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REPORT ON GLOBAL WARMING AND ASSOCIATED IMPACTS

(PHASE I)

teri TATA ENERGY RESEARCH INSTITUTE
NEW DELHI

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Submitted to the
International Development Research Centre, Canada

Tata Energy Research Institute
New Delhi

PREFACE

This report represents the first formal output provided by the Tata Energy Research Institute to the Ministry of Environment and Forests from the project entitled "Professional and Analytical Support on Global Warming and Climate Change". Prior to this report, TERI was privileged to be associated with the technical preparation for and providing support to the International Conference of Select Developing Countries on Global Environmental Issues, organised by the Ministry.

Global negotiations and discussions are likely to intensify in the next few years, as the positions of specific countries and groups become clearer and the impacts of speciic agreements or decisions become better known and quantified. Several countries of the world, particularly the industrialised nations have mobilised a vast array of researchers and institutions to help them in producing analytical work required for current discussions, such as the work of the Inter-governmental Panel for Climate Change (IPCC). In fact, in several cases, governments appear to be going even further and orchestrating the opinions and analyses of specific experts to support positions that appear politicaly preferable to governments themselves. The Ministry of Environment and Forests, while taking the step of setting up an Expert Advisory Committee to advise on global environmental matters, has also awarded this project to TERI to provide regular and wide analytical advice to the Ministry.

In preparation of this report, TERI has mobilised a large number of researchers within the Institute and has recruited professionals where necessary to work exclusively on the activities that have resulted in the submission of this report. The primary authors of each of the chapters in this report are mentioned in the contents, but an equal number of researchers have assisted in various ways by performing portions of the work required for analysis of the problems covered, and for producing this report itself. TERI would very much look forward to comments and feedback from the Ministry so that specific areas of emphasis could be taken in hand for the third report which would be submitted in about a year from now. Meanwhile, work is already in hand for preparation and submission of the second report due towards the end of this year.

Finally, my colleagues and I are deeply appreciative of the opportunity provided to us by the Ministry for working closely on an area of vital importance to this country.

R.K. Pachauri
Director
Tata Energy Research Institute

CONTENTS

GLOBAL WARMING - CAUSES, IMPACTS AND RESPONSES

Dr. R K Pachauri

In the last two years a vast volume of literature has been produced on the subject of global warming, but at the end of many months of intensive debate between scientists, politicians, economists and leaders of public opinion, there is as yet no consensus on the nature and extent of the global warming problem. After an initial period of alarm in 1988, resulting from the severe summer drought of North America, opinion among policy makers particularly in the US and UK appears to be swinging away towards a "do nothing" policy. The contention of the US and UK Governments appears to be that scientific evidence on global warming is still too sketchy to warrant a large scale effort in programmes to curtail, for instance, reduction in use of fossil fuels and transfers of resources to the developing countries. In this context it would be useful to reproduce a small portion (Para 4.1) of the statement that was issued at the end of the conference on "Global Warming and Climate Change - Perspectives From Developing Countries" held at New Delhi during February 1989.

" ...... the build up of greenhouse gases in the atmosphere threatens societies and natural environments in fundamental ways. While significant uncertainities remain, particularly in characterizing the timing and seriousness of regional effects, available information is more than sufficient to justify responsive actions by governments and others. Political leaders and the public should treat the prospect of global warming and adverse climate changes with utmost seriousness and act accordingly. Under the circumstances, governments and others should begin the process of planning and implementing a concerted international response that will require major actions and cooperation on the part of all nations.

It is sometimes said that it is too early to act on global warming. A more accurate appraisal appears to be that societies are already late in responding. It is also said sometimes that a little warming might be beneficial. It seems very likely that the issue is no longer a little warming - the earth is probably already committed to that. The issue now is how big a Warming?".

It is important to remember three aspects of the debate on global warming, which must guide our future actions.

1. The measures which are required for reduction in the threat of global warming are measures that would promote sustainability and have enormous benefits irrespective of the threat of global warming.

2. If the worst predictions on global warming actually come true, and in the mean time we remain oblivious of the threat, it may be too late to reverse the factors behind and the effects of global warming at that stage.

3. The main responsibility for the cumulative impact of global warming lies on the shoulders of the developed countries, and it is, therefore, necessary that they take urgent steps to reduce the emission of greenhouse gases.

Several new facts have come to light recently which add to our understanding of the causes of global warming. In a recent publication by Lashof and Ahuja, published in Nature it has been established that the role of carbon-dioxide in global warming is much higher than previously estimated, largely because of the much longer residence time of carbon-dioxide as against that of other greenhouse gases. This is brought out in Figure 1.

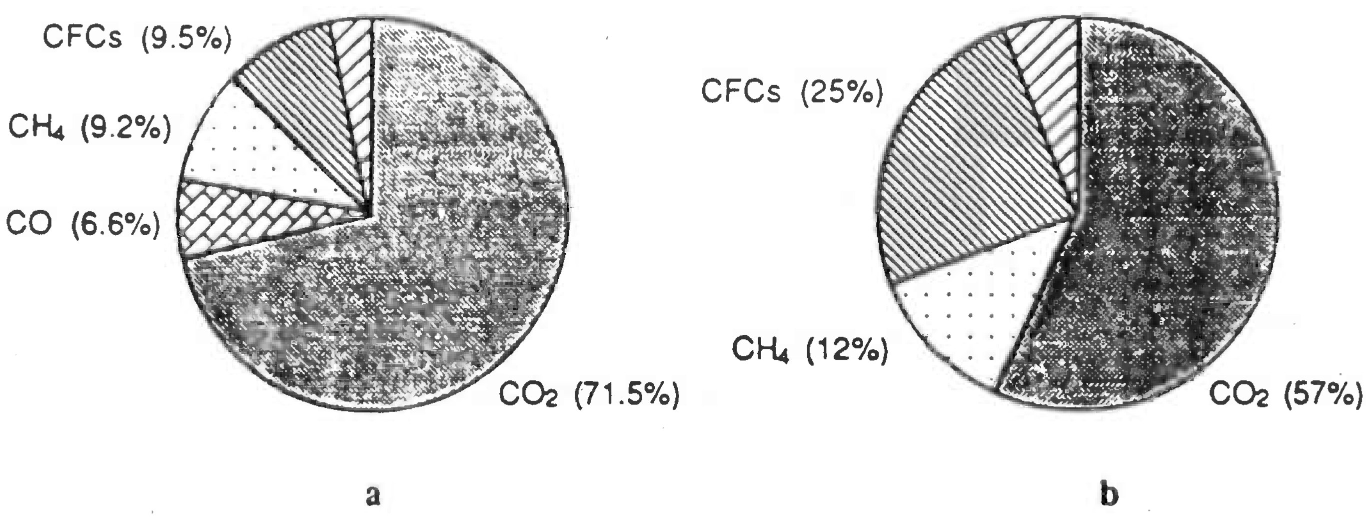


Figure 1
Lashof & Ahuja

Our own research based on construction of time series data on fossil fuel use in different countries of the world, indicates that cumulative emissions produced by burning of fossil fuels have largely been caused by the developed countries, and even if the most optimistic scenarios of growth and increased fossil fuel use were to be made about the developing countries, the cumulative share of the developed countries will remain substantial. These statements are brought out in quantitative terms in Figures 2 and 3.

There are of course several greenhouse gases such as methane, CFC's, oxides of nitrogen and several more; which we would not discuss. In the case of CFC's there is already an international process as embodied in the Montreal Protocol which aims to phase out CFC's within a reasonable time period. The Montreal Protocol is, of course, heavily biased against the developing countries, but there is hope that with adequate efforts from the Third World modifications of this document will correct this tilt in the next few months. On the question of methane emissions, there is still inadequate evidence of the sources of such emissions, and greater physical measurement is necessary, before realistic estimates can be arrived at. Hence, undoubtedly the main component of greenhouse gases remains carbon-dioxide, and since this is produced entirely through human action, the target for response in reducing greenhouse gas emissions lies essentially in controlling carbon-dioxide emissions.

The impacts of global warming can be serious. These include the impact of higher temperatures on agricultural

