were largely left for future negotiations. Various Conference of Parties have since then taken place to finalise the modalities of these mechanisms. There are sharp differences between the developing and developed nations regarding these flexibility mechanisms and negotiations are still continuing. Although the differences are beginning to be worked out, the ultimate fate of the flexibility mechanisms–and the Protocol itself–remain to be seen. Table 4 summarises some of the milestones in the evolution of the global climate policy.

Table 4
Summary of Key Milestones in Global Climate Policy 1979-2002

Year	*Milestones*
1979	**1st World Climate Conference** –Climate as a vital natural resource –Governments should 'foresee and prevent potential man-made changes in climate that might be adverse to the well-being of humanity'
1987	**Brundtland Commission Report** –Need to adopt a sustainable development path that would help meet present needs while leaving enough resources to meet future needs. Precedent set by successful negotiation of **Montreal Protocol**
1988	WMO and UNEP establish **IPCC (Intergovernmental Panel on Climate Change)**
1989	UN General Assembly Resolution calls for **global summit** on environment and development issues
1990	**First Assessment Report of IPCC published** UN General Assembly resolution establishes INC (Intergovernmental Negotiating Committee) to draft a framework convention
February 1991 to May 1992	Representatives of 160 nations negotiate key issues -Commitments to emission targets and Provisions for technology transfer and financial resources to developing countries
May 1992	**INC adopts UNFCCC** (United Nations Framework Convention on Climate Change)
June 1992	UNFCCC opened for signature at **United Nations Conference on Environment and Development (Rio Earth Summit)**
1994	**UNFCCC** comes into force on 21 March 1994 (ratified by 186 countries as of July 2002) –No legally binding targets (Annex I countries to return to 1990 levels by the end of the decade)
April 1995	**First Conference of Parties (COP-1)** in Berlin adopts the **Berlin Mandate.** New round of negotiations launched on a 'protocol or other legal instrument' –No new commitments for non-Annex I countries –Introduction of Activities Implemented Jointly (AIJ)-voluntary cooperative GHG-mitigation projects
December 1995	**IPCC approves its Second Assessment Report.** Its findings underline the need for strong policy action. –The balance of evidence suggests a discernible human influence on global climate –Significant 'no regrets' opportunities available –Potential risk of damage sufficient to justify action beyond 'no regrets'
July 1996	**COP-2** in Geneva takes note of the **Geneva Ministerial Declaration,** which acts as a further impetus to the on-going negotiations –Scientific research provides basis for urgently strengthening action –World faces significant, often adverse impacts from climate change –Legally-binding significant overall reductions in GHG emissions to be negotiated by the next COP.
December 1997	**COP-3** meeting in Kyoto adopts the **Kyoto Protocol** to the UN Framework Convention on Climate Change

Year	*Milestones*
March 1998	**Kyoto Protocol** opened for signature at UN headquarters in New York. Over a one-year period, it receives 84 signatures
November 1998	**COP-4** meeting in Buenos Aires adopts the **Buenos Aires Plan of Action** setting out a programme of work on the operational details of the Kyoto Protocol and the implementation of the Convention. COP-6 set as deadline for adopting many important decisions
November 1999	**COP-5** in Bonn sets an aggressive timetable to achieve measurable progress by COP-6 on the entry into force of the Kyoto Protocol
November 2000	**COP-6** meets in The Hague, but fails to agree on a package of decisions under the Buenos Aires Plan of Action
July 2001	**COP-6 part II** (or COP-6b) resumes in Bonn. Parties adopt the **Bonn Agreements**, registering political consensus on key issues under the Buenos Aires Plan of Action. They also complete work on a series of detailed decisions, but some remain outstanding
October/ November 2001	**COP-7** in Marrakech finalizes and formally adopts COP-6b decisions as the **Marrakech Accords**
October 2002	**COP-8** held in New Delhi

Source: Climate Change, Government of India, Ministry of Environment and Forests website: http://envfor.delhi.nic.in/cc/int_nego/timeline.htm.