REGIONWISE CUMULATIVE CO2 EMISSION

1870 – 2010

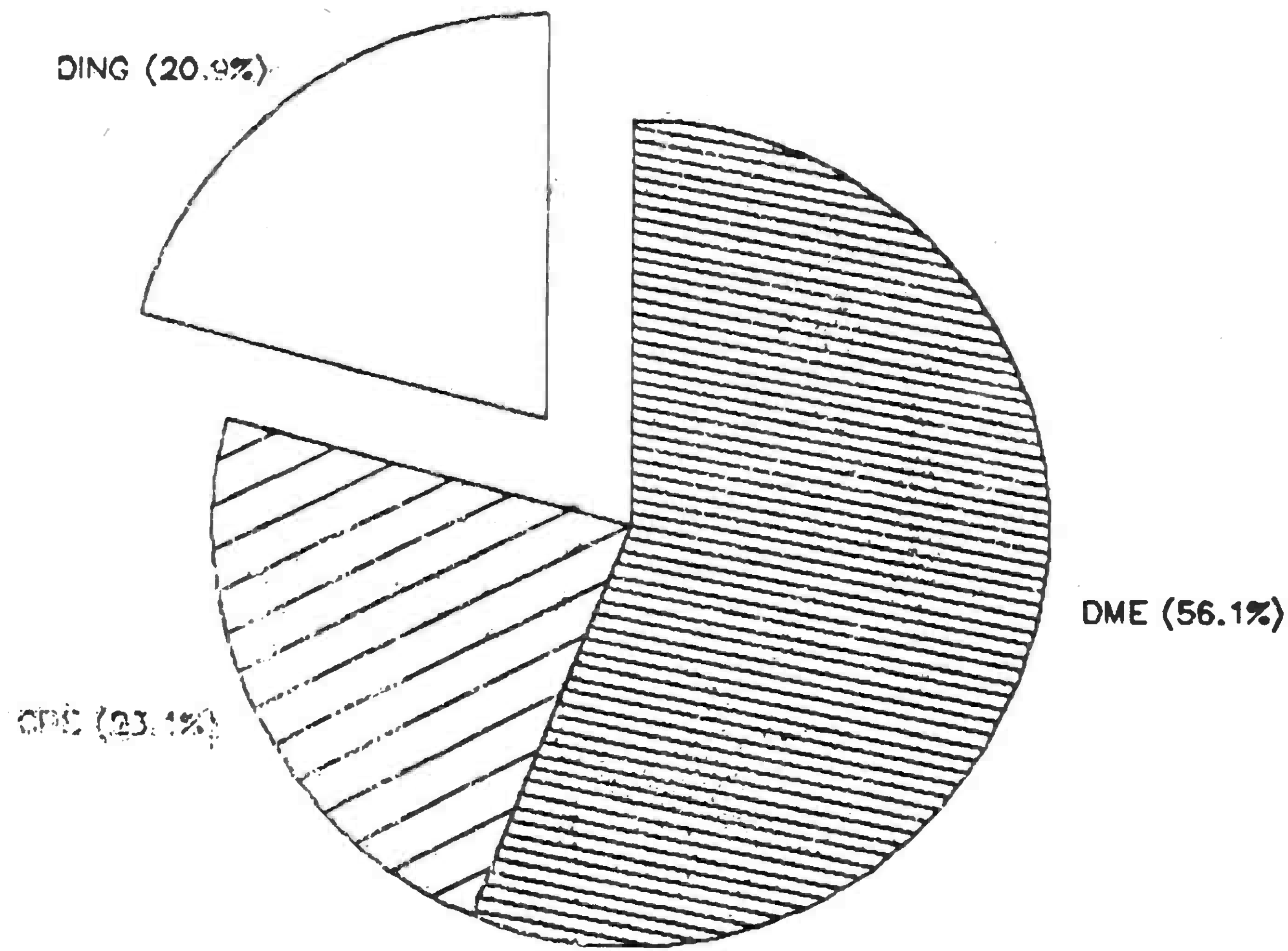
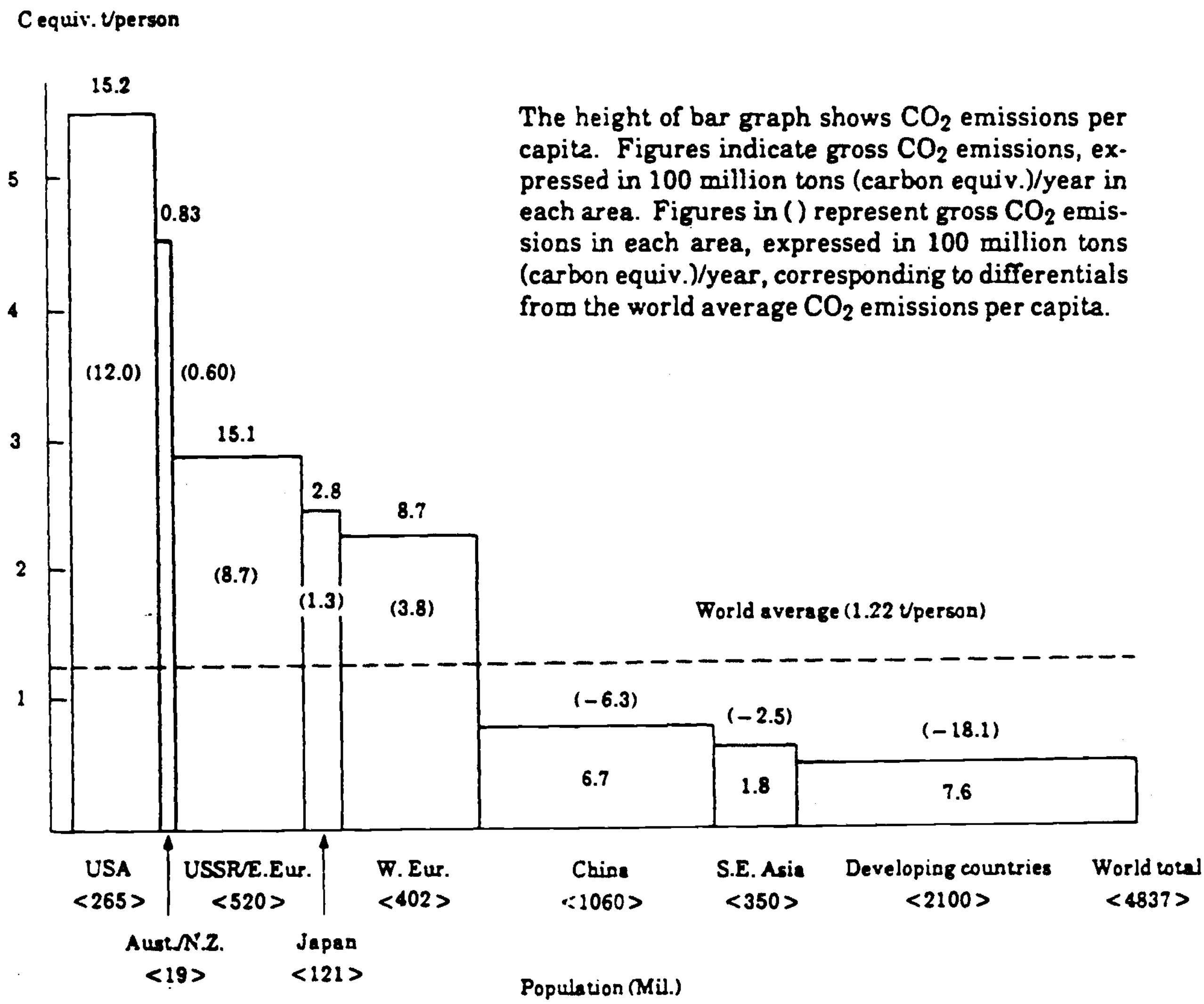


Figure 2

Fig. 3 Simplified Diagram Showing System For Tradable Emission Permits

Population: World Population Almanac (1985)
CO_2 emissions: Calculated from BP Statistical Review (1988)



crops and forestry species. There is already some evidence that certain crops such as wheat may be very sensitive to high temperatures, but much greater research is required before a clear assessment can be made. In the case of forestry too, warmer temperatures can impact unfavorably on certain species and require planned action to counter adverse effects. Given the fact that trees take several years to grow, such action would necessarily have to anticipate impacts in the future and planting of new species undertaken accordingly. This is another area where research is essential on a site specific basis. Global warming would also alter rainfall patterns throughout the world with the possibility of some winners and some losers. In regions where rainfall would become severe, floods could increase in severity. Additionally these various changes can have adverse impacts on normal life including the effect on human health and well-being.

The most serious threat of global warming appears to lie in the possibility of sea level rise. A one meter rise in sea level in the world's oceans can have a disastrous impact not only in terms of completely submerging parts of the Maldives and other low lying regions of the world, but also creating widespread damage through more severe storm surges, etc.

The response to global warming lies in anticipating all the impacts mentioned above. Some of these would require localized action. For instance, the effect of sea level rise on coastal regions would require changes in the location of economic, industrial and defense activities. Sea level rise would also result in increased salinity in coastal areas, which would threaten the availability of drinking water supplies. Water would then have to be arranged from areas further inland or desalination facilities set up in the coastal regions themselves.

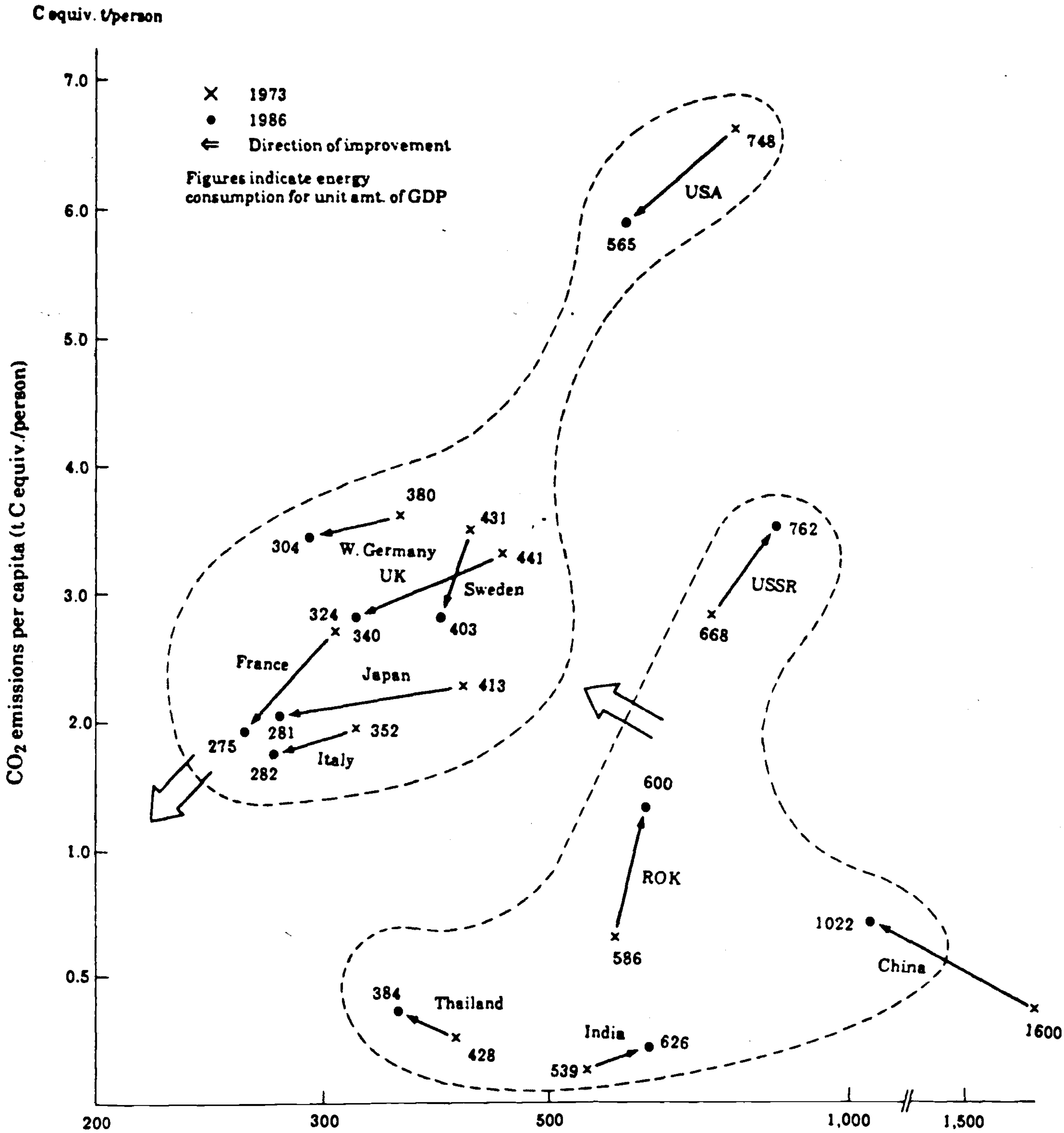
To tackle the root of the problem several measures would need to be taken, which are discussed in detail in the statement of the February 89, New Delhi Conference. However, in essence the actions to be taken would require:

1. Reducing energy intensity throughout the world, but more particularly in the developed countries. The direction and nature of shifts that are necessary are shown in Figure 4.

A movement is also necessary towards those energy sources which are relatively benign in producing greenhouse gases. This includes a shift from coal and petroleum to natural gas and of course to a large range of renewable energy sources such as solar, biomass, wind, and ocean energy. Results in these areas can come only from stronger research and development efforts in the developing countries themselves, which are much better candidates for the use of renewable energy than the developed countries of the North.

Finally a worldwide effort in afforestation is essential. The reduction of green cover, which normally acts as the lungs of the world for absorbing carbon-dioxide has added substantially to the increase in carbon-dioxide concentration in the earth's atmosphere. One estimate is that 1.7 billion tonnes of Carbon were produced by deforestation in the world in 1980. Interestingly afforestation programmes are far more cost effective in the developing countries than in the

Fig. 4 Energy Consumption Per Unit Amount Of GDP And CO_2 Emissions Per Capita



(Source: Prepared from the OECD Energy Balance) developed countries. Accordingly, if the global objective of greater afforestation is to be pursued as a worldwide measure, resources would be far more efficiently utilized through funding of programmes in the Third World than by using these funds in the developed countries. This is brought out in Figure 5.

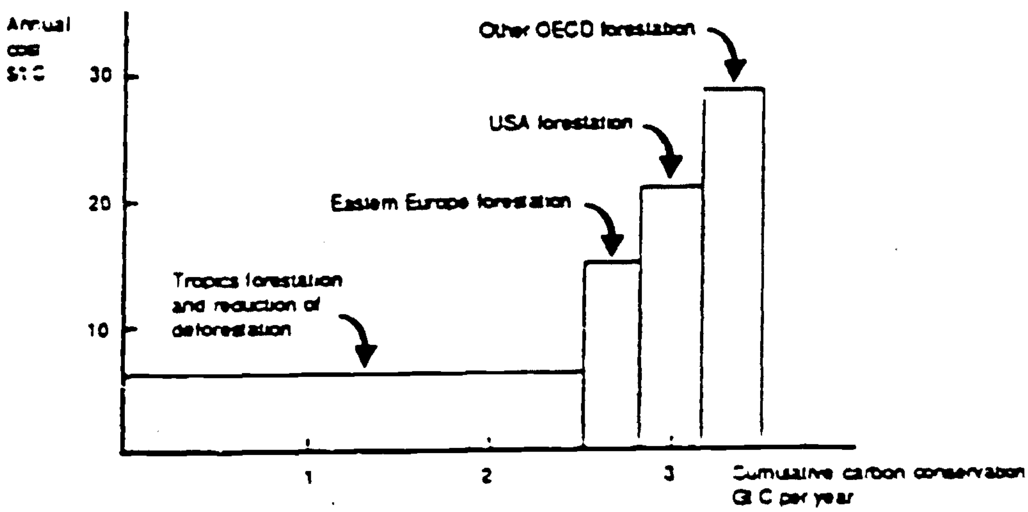
In essence, it can be stated that with a careful choice of plans and projects to promote sustainable development, not only would we be attacking the problem of global warming, but also solving the environmental problems in several regions of the world. A new structure to bring about allocation of resources for such purposes is, therefore, essential, particularly to ensure that the developing countries are not excluded from sustainable paths to the future on account of resource constraints.

Figure 5

Most attractive opportunities in tropics

COST CURVE FOREST MANAGEMENT MEASURES

REGIONAL AVERAGE INDICATIONS



Source: FAO; WRI; McKinsey analysis

GLOBAL WARMING : AN OVER VIEW OF TECHNOLOGY OPTIONS

Abhilasha Behl, Mala Damodaran, Meeta Keswani and Ashok Desai

INTRODUCTION

The atmosphere comprises of several gases, of which nitrogen and oxygen together, form approximately 99%. The remaining 1% is shared by water vapour, carbon dioxide (CO_2), nitrogen oxides (NO_x), ozone (O_3) and methane (CH_4), to name the major ones.

The earth receives most of its energy from the sun's radiation. The wavelength of the radiation emitted by a body varies with its absolute temperature. The warmer a body is the shorter will be the wavelength of its radiation. The sun has an approximate temperature of about 6000 K and radiates energy mostly in the form of visible light and ultraviolet rays. However solar radiation forms only a part of the total radiation received by objects on the earth. 68% of the radiation they receive is from the earth (which has an approximate temperature of 285 K) and the atmosphere, and consists largely of infrared waves.

Some of the infrared radiation escapes from the earth into the troposphere. The proportion that so escapes is reduced by the presence of certain gases in the atmosphere, principally CO_2, NO_2, CO and CH_4. This is the "greenhouse effect"created in the troposphere, on account of the presence of these gases, which are termed as greenhouse gases.

Estimating the current levels of emissions of the greenhouse gases and predicting their future growth presents difficulties since the precise relation between their annual production and the change in their stocks in the atmosphere is not clearly understood. However, their study is important because of their high annual growth rates and their high global warming potential. These gases are described in the following table.

Table 1. The Greenhouse Gases

Activities	Mean Value (1)						
	CO2	CO	CH4	N2O	CFC-11	CFC-12	CFC-22
Atmospheric Conc.(ppmv)[2]	344	Variable	1.65	0.304	.00023	.0004	?
Residence time (years)[3]	2-3	?	11	150	75	111	15
Annual Rate of Increase(%)[2]	0.4	0-2	1	0.25	5	5	?
GWP(molar)[4]	1	1.4	3.7	180	4000	10000	810
GWP(wt)[4 *]	1	2.2	10	180	1300	3700	410

Source: Ahuja,D.R. 1989

1. These figures are subject to varying ranges of uncertainity.
2. UNEP/GEMS,Environment Library No. 1,1987.page 12.
3. Mintzer,I.M."A matter of degrees:The potential for controlling the greenhouse effect", WRI,April,1987. page 5.
4. Ahuja,D. & Lashof. 1989.

* The GWP(wt) of CFC-11 has been assumed to be that for all CFC's.

In order to identify the technologies/processes that are relevant to greenhouse warming, one could identify the major human activities that lead to greenhouse gas emissions. These have been indicated in the following table.

Table 2. Estimates of global anthropogenic emissions

Activities	CO2	CO	CH4	N2O	CFC's
I Energy	19649.9	425	76	1.7	-
Coal Production	-	-	27	-	-
Coal Combustion	8100.8	141.2	0.8	0.7	-
Oil Combustion	8380.7	282.4	0.9	0.7	-
Gas Combustion, Flaring	3168.4	1.4	0.3	0.3	-
Gas Venting, Leakages	-	-	47	-	-
II Industry	501.2	-	30	-	1.77
Cement Manufacture	501.2	-	-	-	-
CFC's	-	-	-	-	1.77
Landfills	-	-	30	-	-
III Agriculture & Forestry	2567	677	243	3.3	-
Animal Husbandry	-	-	78	-	-
Rice Cultivation	-	-	110	-	-
Fertiliser Use	-	-	-	0.5	-
Biomass Combustion	-	677	55	2.2	-
Deforestation, Landuse Changes	2567	-	-	0.6	-
TOTAL EMISSIONS(Tg)	22718.1	1102	349	5	1.77

Source: Ahuja, D.R. 1989

THE GREENHOUSE GASES

Carbon Dioxide

CO_2, as a greenhouse gas, has received the greatest attention, worldwide. There is a fair consensus on the reasons for its increasing emissions, its current levels and the future trend.

As is evident from Table 3, CO_2 contributes approximately 70% of the global warming potential of all the five greenhouse gases that we are considering. However this figure is based not the annual emissions but on the stock of the gas which depends on its residence time (Ahuja D.R, Lashof.1989). This is also corroborated by the fact that the energy sector, which is the major source of CO_2 emissions,contributes to 68% of the global warming potential of all anthropogenic activities.

Table 3. Global warming potential of the gases
(Emissions per year x GWP(wt))

Activities	CO2	CO	CH4	N2O	CFC's	GWP-activity share	Percent Share
I Energy	19649.9	935	760	306	-	21650.9	68.0
Coal Production	-	-	270	-	-	270	0.8
Coal Combustion	8100.8	310.64	8	126	-	8545.44	26.8
Oil Combustion	8380.7	621.28	9	126	-	9136.98	28.7
Gas Combustion, Flaring	3168.4	3.08	3	54	-	3228.48	10.1
Gas Venting, Leakages	-	-	470	-	-	470	1.5
II Industry	501.2	-	300	-	2301	3102.2	9.7
Cement Manufacture	501.2	-	-	-	-	501.2	1.6
CFC's	-	-	-	-	2301	2301	7.2
Landfills	-	-	300	-	-	300	0.9
III Agriculture & Forestry	2567	1489.4	2430	594	0	7080.4	22.2
Animal Husbandry	-	-	780	-	-	780	2.5
Rice Cultivation	-	-	1100	-	-	1100	3.5
Fertiliser Use	-	-	-	90	-	90	0.3
Biomass Combustion	-	1489.4	550	396	-	2435.4	7.7
Deforestation, Landuse Changes	2567	-	-	108	-	2675	8.4
GWP-gas share	22718.1	2424.4	3490	900	2301	31833.5	100.0
Percent share	71.4	7.6	11.0	2.8	7.2	100.0	

Source: Ahuja, D.R. & Lashof,D. 1989.

The atmospheric concentration of CO_2 is estimated to be growing at an annual rate of 0.5%. It increased from about 275 ppmv in 1750 to about 285 ppmv in 1900. From that period it has increased rapidly to 345 ppmv in 1985 (Mauna Loa, Hawaii).

CO_2 emissions come mainly from combustion of fossil fuels and given the fact that developing countries are likely to increase their levels of energy consumption, one can expect emissions to increase, unless these and the developed countries reduce their emissions. The global CO_2 emissions from combustion of coal, oil and gas; those released during the calcining process in cement manufacture; and loss of carbon sink due to deforestation and land use changes, have been entered in their respective cells in Table 2. Thus we have a total global CO_2 emissions of 22718 Tg per year.

Methane

The contribution of methane to the global warming potential ranks second after CO_2. According to Table 3, it is about 11%. This is largely due to the predominance of methane-emission related activities e.g. rice cultivation, animal husbandry and biomass combustion, particularly in the developing countries. The atmospheric concentration of methane has increased from about 0.7 ppmv in pre-industrial times to about 1.65 ppmv in 1985 (UNEP, 1987). The global CH_4 emissions are mainly due to the opening up of new seams and release of entrapped coal gas during coal mining; coal, oil and gas combustion; gas venting and leakages; the bacterial decompositon of organic matter deposited in landfills; the digestive processes of ruminating cattle; rice fields; swamps, termites, and biomass combustion. The current levels of global CH_4 emissions are 350 Tg per year.

CH_4 levels have been increasing more or less parallel with the growth of human population. If this relationship continues to hold, CH_4 concentrations are expected to reach 2.5 ppmv by 2050 A.D. However, future predictions cannot be made very clearly as the situation might change. For instance, although the soil is a natural sink for CH_4, the increasing use of nitrogenous fertilizers has led to a decrease in the absorptivity of the soil. However, fertilizers like urea and ammonium sulphate tend to decrease CH_4 emissions (Pearce, 1989). Also a global warming could release the CH_4-hydrides from the oceans. An increase of 20% in CH_4 emissions can be attributed to the release of ancient CH_4 locked up in the ice caps. In addition, Soviet analysts predict the formation of 100 square kms of peat bogs in Siberia every year. All these could lead one to believe that CH_4, which at present is responsible for about 11% of the global warming might tend to assume a higher position in the hierarchy of the greenhouse gases.

Carbon Monoxide

The sources of carbon monoxide(CO) emissions are fossil fuel and biomass combustion. Okken and Kram(1989) have estimated that 20% of anthropogenic emissions are from oil combustion, 10% from coal and 0.1% from natural gas sources. Using these proportions we can estimate the current level of global CO emissions to be 1102 Tg per year. Another aspect of increasing atmospheric CO concentrations is an increase of ozone(O_3) molecules in the lower atmosphere as CO catalyses the reaction in which O_3 is formed from O_2. This reinforces the global warming as O_3 acts like a greenhouse gas in the troposphere.