It has been well recognized that the rise in the temperature due an increase in the atmospheric concentration of GHGs will have widespread repercussion on earth, although there are uncertainties associated with the magnitude, timing and regional pattern of these impacts. Hence, efforts must be made to reduce the emission of these GHGs. The reduction in the emission of the GHGs can be accomplished by any of the following means:

- substitution of more polluting fossil fuels (e.g. coal) by less polluting ones (i.e. natural gas), or intra-fossil fuel substitution.
- non-fossil fuel substitution, i.e. substitution of non-fossil fuels (e.g. nuclear, solar) for fossil fuels.
- Product substitution or substitution of energy intensive products by non-energy intensive products. And finally,
- reducing deforestation and increasing afforestation.

Adoption of any of the above-mentioned methods will affect the economy as any reduction in the emission of GHGs imposes some economic costs. In any policy decision relating to the abatement of GHGs, estimates of the magnitude of economic costs associated with such abatement, choice of options available for abatement and the costs associated with each of them becomes essential among considerations. Various models, both at the global and country specific level have been formulated worldwide by economists, scientists, engineers and others to study the impact of global warming. The economists have focused both on the impact of climate change and global warming on the economy as well as on the impact of the control of GHG emissions on the macro economy through its general equilibrium effects. These studies have also analysed among others, the issue of impact of any reduction in emission of GHGs on the sectoral outputs, choice of technology, distribution of income etc. Some of the important global models analysing such impacts are those by Manne and Richels (1992), Nordhaus (1994), Edmond and Reilly (1994), Burniaux et al (1991), Cline (1992) etc. Apart from the global models, Zhang (1996), Blitzer et al (1992a, b), Murthy et al (1997), Ghosh (1990), Naqvi (1997) etc. have formulated country specific macro models to study the possible impact, the emission reduction will have on respective countries' economy along with the choice of policy instruments for effecting the emission reduction at minimum cost.

SCOPE OF THE PRESENT STUDY

As already mentioned, the level of economic activity has increased enormously after the industrial revolution resulting in manifold increase in the emission of GHGs. As a result, over the years, there has been a considerable build up in the atmospheric concentration of CO_2 and other GHGs resulting in some amount of warming. The Global CO_2 emissions from the combustion of fossil fuels increased from 14183.9 mn tonnes of CO_2 (mn t CO_2) in 1971 to 22105.6 mn t CO_2 in 1998, increasing at an average annual rate of 1.66 per cent between this period. It is obvious that over the years, if left uncontrolled, the greenhouse gas emission will increase manifold, thereby adversely affecting the humans. Greenhouse gas mitigation is, therefore, crucial for the stabilization of atmospheric greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system. Table 5 below shows the total CO_2 emissions from fossil fuels across different countries and different regions of the world for the years 1990 and 1998. As is evident from Table 5 the developed countries are the largest emitters of CO_2. Not only are their contribution to the global CO_2 emissions high vis-à-vis the developing countries, their per capita emissions are also large as compared to the developing countries. It is therefore expected that the developed countries would bear a large part of the burden of reducing CO_2 emissions.

India, being a Non-Annex I country, it is currently not bound by the Kyoto Protocol to curtail its emission of CO_2 and other GHGs, but in future the major developing countries like India, China, and Brazil that are large emitters of GHGs accounting for 13.83 per cent, 44.72 per cent and 4.51 per cent of the developing world's emissions respectively may also be required to make commitments towards reducing their emissions. In view of this, the study looks into the economic implications of restricting CO_2 emissions, which is one of the major GHG, due to the consumption of fossil fuels for a developing country like India.

Table 5
CO_2 Emissions from Fossil Fuels Across Different Regions of the World in 1990 and 1998

Regions	*1990*			*1998*		
	Total Emissions (mn t CO_2)	*Per cent of Total Emission*	*Per capita Emission (tCO_2)*	*Total Emissions (mn t CO_2)*	*Per cent of Total Emission*	*Per capita Emission (tCO_2)*
OECD N. America	5562.1	26.93	15.44	6243.3	28.24	15.80
OECD Europe	3927.5	19.02	8.00	3933.7	17.80	7.71
OECD Pacific	1563.4	7.57	8.36	1839.7	8.32	9.41
Africa	598.9	2.90	0.96	728.65	3.30	0.96
Middle-East	600.05	2.91	4.60	924.18	4.18	5.78
Non-OECD Europe	442.43	2.14	6.78	393.73	1.78	6.20
Former USSR	3544.09	17.16	12.26	2206.44	9.98	7.56
Latin America	625.06	3.03	1.77	866.43	3.92	2.15
Asia	3788.39	18.34	1.39	4969.48	22.48	1.61
Mexico	296.9	1.44	3.59	356.3	1.61	3.72
India	594.7	2.88	0.70	908.2	4.11	0.93
China	2389.32	11.57	2.09	2893.15	13.09	2.32
US	4843.8	23.45	19.38	5409.8	24.47	20.10
UK	572.3	2.77	9.90	549.5	2.49	9.28
Japan	1048.5	5.08	8.48	1128.3	5.10	8.92
Developed Countries	15639.57	75.73	10.27	15541.05	70.30	9.62
Developing Countries	5012.35	24.27	1.35	6564.56	29.70	1.54
World #	20651.92	100.00	3.95	22105.61	100.00	3.87