Nitrogen Oxides

Anthropogenic nitrogen oxide (NO_x) emissions come from fossil fuel combustion, primarily from the oxidation of atmospheric nitrogen during combustion in the presence of air. They also result from natural microbial activity, biomass combustion and from the application of nitrogenous fertilizers in agriculture. Natural sources of N_2O are lightning, volcanoes, burning of vegetation and from soil and water bodies. However N_2O photo-dissociation in the stratosphere; this reduces its atmospheric concentration.

The current global emission levels are estimated to be about 21.59 Tg per year. For the future, although this increase in N_2O levels cannot continue indefinitely because both fossil fuels and potentially cultiviable land is limited, there is the disturbing fact that the residence time of the N_2O molecule is 170 years. Thus, even if emissions stop rising now, the N_2O levels in 2030 A.D. will be around 0.375 ppmv. This compared to the present levels of about 0.304 ppmv implies an increase of about 23% and, infact a 34% increase over pre-industrial levels.*

Chlorofluorocarbons

Chlorofluorocarbons or CFC's, as they are more commonly known, are used in the production of a variety of products. Unlike other greenhouse gases, the reasons for their emissions are purely industrial and not natural. They are used as working fluids in refrigeration and air-conditioning, as propellants in aerosols, as solvents for cleaning agents, as foam-blowing agents in the production of plastics.

These chlorofluorocarbons have a twin role to play. First, in their capacity to trap the infrared radiation emitted by the Earth, they act as greenhouse gases. Second,

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* UNEP, 1987. page 19.

they have a high ozone depleting potential. This is because they are relatively stable and pass through the troposphere to reach the stratosphere, where in the presence of strong sunlight they break down, releasing free chlorine. This Cl combines with O_3, converting it to O_2. The ClO molecule combines with nascent O to form O_2 and nascent Cl, which in turn reacts with O_3 once again. This process continues for the residence time of the CFC molecule and leads to a depletion of the O_3 layer surrounding the earth. This results in a greater amount of ultra-violet radiation reaching the earth causing an increase in the occurrence of skin cancer, cataracts, suppression of the immune response system and increased damage to crops and aquatic organisms.

In the past, CFC production was increasing sharply till about 1974, after which it slowed down, as new restrictions took effect. The current CFC emission level is 1.786 Tg per year.

TECHNOLOGY OPTIONS

A look at the total annual global emissions in Table 3 reveals the fact that it is the CO_2 emissions that present the most pressing and immediate problem. However, considering the long residence times and high rates of growth of the other greenhouse gases, it is advisable to explore the technology options for reducing the emissions of the other greenhouse gases,particularly that of CH_4 and the chlorofluorocarbons. These technology options can be categorised in the following way:

(A) Those technologies that reduce the greenhouse gas emissions from fossil fuel combustion.

(i) Those technologies that produce the same level of energy using less fossil energy or those that use less fossil energy per unit of energy produced. These will include energy conservation technologies and those that harness the renewable sources of energy that produce less or no greenhouse gases.

(ii) Altering the mix of fossil fuels used so that greenhouse gas emissions are reduced.

(iii) Filtering out the greenhouse gases from fossil fuel combustion emissions, before they are emitted into the atmosphere. This includes a Clean Coal technologies.

(B) Developing alternatives to products and fuels whose production leads to greenhouse gas emissions, directly or indirectly.

(C) Recovery of greenhouse gases from the atmosphere.

Energy Conservation

World energy demand has catapulted in the recent years. Infact it rose from 21 exajoules in 1900 to 318 exajoules in 1988. Coal, oil and natural gas supply 88% of this, Oil contributes 38%, Coal about 20-30% and natural gas, 20% (Gibbons, 1989). Many developing countries still rely heavily on non-commercial sources, but as their economies are developing their dependence on fossil fuels is bound to increase. Therefore, the probability of fossil fuel combustion reducing substantially in the near future is rather low. What are then our options? One would be to go in for a large scale energy conservation programme. This entails deploying those technologies that contribute to increasing the efficiency of energy use.

Industrial Sector

Since the largest use of energy is in the Manufacturing sector it would be useful to explore the technology options existing here.

1) Efficient fluorescent lighting which involves high reflectance fixtures, electronic ballasts and high efficiency bulbs that decrease electricity reqts. by almost half.
2) Electronic sensors and motor controls that range from relatively simple combustion controls,to those based on sensing CO or O_2 in the stack gas,to controls that sense variables like temperatures, pressures and flow rates.
3) Energy management systems e.g sophisticated time clocks to automatically turn lights off and on according to light requirements .
4) Submetering of electricity use at a departmental level in order to monitor the electricity requirements by each department.
5) Variable speed controls(VSC's) for motors.
6) Electric are steel making that involves using an electric arc furnace for melting and processing of scrap metal.
7) A new process of aluminium smelting using new anode and cathode which would reduce energy requirements by 15%.
8) A device for reducing air leakages in compressed air systems serving large sheet-metal stamping presses e.g. for automobile parts.

9) Plasma Processing :In a plasma reactor energy is deposited when an electric arc is struck between a set of electrodes in a gas stream. These are under development for smelting of iron ore in Sweden. Of course the possibility of this method replacing the one based on coal will depend on the relative prices of coal and electricity in the future. A more likely near term application is a plasma torch treatment of dust from electric arc furnaces, which is a hazardous waste.

10) Freeze concentration is based on the preference in phase change for one component in mixed liquids, as in the common vaporization separation process. Heat is removed from the mixture until crystallization begins, then the crystals are physically separated and melted. One application is in the dairy industry.

11) Cogeneration: Economies can be achieved, even with small generation systems, when both heat and work are produced together. Much of the energy remaining in the used steam can be used as a heat source for other industrial processes. Most cogeneration in industry is accomplished with a boiler, a steam turbine to drive the generator, and by delivery of exhaust steam to the site where the heat is needed. A typical system of this kind converts only 10-15% of the energy into electricity (Ross, 1989). In recent years natural gas-fired turbines are being adopted that convert 24-30% of energy into electricity. Steam-injected gas turbines convert 34-40% of fuel energy into electricity.

Most of the above examples are specific to a manufacturing process and cannot be summarised by a short list of generic tecnnologies. In addition, the examples suggest that although it is difficult to reduce the energy intensity of endothermic chemical processing, it is practical to reduce greatly the overall energy of fabrication and assembly in manufacturing.

Domestic Sector

There are also substantial possibilities of energy conservation in the domestic/residential sector.

1) Replacement of incandescent lamps by compact fluorescent tubes;the former consumes 75 watts whereas the latter consumes only 18 watts and also lasts 10 times longer (Keepin & Kats,1988).
2) Improving the efficiency of domestic appliances, particularly those that have a high energy consumption or usage e.g Air-conditioners, refrigerators. In case of refrigerators there are several technologies that contribute to improving the efficiency e.g. increased cabinet and door insulation thickness, two-speed compressors, adaptive defrost or 'smart controls' to adjust time between defrost cycles to minimise energy used, efficient fans.
3) Improved daylighting through better fenestration.
4) Recovery of waste heat through better insulation of buildings and better building materials.

Energy alternatives

Environmental, geopolitical and economic pressures on fossil fuel use have besides restricting fossil fuel use, prompted a search for energy alternatives. A look at following table reveals that there are energy sources that renewable and do not have any carbon content. Let us take these and some other sources individually.

Table 4. Carbon release in the production and combustion of fossil fuels

Fuel	Carbon, g/MJ
Oil	19.2
Gas	13.7
Coal	23.8
Shale oil mining[a]	27.9
Solar	0.0
Nuclear	0.0
Hydro	0.0

[a] Western US shale oil from carbonate rock

Source : G. Marland, 'The impact of synthetic fuels on global carbon dioxide emissions', W.C. Clark, ed, Carbon Dioxide Review, Oxford University press, New York, 1982.

Nuclear power

Nuclear power today generates about 17% of the world's electricity* and would seem an attractive option given the fact that its deployment is devoid of any CO_2 emissions or those that are responsible for acid rain(e.g.SO_2). However the enormous cost of their installation and maintainence,the recent accidents at Three Mile Island (USA) and Chernobyl (USSR), doubts about adequate radioactive waste management techniques, lack of a remedy for proliferation of weapons-grade nuclear materials has by and large tarnished public perception of reactor reliability. Research has been carried out to develop common generic technical features to respond to the goals of passive stability, simplification, ruggedness, ease of operation and

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* Gibbons J. H. et al, page 138.

modularity. Some of the new reactors are the Light Water Reactor(LWC), the Liquid Metal Reactor(LMR) and the High Temperature Gas-cooled Reactor(HTGR).

Nuclear Fusion

Nuclear fusion as an alternative source of energy is very attractive for many reasons. Uranium, of which there are limitless supplies, is used as fuel in fusion. One of the distinct advantages of fusion is that it produces much more energy per unit of uranium (or thorium) and, besides, its deployment has less troublesome radioactive byproducts. But, the demonstration and commercialization of the same will require tremendous investment and therefore may take decades.

Solar Energy

Solar energy, unlike nuclear power is inexpensive. Photovoltaic cells now directly convert sunlight into electricity and are being used in small scale applications like calculators, watches and satellites. Further advances in Microelectronics and semiconductors promise to increase efficiency. Solar power generation is taking place on a larger scale at plants that convert solar energy into heat. These use mirrors or lens to focus sunlight onto a receiver containing a fluid that then conducts heat to a convential electric generator. However, this central tower technology has proved very expensive and therefore little investment has been made in this direction recently. Research on advanced lightweight mirrors and better heat transfer fluids, such as molten salts, may improve these results. We may conclude that the present status of solar technology does not render it sufficient enough to supply base loads, but it can be used to boost supplies during peak periods. Solar powered pumps can be used raise water to reservoirs.

Biomass

Biomass which consists of wood and organic waste provides energy for much of the world.Conversion of biomass to CH_4 or alcohol transportation fuels, will increase the value of this energy source. Power plants fueled by urban solid waste may become a modest but economical energy source as garbage-disposal problems worsen, although, technolgies, to separate combustible from non-combustible materials and devices to control emissions would have to be developed. The CO_2 emissions associated with burning biomass can be offset by regrowing the plants or trees,thereby renewing the "carbon sink" they initially provided.

Alter the Mix of fossil fuels used

Apart from a reduction in the amount of fossil fuel used per unit of energy produced another alternative would be to alter the mix of fossil fuels used. According to a UNEP estimate natural gas produces 60% of CO_2 that coal does, oil produces 80% and synthetic fuels like methanol (that are produced from fossil fuels) produce 150%. Hence it would make more sense to rely more on natural gas, to a lesser extent on oil and least on synthetic fuels.

Filter out the greenhouse gases

Another option would be to reduce greenhouse gas emission from fossil fuel combustion by filtering out the greenhouse gas content before it is expelled in the air. There has been a lot of work done on this via the Clean Coal technologies

(Cruver, 1989).

After oil, coal is the most used fuel in the world. Coal combustion is one of the most polluting of all the combustion activities. It has been estimated that within the next 20 years, coal will surpass petroleum as the world's most used fuel. Global coal production is expected to triple over this period. It is imperative that a continuous upgradation of coal utilization technologies takes place in order to minimize energy cost and environmental damage.

Two such technologies exist as potentially feasible ones and can be incorporated into the existing production process with only minor modifications. These are (i) the integrated gasification combined cycle(IGCC) & (ii) fluidized bed combustion(FBC). There are two variations of the fluidized bed combustion technique (a) atmospheric fluidized bed combustion (AFBC) & (b) pressurized fluidized bed combustion. (PFBC)

In the IGCC, coal is mixed with steam in the gasifier and converted into coal gas. This coal gas is then fed into a gas combustion turbine where it is burnt to produce electricity. The flue gas emerging from the combustion turbine is then sent to a waste heat reboiler and steam turbine. Here the warm flue gas is heated and passed over a turbine, thereby extracting an additional amount of electricity. In comparison to the conventional method of electricity generation which operates at 31.5% efficiency, this method has an efficiency of 32.9%(14). In this process the sulphur in the coal is converted to elemental sulphur, which can then be sold. Since heating/burning conditions are controlled, the quantity of NO_x produced is less.

The FBC process entails the mixing of coal with limestone. This mixture is then suspended in the combustion furnace using a stream of upward flowing air. In the fluidized bed combustor, the limestone absorbs the sulphur, producing a benign, dry, gypsum-like waste that can be used in fertilizers and as a construction material. The steam generated passes over a turbine to produce electricity. The flue gases existing in the combustor are made to pass through a gas turbine to produce an additional amount of electricity. The combustion temperatures in this process are about half as those in conventional boilers, thereby limiting the amount of NO_x formation. The advantage of the FBC is the flexibility in the kinds of fuels which can be used as feedstock e.g. coal, oil shale, tree bark, cow manure. The conversion efficiency in this case is 39.75%. The PFBC & AFBC are similar except that the former, operates at a pressure of 10 atmospheres as against that of 1 atmosphere in the latter, giving it the advantage of a higher thermal efficiency and permitting the use of a smaller boiler which can be shop-fabricated.

While neither of the technologies described above lead to a reduction in the amount of CO_2 produced, they do aid in :

(i) decreasing the amount of pollutants from coal combustion

(ii) increasing the efficiency of conversion of coal to electricity;

(iii) reducing the amount of nitrogen oxides formed.

Developing substitutes for products

Developing substitutes for products whose production leads to greenhouse gas emissions has been another field where research is going on.

Industrial sector

In the industrial sector substitutes have been developed for chlorofluorocarbons, in the production of air-conditioners and refrigerators, aerosols, solvent cleaners etc. These are known as hydrochlorofluorocarbons or HCFC's, which on account of their hydrogen content are less stable than chlorofluorocarbons and therefore have a lesser ozone depleting potential than chlorofluorocarbons (Turiel & Levine, 1989). These are being successfully used in some industries in the U.S. However, there are some reservations regarding the impact of their use on the efficiency of the products. Besides chlorofluorocarbons,there are also processes that enable effective recovery of the refrigerant during servicing and reduce leakage of the same. In the field of refrigeration there is also the possibility of substitution of foam insulation by evacuated insulation panels e.g. compact vacuum panels or powder filled panels.

Transportation sector

In the transportation sector there is substantial scope for energy conservation. By using new fuel efficient technologies it is possible to achieve gains through fuel economy as is shown in the following table.

Table 5. Potential Gains in Fuel Economy from New Automobile Technologies

Technology	Percentage Gain in Fuel Economy by Mid-1990's
New Engine Designs (e.g., Improved shape of combustion Chamber)	4
Variable Valve Timing	8
4 Valves Per Cylinder	8
Multi-point Fuel Injection	7
Improved Lubricants and Friction Reducing Materials	4-5
Electronic Transmission control	3
Continuously Variable Transmission	12
Improved Tires	5
Improved Aerodynamics	5
Efficient Accessories	2

* Note: Gains are not additive.

Source: Chandler, W.,H. Geller, and M. Ledbetter, Energy Efficiency: A New Agenda, American Council for an Energy - Efficient Economy (July 1988).

In addition to improving the fuel efficiency, fuel substitution has been explored as a way to reduce greenhouse gas emissions. The primary options available are electricity, natural gas (compressed or liquified) and methanol. Electric vehicles being developed are largely vans that travel short routes on regular schedules, because electric vehicles have power and range limitations that make them less suited for the average consumer (Streets, 1989).

Prototype natural gas and methanol vehicles are more directly comparable with today's gasoline fuelled vehicles.None of these alternative fuels has a significant share of the transportation sector energy use and market penetration of these technologies is slow. A study was carried out by Deluchi, Johnston and Sperling, in which they estimated the emissions of CO_2, CH_4 and N_2O from fuel extraction to end use for each of the alternatives mentioned above and compared these to those from gasoline powered vehicles on an equal-work-provided basis. The results are summarized in the following table. Emissions of three gases are reported as CO_2 equivalent emissions.

Table 6. Emissions of Greenhouse Gases from Alternative Transport Fuels

FUEL/FEEDSTOCK	TOTAL (CO_2 - equivalent emissions, GT/yr)	% CHANGE (per mile*, rel. to petroleum)
EVs from nonfossil electric	0	-100
CNG/LNG/methanol from biomass	0	-100
CNG from natural gas	1.081	-19
EVs from new natural gas plants	--	-18
LNG from natural gas	1.135	-15
Methanol from natural gas	1.293	-3
EVs from current power mix	--	-1
Gasoline and diesel from crude oil	1.336	--
EVs from new Coal plants	--	+26
Methanol from coal, 30% Incr. eff.	2.026	+52
Methanol from coal, baseline	2.639	+98

Source: Deluchi, M., R. Johnston, and D. Sperling, Transportation Fuels and the Greenhouse Effect, University of California Davis Report, UER-180 (December 1987).

* Per mile of vehicle running.

There are two options that reduce CO_2 emissions by 100% these are using electric vehicles charged with electricity from non-fossil power plants (such as hydro or nuclear) and natural gas or methanol produced from biomass which is continously replaced. Vehicles running on compressed natural gas release 19% less CO_2 equivalent emissions than their gasoline powered counterparts. (Although natural gas burns with about half the CO_2 that gasoline does, methane leakage during fuel production make its CO_2 equivalent emissions much higher). Electric vehicles powered from gas-fired power plants contribute 18% less CO_2 equivalent; vehicles using liquified natural gas, 15% less; those using methanol from natural gas, 3% less. Alternatively, if additional power for electric vehicles were supplied by new coal-fired plants, emissions would be 26% higher.

Recovery of greenhouse gases from the atmosphere

A number of scientists and environmentalists have proposed the idea of a massive reforestation of the earth coupled with a change to a wood economy in which materials such as concrete, aluminium and plastics were replaced by timber. This would enlarge the biological carbon sink,with the result a greater proportion of carbon in the carbon cycle would find its way into the earth's biomass rather than into the atmosphere. Such a scheme would have many obvious environmental advantages other than reducing the threat of global warming.

However there are two reservations. First, even if the pace of reforestation increases in the next few decades, by the time the new trees have matured, the first wave of climatic change might have occurred. Second, the scale of operation seems unfeasible. Although the clearing of forest land for agriculture was originally responsible for the increase in CO_2 levels, it is fossil fuel combustion that has assumed greater importance. Current levels of deforestation-assuming all the timber is burnt-produce only one fifth as much CO_2 as fossil fuel combustion. An area much bigger than France willhave to be reforested annually to mop up the CO_2 from fossil fuel combustion.*

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*UNEP, page 36

CONCLUSIONS AND ISSUES FOR DISCUSSION

The threat of a global warming is fairly well established now. How much warming and how soon, is not clearly known, as there are varying hypotheses. However, considering the eventuality of a global warming it would be prudent to take remedial and preventive steps now.

On analysing the technology options available, it would be advisable to explore those energy options that are easiest to implement in the different national and regional markets and also show the best ratio between benefit and cost. Within a longer time horizon, with continued, progressive R & D efforts in greenhouse-relevant technologies, it would be possible to exploit fully, potential energy technologies that now look attractive but are slow to emerge.

At present, and for the near future, technologies for improving energy efficiency seem to be the best option for reducing emissions, particularly of carbon dioxide, the single biggest source of greenhouse gases. Development and diffusion of technologies for more efficient uses of energy in manufacturing processes, buildings and the transportation sector would offer the important additional advantage of increased productivity, decreased pollution and economic growth. Other near term solutions include replacement of chlorofluorocarbons, preservation of forests and biomass through reforestation schemes and switching to less carbon-intensive fuels such as natural gas. In the longer term, the key technology options would be those which enhance the opportunities for increased use of carbon-free renewable sources such as hydro, geothermal, solar and nuclear energy.

Confronted with an expected problem of climate change, the transfer and adaptation of greenhouse-relevant energy technology will become a key element to any viable response strategy. It is imperative to collect rigorous environmental and technical data to analyze priorities for energy technology implementation and preparation. These and other issues were debated in the IEA/OECD Experts Seminar held in Paris in April 1989. Their recommendations were to:

(i) establish clearinghouse arrangements and/or networks that would allow and improve the gathering and diffusion of data on greenhouse-gas related energy technology.

(ii) collect, transfer, and trade information concerning design, construction, operation, adapatation and economics of available, demonstrated and innovative energy technologies for the containment of greenhouse gas production.

(iii) contribute to the supply of extension services including technology appraisals, advice on regulations and standard, project planning and personnel training, organizational set-ups and project monitoring.

(iv) co-ordinate R&D efforts, help define priorities and promote collaboration on specific tasks and projects, and collect information about existing activity.

The major issues that developing countries must address and initiate discussions with the developed countries on are as follows:

1. The economic systems in a number of developing countries use technologies that are relatively inefficient in consumption of energy and, therefore, contribute to avoidable emissions of greenhouse gases. During the past two decades the oil price increases in 1973-74 and 1979-80 have resulted in the development of energy efficient technologies that are available in several countries of the North. The transfer of these technologies to the developing countries can only take place if there are effective financing arrangements to bring this about. A case in point is the transfer of technologies related to production of substitutes for CFCs. Since substitutes are being developed largely by the private sector in the countries of the North, transfer of knowhow related to them can only take place on a commercial basis, which is beyond the capacity of the developing countries and certainly not fair to expect. An institutionalized financing arrangement to bring about such transfers is essential.
2. To upgrade technologies, it would be essential to develop local skills both for R&D and effective absorption of new technologies. Existing institutions in the Third World as well as new ones would have to be created to fulfill this objective. This would require local initiative and direction, but could be facilitated by flow of skills and support not only from the North, but also on the basis of South-South cooperation.
3. A critical requirement for technology development is the effective retrieval and dissemination of information.

Clearing houses for information dissemination on technologies would need to be established not only on an international basis, but also nationally and regionally, with adequate networking and communication arrangements.

4. Multilateral organizations and bilateral assistance programmes have traditionally financed new capacity for a range of economic activities. In view of the importance of technology upgradation, it is necessary to enlarge this focus by allowing adequate financing for retrofits which would result in overall upgradation of technology. Organizations such as the World Bank could take a major lead by reorienting their policies in this direction, and national organizations and institutions would need to work in coordination to identify a production process whereby existing structures and production systems can be upgraded through technology improvement.