#: World emissions do not include emissions from international marine and aviation bunkers.

Source: IEA (2000), CO_2 Emissions from Fossil Fuel Combustion 1971-1998, International Energy Agency.

If India were to impose an upper bound or restriction on the emission of CO_2 various problematic issues are bound to crop up. An in depth study of the economic costs in terms of the output foregone, changes in the level of consumption, changes in the poverty ratio associated with the reduction of CO_2 emissions has been carried out in the present study for India. A multi-sector macroeconomic terminal year optimization model is formulated to analyse the macroeconomic implications of restricting GHG emissions for India. This multi-sector non-linear programming model is static in its mathematical nature and it optimizes the objective function for a terminal year. Although our multi-sector programming model is static in its mathematical nature, it captures the aspects of dynamics involved for the change between the terminal year and the initial year through the introduction of appropriate stock flow conversion factors for phasing the total required capital accumulation over time in the form of investments, in the different periods for affecting such changes. The macro-economic variables that are endogenously determined by our model are investment, level of consumption, level of output or GDP. Public consumption and Exports are variables whose values are exogenously determined. CO_2 emissions from the use of fossil fuels is calculated for India and are subject to a number of hypothetical emission reductions scenarios in order to analyse the macroeconomic implications of these emission reductions scenarios on the India economy. The hypothetical emission reduction scenarios formulated are (a) the Kyoto compliance scenario (KT), which requires India's total CO_2 emissions to be brought down to a level, which is 5.2 per cent below India's 1990 level of CO_2 emissions during the different terminal years under consideration. In this scenario the total CO_2 emissions have to be reduced to 127960.80 thousand tonnes of carbon, which is India's hypothetical target in a situation of Kyoto type protocol restriction, and (b) the Kyoto Per capita compliance scenario (KP), which sets for India, the CO_2 emission reduction target, for the various terminal years under consideration, to be 887744.19 thousand tonnes of carbon. We call these scenarios the Kyoto scenarios. These emission reduction scenarios are discussed in details in Chapter 3.

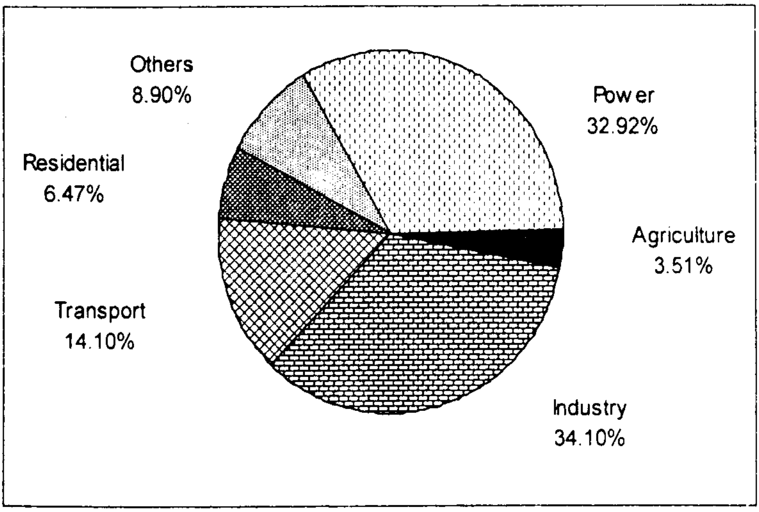
Sensitivity analysis has been carried out (i) by introducing technical change expressed in terms of reduction in energy usage per unit of output in the model and (ii) for different trade policy regimes. Variation in the trade policy is brought by considering different combination of trade deficit and rate of growth of exports.