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INDIA'S CONTRIBUTION TO GLOBAL ANTHROPOGENIC EMISSIONS OF GREENHOUSE GASES, 1987-88

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Energy consumption in India is likely to continue to rise in the coming years because of rapid population growth, increased urbanisation, greater transport needs, accelerating industrial development and improvements in standards of living. Compounded with these, limited financial resources tend to reduce the room for manoeuvre in taking maximum advantage of improvements in energy production, distribution and consumption techniques. The impending threat of global warming and consequent deleterious effects make it necessary to identify a suitable range of technology options for tackling the problem of global warming in the Indian context, and to assess the prospects for international collaboration on these energy technologies.

It is with this view in mind that an attempt has been made to list various human activities which are the primary sources of greenhouse gas emissions and their relative share in global emissions. In making the estimates presented below we have followed the methodology of Dilip R. Ahuja in his paper 'Regional Anthropogenic Emissions of Greenhouse Gases' (1989) with suitable refinements made. The methodology adopted and estimates obtained are discussed in the following sections.

Methane (CH_4) emissions from coal mining

Coal is formed as a result of the metamorphosis of partially decomposed plant debris. The process involves a progressive change in the plant debris; from peat to lignite and then through higher ranks of coal to anthracite, involving a series of chemical changes. These chemical reactions result in certain gases,primarily methane, becoming entrapped in the coal bed. This methane is released when new coal seams are opened up. The magnitude of release varies- depending upon the shape and depth of coal reserves, the rank of the coal and the technology of mining. Edmonds (1989) [11] has estimated coal-methane release factors for different regions of the world, based on data compiled by the International Energy Agency and the 1983 World Energy Conference. These are enlisted in the table below :

Table 1. Region-wise coal-methane emission factor

Region	Emission Factor (m^3/tonne)
USA	6.6
Canada & W.Europe	7.8
Japan, Australia & New Zealand	6.1
USSR & E. Europe	7.3
China & Centrally Planned Asia	13.7
Middle East	13.1
Africa	13.8
Latin America	3.7
South & East Asia	11.3
World Average	8.4

Using the emission factor of South and East Asia for production of coal, in India an estimate of 2.17 Tg of CH_4 is arrived at.

Carbon dioxide (CO_2) emissions from fossil-fuel combustion

At present CO_2 emissions are the single largest cause of elevated terrestrial temperature from the greenhouse effect. Increases in CO_2 concentrations result primarily from intensified burning of fossil fuels - coal, oil and natural gas - which liberates the chemical in varying amounts. Each of these three sources of CO_2 emissions are discussed below :

CO_2 emissions from coal combustion

Combustion of coal essentially contributes to the emission of four greenhouse gases viz CO_2, CO, CH_4 and N_2O. Calculation of regional CO_2 emissions from coal combustion involves three steps - estimating the annual consumption of coal, the fraction of coal produced but not oxidized and the average carbon content of coal consumed.

The annual consumption of coal for the year 1987-88 was 180.00 Mt [16], with the coking coal accounting for about 23 % of the total consumption or offtake. In India, around 9.0% [16] of total coking coal is used for non-energy use in the fertilizer industry, of which 75% undergoes delayed oxidation. As a result of coal combustion, while CO and hydrocarbons get fully oxidized to form CO_2 in the atmosphere, particulate matter remains largely unoxidized. This leads to our result that about 0.21% [2] of carbon in coal burnt within a year will be discharged unoxidized.

The carbon content of coal is ultimately linked to its heating value. Taking the average gross calorific value of Indian coal to be 23 GJ/tonne, the carbon content works out to be 57%. Therefrom, on the basis of total carbon burnt, the annual CO_2 emissions are estimated to be 389.33 Tg.

The steps involved in computing CO_2 emissions from coal combustion are shown below in Table 2.

Table 2. CO_2 emissions from coal combustion

(1) S.No.	(2) Variable	(3) Unit	(4) India	(5) Remarks
1	Consumption	Tg/yr	180.00	1987-88
2	Fraction coking coal		0.23	
3	Fraction fertilizer industry		0.090	
4	Fraction delayed oxidation		0.75	Marland,Rotty
5	Coal for energy use	Tg/yr	177.25	
6	Fraction unburnt		0.0021	
7	Coal oxidized		176.88	
8	Gross calorific value	GJ/tonne	23.00	
9	Carbon content [.0248(8)+.017]		0.57	
10	Adjustment for low/ high heat values		1.055	
13	Carbon burnt	Tg C/yr	106.18	
14	CO2 emitted	Tg CO2/yr	389.33	

<u>CO_2 emissions from oil combustion</u>

CO_2 emitted from combustion of hydrocarbons is estimated by taking the consumption of petroleum products for the year 1987-88 which is 49.01 million tonnes [21]. Liquefied natural gases are added to the quantum of crude production and treated as liquid fuels. Adjustments are made to take into account the quantity of petroleum products used for non-fuel purposes and those sequestered in the atmosphere due to incomplete combustion. Some petroleum products end up in the form of fibres, lubricants and greases, paving materials, waxes and petroleum coke. Marland and Rotty [27] make the following assumptions about the fraction of annual production of each of these class of compounds that remain unoxidized for prolonged periods of time.

Waxes & Petroleum Coke	0%
LPG & Ethane from Gas Plants	40%
Lubricants	50%
Naphtha	80%
Asphalt	100%

On an average 6.7% of world petroleum production is used for manufacturing the above mentioned products. For India, this proportion is estimated to be about 8% [21] (Table 2). A portion of petroleum does not undergo oxidation viz. the airborne fraction of particulate matter and unburnt hydrocarbons. Marland and Rotty [27] assume this fraction to be 1.5% (± 1%) as a global average. To estimate the portion not oxidized, the two fractions are summed up.

Finally, the carbon content of liquid fuels is assessed. Crude oil is a complex mixture of hydrocarbons. Marland and Rotty (1984) [27] have estimated that the average carbon content, by weight, varies only slightly from year to year and is approximately 85% (± 1%). A similar carbon content of 85% is taken for liquefied natural gas as well.

On the basis of above factors, the total amount of carbon burnt and the corresponding CO_2 emissions are computed, which work out to be around 138.01 Tg per annum. (Table 3).

Table 3. CO_2 emissions from oil combustion

(1) S.No.	(2) Variable	(3) Unit	(4) Range	(5) India	(6) Remarks
1	Consumption	Tg/yr		49.01	1987-88
2	Naphtha	Tg/yr		2.85	production
3	Fraction delayed oxidation			0.80	unoxidized fraction
4	Asphalt/bitumin	Tg/yr		1.38	production
5	Fraction delayed oxidation			1.00	unoxidized fraction
6	Lubricants	Tg/yr		0.79	production
7	Fraction delayed oxidation			0.50	unoxidized fraction
8	LPG(from crude oil & natural gas)	Tg/yr		1.69	production
9	Fraction delayed oxidation			0.00	unoxidized fraction
10	Ethane	Tg/yr		0.00	production
11	Fraction delayed oxidation			0.40	unoxidized fraction
12	Total fraction unoxidized			0.08	total fraction unoxidized
13	Amount combusted	Tg/yr		44.96	
14	Fraction unburnt		(0.005-0.025)	0.015	conbustion efficiency
15	Total burnt	Tg/yr		44.28	
16	Carbon content		(0.84-0.86)	0.85	
17	Carbon burnt	Tg C/yr		37.64	
18	CO_2 emissions	Tg CO_2/yr	138.01		

<u>CO_2 emissions from natural gas combustion and flaring</u>

Natural gas combustion

Estimates of CO_2 emissions from combustion of natural gas are based on the consumption data of natural gas for 1987-88 [21], which is 7971 million cubic metres. A part of total production, i.e. about 1316 million cubic metres, was used for the manufacture of LPG, which is included in the foregoing section. Of the remaining, about 53.0% is used for non-fuel purposes in the in the fertilizer and petrochemical industries [21]. It is further calculated that out of each year's consumption for non-energy use, nearly two-thirds of the carbonaneous matter gets oxidized in that year itself.

Owing to incomplete combustion, about 0.21% [2] remains as soot in the stack whilst the remaining gets converted to CO_2 in the year of production itself (Table 4).

Natural gas flared

Almost all th~ gas flared is associated gas at oil wells in countries where there are no facilities for the recovery of gas, and no infrastructure or markets for the use of gas. In most cases natural gas liquids are extracted before flaring the gas. For estimating CO_2 emissions from flaring of natural gas, we assume that all of it gets converted to CO_2 and none escapes as methane. In India, around 125.98 PJ (or 3442 million cubic metres) of natural gas was flared [21] in 1987-88 (Table 4). The total CO_2 emitted is calculated to be 14.18 Tg per year.

The carbon content of natural gas (which is related to its calorific value) is taken to be about 13.65 g/MJ or about 510 g/m^3 of dry natural gas.

Table 4. CO_2 emissions from gas combustion and flaring

(1) S.No.	(2) Variable	(3) Unit	(4) Range	(5) India	(6) Remarks
1	Production	10^6 cum/yr		7971.00	1987-88
2	Used for LPG mfg.	10^6 cum/yr		1316.00	1987-88
3	Net of LPG production	10^6 cum/yr		6655.00	
4	Energy content	MJ/cum		36.60	
5	Production	PJ/yr		243.57	
6	Fraction non-energy uses			0.53	
7	Fraction non-energy use oxidized			0.67	
8	Gas burnt	PJ/yr		157.26	
9	Fraction unburnt			0.0021	combustion efficiency
10	Total burnt			155.69	
11	Total flared	PJ/yr		125.98	
12	Carbon content	g C/MJ		13.65	
13	Carbon burnt	Tg C/yr		3.87	
14	CO_2 emitted	Tg CO_2/yr	14.18		

Carbon monoxide (CO) emissions from fossil-fuel combustion

Emissions of CO from fossil fuel combustion in India are determined on the basis of current global CO emissions. The most likely global estimates of CO emissions from fossil fuels is considered to be 425 Tg/yr [1], which is roughly 30%-35% of the total annual global CO emissions. Okken and Kram (1989) [29] have assessed that the percent contribution by coal, oil and natural gas, in this case, is approximately 10%, 20% and 0.1% respectively. These proportions are used for apportioning CO emissions amongst coal, oil and natural gas sources for the world. For India, CO emissions are taken to be proportional to its CO_2 emissions which works out to be 11.44 Tg/yr. Detailed calculations are presented in Table 5.