Thus a number of different scenarios have been considered, the results of which would be useful in making policy decision regarding participating in international efforts like Kyoto Protocol to reduce the emission of greenhouse gases globally, the level to which we can restrict our emissions without sacrificing the goal of economic growth and development. Such an analysis would, therefore, be helpful in building our knowledge base for taking a policy position regarding the level of CO_2 control that may arise in any of the Kyoto related Conferences or any other such international discussion forums. This would provide the basis for future arguments in dialogues of international negotiations on the sharing of global costs of control of emissions and setting of emission norms at the country level accordingly.

Any commitments towards reducing emissions would mean that all the sectors in the economy would have to make efforts for reducing their respective CO_2 emissions so that the national emission targets are met. Power sector in India, being heavily reliant on coal is one of the largest emitters of CO_2. In the year 2000-01 about 81.7 per cent of the power generated by the utilities was from thermal sources. The power sector consisting mainly the coal fired thermal power utilities is therefore, one of the major sources of carbon dioxide emissions in the country accounting for about 32.92 per cent of the total CO_2 emissions in 2000-01 (see Figure 2 below). Being one of the largest polluters, the power sector in India would naturally have to bear a large share of the responsibility towards mitigating CO_2 emissions. The study also analyses the potential cost, expressed in terms of the value of electricity foregone, imposed on the coal fired thermal power plants of any reduction in CO_2 emissions. More specifically, it aims to estimate the marginal abatement costs, which correspond to the costs incurred in terms of the loss of the value of electricity foregone by the power plants to reduce one unit of carbon dioxide from the current level. The aim of such an exercise is to derive in case of the coal fired thermal plants in the country the shadow prices, expressed in terms of the output foregone, of reducing carbon dioxide emissions. These shadow prices provide an answer to the question: How much does it cost the coal fired thermal power plants in India to reduce CO_2 emission in terms of the foregone output or revenue? These estimates would help us in formulating environmental policies for the power sector in the country.

The theoretical framework of our model is based on the production theory and in particular on the distance function approach. We have used the Output-Distance Function and its duality with the revenue function to calculate the marginal abatement cost of reducing CO_2 emissions expressed in terms of the value of electricity foregone, for the power sector in India. We have applied the deterministic parametric output distance function approach in our analysis. This analysis has been carried out by using primary data collected from various thermal plants located in and around West Bengal.

Figure 2: Sectoral Contribution to Carbon Emission from Fossil Fuels in India (2000-01)



Source: Derived from Energy Balance Table using TERI Energy Data Directory and Yearbook (various years) and IPCC Greenhouse Gas Inventory Reference Manual.

It is well recognised that carbon dioxide emission from the use of fossil fuels is one of the major sources of global warming accounting for about one half of the total global warming as can been seen in Figure 1. As India's commercial energy is mainly based on fossil fuel, concern for sustainable energy supply and control of environmental externalities points to the importance of energy efficiency. The energy efficiency is therefore of crucial importance for the abatement of global warming. Among the various policy options for achieving higher energy efficiency, liberalization of the economy–both internal and external–for greater competitiveness in industry and trade has been supposed to so restructure the technology and the institutions of the economy as to induce efficient allocation of resources and accompanying choice of energy efficient technology as driven by the market forces. India introduced a series of measures of economic reforms since 1991 for enforcing greater competitive efficiency in her economic system. While the economic reforms in industry and trade in general targeted to restructure the ownership, technology and operational mode to make them competitive, the reforms in the energy sector aimed at enhanced supply side efficiency through privatization, price reform and globalization. The study also examines whether the measures of economic reforms both at the macro-economic and at the energy sector level have been able to make any significant impact on the energy efficiency and the environmental externality in the form of emission of carbon dioxide. It examines the validity of the hypothesis that economic reforms have had really spin off in terms of achievement in higher energy efficiency in the use and supply of energy given the experience of the reforms in the Indian economy since 1991. It enquires if the economic reforms process till the end of nineties has been able to effectively restructure this industry to enhance the supply competitiveness from domestic sources. These enquiries have involved some analysis based on econometric modeling among others.

Finally the results of our analysis would be helpful in making policy decisions regarding participation in any international effort for reducing GHG emissions. They would provide the basis for future arguments in dialogues of international negotiations on the sharing of global costs of control of emissions and setting of emission norms at the country level accordingly. These results would also be helpful in making policy decisions not only at the macro level but also at the energy and power sector level to achieve energy efficiency and reduce emissions from the consumption of fossil fuels.