Table 5. Emissions from fossil fuel burning

(1) S.No.	(2) Variable	(3) Unit	(4) Coal	(5) Oil	(6) Gas	(7) Total
(i) CO emissions from fossil fuel combustion						
1	World-CO_2	(Tg/yr)	8100.80	8380.70	3168.40	19649.90
2	World-CO	(Tg/yr)	141.20	282.39	1.41	425.00
3	World-CO/CO_2 {2/1}		0.0174	0.0337	0.0004	0.0216
4	India-CO2	(Tg/yr)	389.33	138.01	14.18	541.52
5	India-CO {3*4}	(Tg/yr)	6.79	4.65	0.01	11.44
(ii) CH_4 emissions from fossil fuel combustion						
6	World-CH4	(Tg/yr)	0.66	1.33	0.01	2.00
7	World-CH4/CO2 {6/1}		0.0001	0.0002	0.000002	0.0001
8	India-CH4 {7*4}	(Tg/yr)	0.03	0.02	0.00003	0.05
(iii) N2O emissions from fossil fuel combustion						
9	World-N2O	(Tg/yr)	0.57	1.15	0.01	1.73
10	World-N2O/CO2 {9/1}		0.0001	0.0001	0.000	0.0001
11	India-N2O {10*4}	(Tg/yr)	0.03	0.02	0.00003	0.05

Methane (CH_4) emissions from fossil fuel combustion

Burning of fossil fuels is a minor source of CH_4 emissions. Global estimates of methane from all types of commercial energy use are estimated to be 2 Tg/yr in the EPA's Draft Report to Congress [26]. As tentative estimates at the global level, this can be apportioned between coal, oil and natural gas in the same proportion as that for CO. Assuming the ratio of CH_4 to CO_2 emissions to be the same as for the world, CH_4 emissions from fossil fuel combustion for India are estimated at 0.05 Tg/yr (Table 5).

Nitrous oxide (N_2O) emissions from fossil-fuel combustion

Uncertainty is inherent in the estimation of N_2O emissions from the burning of fossil fuels. They vary drastically between 1 and 3 Tg N [1]. In this paper, EPA's estimates of global flux from these activities are adopted and again apportioned between coal, oil and natural gas in the same proportion as CO_2. Total emissions work out to be 0.05 Tg/yr (Table 5).

Methane (CH_4) emissions from natural gas venting and leakages

The three ways in which CH_4 can be lost to the atmosphere during the course of production and distribution of natural gas are :

(i) A portion of associated gas is vented intentionally during the process of drilling.

(ii) Some gas escapes unburnt when flared, and

(iii) Leakages occur from distribution lines, which account for the bulk of loss of natural gas.

Table 6 contains details of methane emissions for India from this source. All data pertain to the year 1987-88.

Also, we have assumed that natural gas is all methane (though actually it is close to 90% methane) and that 22.4 litres of natural gas embodies 12g of carbon. The conversion from cubic metres to Tg/yr is worked out by taking the average calorific value for natural gas as 8740 kcal/m³ and 9000 kcal/kg for India [21]. The contribution from this source is 0.23 Tg/yr.

Table 6. Methane emissions from natural gas venting and leakages

(1) S.No.	(2) Variable	(3) Unit	(4) World	(5) India (1987-88)
1	Production	(Tg/yr)	1302.00	7.74 *
2	Flaring	(Tg/yr)	18.20	3.34 *
3	Leaks(2.5% of amount piped)	(Tg/yr)	32.55	0.19
4	Venting & Incomplete flaring	(Tg/yr)	14.50	0.04
	Total		47.05	0.23

Source: * : Ref.(21)

Industry

Carbon dioxide (CO_2) emissions from cement manufacture

Production of cement involves a calcining process whereby limestone dissociates to form calcium oxide and carbon dioxide. It is estimated that for every Tg of cement produced, roughly 0.502 Tg CO_2 is released [30]. The CO_2 produced by fossil fuel burning in kilns and to produce the electricity consumed in cement plants is accounted for in the section on energy emissions. Cement production data for India pertain to be year 1987-88. Calculations are shown in Table 7. Emissions from the calcining process are 18.77 Tg/yr.

Table 7. CO_2 Emissions from cement manufacture

(1) S.No.	(2) Variable	(3) Unit (Range)	(4) World	(5) India (1987-88)
1	Emission factor	Tg CO2/ Tg cement	0.502	0.502
2	Production	Tg/yr		37.4 ●
3	Emissions	Tg CO2	501.20	18.77

Source:
●: Ref.(17)

<u>Chlorofluorocarbon (CFC) emissions</u>

CFCs are a group of volatile chemicals which, in spite of a low concentration in the atmosphere, have a high global warming potential. These chemicals, unlike the other greenhouse gases, are strictly synthetic and are not known to occur in nature. They have a number of uses such as refrigerants, propellants, solvents and thermal insulators. A class of bromine-containing chemicals called 'halons' is found in fire extinguishing systems. India's production of CFCs has been estimated as 13.02 Gg for the year 1988 [20]. There are a variety of CFCs produced amongst which CFC-11 and CFC-12 are the two most commercially important ones(Table 7).It is assumed that the portion of CFCs "banked*" are ultimately released to the atmosphere.

The term CFCs encompasses a number of different gases with varying characteristics and behaviour. In our study, all CFCs have been converted to CFC-11 equivalent basis (Fisher et. al. 1989) [12]. Indian production of CFCs is

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* A high proportion of the CFCs are embodied in refrigerators, air conditioners and certain kinds of closed cell foams which remain trapped until the devices are scrapped years later. In some other applications viz. aerosol propellants and open cell foams, CFCs are released into the atmosphere within a short time.

assumed to be a percentage of the global production and its contribution to global CFC emissions is estimated to be 0.01 Tg/yr (Table 8).

Table 8. Contribution to global warming from chlorofluorocarbons (on CFC-11 equivalent basis)

(1) S.No.	(2) Type of CFC	(3) Relative GWP	(4) Production India-1988 (Gg)	(5) CFC-11 Equivalent (Gg)
1	CFC-11	1.000	0.95	0.95
2	CFC-12	3.050	2.45	7.48
3	HCFC-22	0.365	1.84	0.67
4	CCl4	0.370	7.24	2.68
5	CH3CCl3	0.025	0.54	0.01
	Total		13.02	11.79

Halons are presently being imported. Owing to a controversy over their GWP we have not included them in our estimate.

Sources:
Col(3): Ref.(1)
Col(4): Ref.(20)

Methane (CH_4) from landfills

CH_4 is produced during the anaerobic decomposition of organic matter in landfills. To estimate methane generation from landfills for India, only refuse generated by urban population is taken. The other factors considered are - urban population, average refuse generation rate, compostable fraction, fraction landfilled, characteristics of refuse (moisture content and carbonaceous matter), average temperature in landfills at a depth of 2-4 m etc.

Calculations for India are shown in Table 9. The share of urban population is taken to be 27% [8,17] and average daily refuse generated per urban dweller to be 0.4 kg [31,33] of which 40% is the compostable fraction. Average carbon matter in refuse from Indian cities is about 12.27% [31] on dry weight basis and the moisture content varies between 22%-31% [30,4]. The average carbon content of city refuse was calculated by taking the percentage of carbon(on a dry weight basis) for cities categorized by population size [33]. Taking the number of cities falling under each city class [10], a weighted average for the carbon content in urban waste was calculated,which worked out to be around 12%(on a dry weight basis). The fraction landfilled is taken to be 80% with the average landfill temperature as 35°C. Methane generated due to decomposition of this organic matter is 2.18 Tg/yr and is worked out in Table 9.

Table 9. Methane emissions from landfills

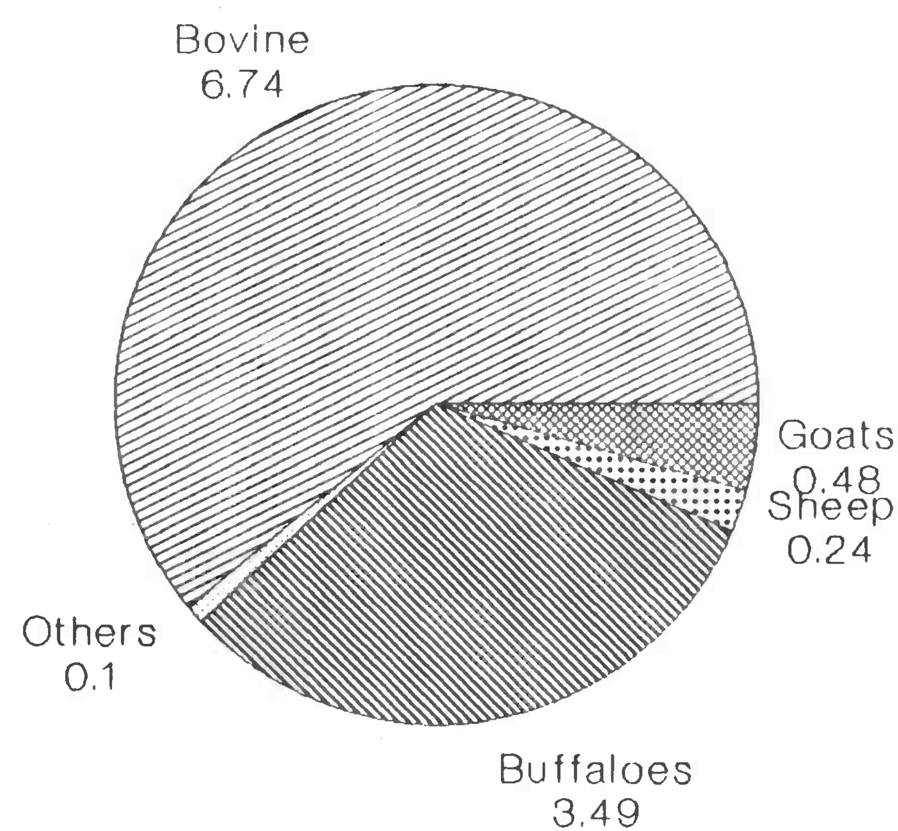
(1) S.No.	(2) Variable	(3) Unit	(4) India	(5) Remarks
1	Total population	million	796.60	1987-88
2	Urban fraction		0.27	
3	Urban population	million	215.08	
4	Refuse generation rate	kg/cap/d	0.40	
5	Total refuse	Tg/yr	31.40	
6	Moisture fraction		0.31	
7	Total dry refuse	Tg/yr	21.67	
8	Carbon fraction		0.12	explained in text
9	Total carbon	Tg C/yr	2.66	
10	Fraction landfilled		0.80	
11	Carbon landfilled	Tg C/yr	2.13	
12	Avg landfill temperature	C	35	
13	Fraction dissimilated [.014*(12)+.28]		0.77	
14	Methane production	Tg CH4/yr	2.18	

Agriculture & Forestry

Methane (CH_4) from animal husbandry

CH_4 is produced in the intestines of cattle and ruminants. All animals discharge a part of their feed energy in the form of CH_4 emissions as a consequence of fermentation of carbohydrates during the process of digestion. The rate of methane production is a function of

Methane from Animal Husbandry



Units:Tg/yr

the quantity and type of feed material, body weight, energy expenditure and enteric ecology [5]. Emissions are directly related to body weight, feeding levels, cellulose forage content in the diet and work output.

Table 10. Methane emissions from animal husbandry

(1) S.No	(2) Type of animal	(3) Emission factor (kg/cap/y)	(4) Population (million)	(5) Emissions (Tg CH4/yr)
1	Bovine	35.00	192.45	6.74
2	Buffaloes	50.00	69.78	3.49
3	Sheep	5.00	48.76	0.24
4	Goats	5.00	95.25	0.48
5	Pigs	1.00	10.07	0.01
6	Camels	58.00	1.08	0.06
7	Horses & ponies	18.00	0.90	0.02
8	Donkeys & mules	10.00	1.16	0.01
	Total			11.05

Sources :
Col(3): Ref.(1)
Col(4): Ref.(14)

The quantative estimates of emission rates are obtained from Crutzen et al [9]. Multiplication of emission factors by animal population [14] gives an estimate of CH_4 emissions from animal husbandry in India i.e. 11.05 Tg/yr. Detailed calculations are in Table 10.