OUTLINE OF THE STUDY

The study analyses the macroeconomic implications of restricting greenhouse gas emissions for India. Of the various greenhouse gases we have considered only carbon dioxide gas which is the most important of the greenhouse gases. The study consists of the following chapters:

This chapter 1 (i.e. Introduction) summarises the various issues discussed in the book and puts forward the motivation, objective and scope of this study.

Chapter 2, reviews some of the major models–both global and country specific, that have been formulated worldwide over the years by the economists, scientists, engineers and others to analyse or study the impact of global warming. The economists have focused both on the impact of climate change and global warming on the economy as well as on the impact of control of GHG emissions on macroeconomic costs through its general equilibrium effects. Models analysing the impact of control of greenhouse gases on the economy have also been reviewed. In addition this chapter also reviews models or studies that have used the distance function approach to estimate the shadow prices of the different pollutants (undesirable output) expressed in terms of the value of the output (desirable output) foregone.

For the economic analysis of CO_2 emission limits for India, a multi-sector terminal year optimization model, which is a projection model for a future year, though static in its mathematical nature, is described in Chapter 3. The data requirements of this multi-sector non-linear programming model, the calibration of the model's parameters and the various scenarios that has been generated have also been considered in this chapter. These issues are considered to be essential for the empirical application of the macroeconomic model.

After having carried out the detailed description of the macroeconomic model in Chapter 3, we devote Chapter 4, for analysing the macroeconomic impacts of alternative carbon limits for India. For this, we initially develop a business as usual scenario and sensitivity analysis is then carried out to study the impact of alternative scenarios on the various macroeconomic variables like output, consumption, investment and poverty relative to the business as usual scenario.

In Chapter 5, we have used the output distance method to estimate the shadow prices of reducing CO_2 emissions expressed in terms of the value of the output (i.e. value of electricity) foregone for the power sector in India, which is one of the largest emitter of CO_2 in India. We have used a primary survey data of the coal fired thermal plants located in and around West Bengal for this analysis.

It is well recognised that India's commercial energy is dependent mainly on fossil fuels which is one of the important sources of greenhouse gas emissions. Efficient utilisation of the energy is therefore essential for controlling the emission of these greenhouse gases. India introduced a series of measures of economic reforms since 1991 for enforcing greater competitive efficiency in her economic system. The reforms in the energy sector aimed at enhanced supply side efficiency through privatization, price reform and globalization. In Chapter 6 we examine whether the measures of economic reforms both at the macro-economic and at the energy sector level have been able to make any significant impact on the energy efficiency and the environmental externality in the form of emission of carbon dioxide.

Finally, based on the findings of chapters 4, 5, and 6 we conclude by drawing policy conclusions in Chapter 7.

NOTES

1. The *IPCC (1990)* defines *Radiative Forcing* as follows: "If the climate system is in equilibrium, then the absorbed solar energy is exactly balanced by radiation emitted to space by the earth and atmosphere. Any factor that is able to perturb this balance, and thus potentiality alter the climate, is called a radiative forcing.
2. Current radiative forcings may be considered more important from the policy aspect. Discounting can be accommodated by multiplying future forcings by e^{-rt}, where r is the discount rate.
3. The GWP of CH_4 in the atmosphere is influenced through carbon emissions as it gets oxidized to CO_2 and H_2O. Again, CO a non-GHG may be oxidized to CO_2 a GHG in the atmosphere, besides contributing towards additional forcing through coupling of CH_4-CO-OH as CO emissions increase the residence time of methane.
4. Lorius, C., J. Jouzel, D. Raynaud, J. Hansen and H. Le Traut ((1990), "The Ice-Core Record: Climate Sensitivity and Future Greenhouse Warming" *Nature*, 347, pp. 139-45.
5. World Commission on Environment and Development (1987), *Our Common Future*, Oxford University Press, Oxford.
6. The Annex I countries (known in the Kyoto Protocol as the "Annex B" Countries) were named after a list in the appendix to the Framework Convention on Climate Change and consisted of mainly the developed nations of the world. The Annex I countries are Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, European Economic Community, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom of Great Britain and Northern Ireland, and United States of America. The remaining countries are called the non-Annex I countries (or the non-Annex B countries in the Kyoto Protocol).