Methane (CH_4) emissions from rice cultivation

CH_4 is released by waterlogged soils in paddy fields due to anaerobic decomposition of organic matter. The quantity of CH_4 produced is dependent on the growth phase of the crop, temperature, irrigation practices, presence of organic matter, fertilizer usage, rice species, number and duration of harvests etc. CH_4 emissions increase exponentially with rising temperature, roughly doubling for a temperature rise from 20°C to 25°C [22]. Global estimates of emission rates vary from 25 g/m^3/harvest (for California) to 54 g $/m^2$/harvest (for Italy). Owing to the paucity of data for Asian countries, the flux-temperature relationship is derived from Italian data and it gives a high flux of 120 g/m^2/harvest CH_4 for India.

Of the total area under rice cultivation, areas under upland cultivation have to be deducted since the fields in the hills are not inundated and therefore do not contribute to CH_4 emissions. For India, the fraction under upland farming is taken as 15% [1]. The total area under rice cultivation is 38.81 million hectares for 1987-88 [17] with 2.96 million hectares cultivated in the dry rabi season and 35.85 million hectares in the wet kharif season. Assuming that upland farming is during the wet season, the area with water-logged rice fields works out to be 32.99 million hectares.

Emission factors have been calculated on the basis of average soil temperature and average vegetation period. The emissions from inundated paddy fields work out to be around 29.44 Tg/yr. For detailed estimation of CH_4 emissions from rice fields, refer Table 11.

Table 11. Methane emissions from paddy fields

(1) S.No.	(2) Avg soil temperature (°C)	(3) Methane release rate (g/sqm/d)	(4) Vegetation period (days)	(5) Area harvested (Gmsq) (1987-88)	(6) Methane emissions (Tg/yr)
1 Dry season	26	0.68	120	29.60	2.42
2 Wet season	28	1.00	90	300.29	27.03
Total				329.89	29.44

Sources:
Col(5): Ref.(17)

Nitrous oxide (N_2O) emissions from use of nitrogenous fertilizers

Owing to rising global population and expanding food needs, fertilizer use is expected to become an increasingly significant source of N_2O emissions in the future, particularly in case of a developing country like India.

The evolution of N_2O from soils where fertilizer is used is dependent upon the type and amount of fertilizer used and its method of application, the soil and ambient conditions, the type of crop grown and irrigation practices adopted etc. The fraction of fertilizer lost to the atmosphere as N_2O ranges from 0.001-0.05% for nitrates, 0.01-0.1% for ammonium fertilizers and 0.5-5% for anhydrous ammonia [13]. The median estimate is taken to be 1.5 Tg/yr nitrogen from fertilizer use.

Emission factors for different fertilizers can be computed taking into account varying nitrogen content and emission rates of N_2O. The N_2O emission factors for nitrogenous fertilizers are calculated from their nitrogen content and the fraction of nitrogen released in the year of application. The quantity of nitrogen released is multiplied by the factor 44/28 to estimate the amount of N_2O released per unit of nitrogen. From the annual fertilizer production data of 1987-88 i.e. 17.93 Tg the emissions work out to be 0.038 Tg/yr [31]. Further details are presented in Table 12.

Table 12. N_2O emissions from use of nitrogenous fertilizers

(1) S.No.	(2) Type of fertilizer	(3) Nitrogen content (%)	(4) Nitrogen release (%)	(5) Emission factor {(2)*(3)*44/12} (g N2O/g)	(6) Annual production (1987-88) (Tg)	(7) Emissions (Tg)
1	Ammonium chloride	26.40	0.10	0.00041	0.08720	0.00004
2	Amm.nit.limestone	20.50	0.10	0.00032	0.42120	0.00014
3	Ammonium sulfate	21.00	0.10	0.00033	0.66110	0.00022
4	Amm.sulfate nitrate	26.00	0.10	0.00041	0.57880	0.00024
5	Urea	46.00	0.50	0.00361	10.03820	0.03628
6	Amm.phos.sulfate	14.50	0.10	0.00023	0.19500	0.00004
7	Diammonium phosphate	18.50	0.10	0.00029	1.24840	0.00036
8	Nitric phosphate	18.00	0.10	0.00028	0.62340	0.00018
9	Nitrate,soda-potash	15.00	0.10	0.00024	1.94400	0.00046
10	Super phosphate	0.00	0.00	0.00000	2.13610	0.00000
	Total				17.93340	0.03795

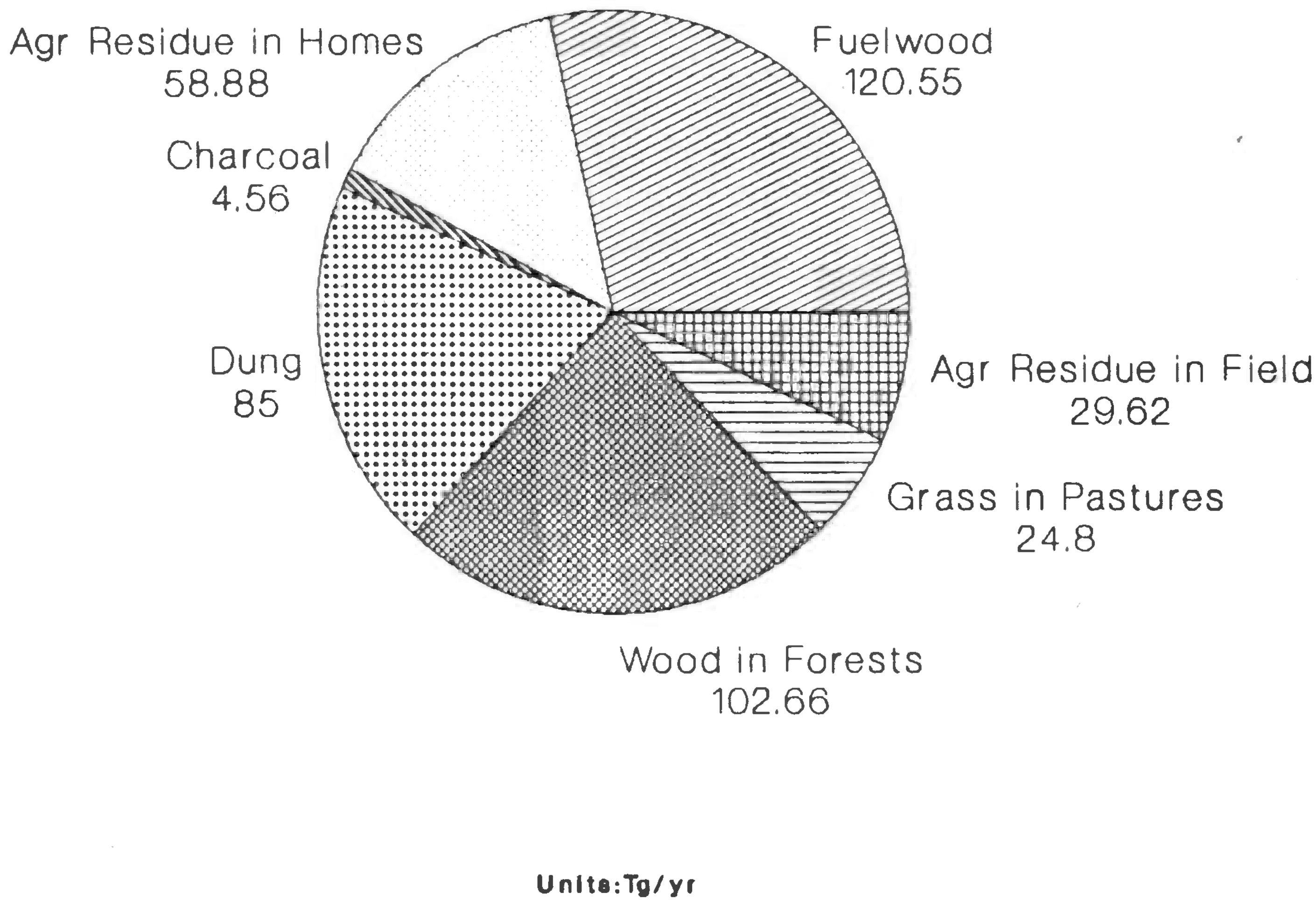
@ refers to production in 1985-86
SOURCES:
Col.(6): Ref.(31)

Emissions from biomass combustion

Burning of biomass can be broadly classfied into two categories. The first refers to burning in confined spaces for domestic and commercial use (ie. cooking, water heating etc) and the second to burning on a large scale, in relatively unconfined and uncontrolled conditions, as in slash and burn agriculture, prescribed burning in forests and pastures, accidental forest fires and burning of agricultural residues and crop stubbles in the fields. The quantity of dry biomass burnt annually is calculated for each of these categories.

Biomass combustion results in the release of four inorganic gases - CO_2, CH_4, CO and H_2O. The emissions of CO_2 contribute to greenhouse warming only to the extent that the emissions are in excess of those fixed by plants i.e. net magnitude of deforestation, which is dealt with in the next section.

Biomass Combustion



In India, the amount of biomass burnt annually is calculated to be about 426.06 Tg [15,23,24,28] or about 6.27% of the global level of 68000 Tg/yr. India's share of CO, CH_4 and N_2O emissions is taken to be the same proportion (6.27%) of the corresponding global figures(Table 13).

Table 13. Estimation of emissions from biomass burning

(1) S.No	(2) Variable	(3) Unit	(4) World	(5) India (1987-88)	(6) Remarks
1	Biomass burnt	Tg dry/yr	6800.00	426.06	refer table 13
2	CO emissions	Tg CO/yr	660.00	41.35	
3	CH4 emissions	Tg CH4/yr	55.10	3.45	
4	N20 emissions	Tg N2O/yr	2.20	0.14	

Table 14 & 15 contain detailed calculations of biomass burnt [24] in India from different activities.

Table 14. Estimation of biomass burnt annually in India

(1) S.No.	(2) Type/ location	(3) Consumption per capita (kg/yr)	(4) Population (million)	(5) Domestic use (Tg/yr)	(6) Commercial use (Tg/yr)	(7) Total (Tg/yr)
1	Fuelwood					
	Urban	116.40	215.1	25.04	0.94	25.98
	Rural	158.00	581.5	91.88	2.69	94.57
2	Charcoal					
	Urban	0.20	215.1	0.04	0.78	0.82
	Rural	3.80	581.5	2.21	1.53	3.74
3	Agr residue*					
	Urban+		215.1			
	Rural		581.5			58.88
4	Dung					
	Urban	35.60	215.1	7.66	0.00	7.66
	Rural	133.00	581.5	77.34	0.00	77.34
					total	268.98
		(7) Remarks	(8) Biomass/ unit area (kg/sqm)	(9) Area (sqkm/yr)	(10) Burning efficiency	(11) Biomass burnt (Tg/yr)
5	Wood in Forests	-burnt for regeneration	5.20	7919	0.10	4.12
		-burnt for protection against fires	5.20	9504	0.10	4.94
		-burnt owing to accidents	5.20	10000	0.80	41.60
		-burnt for shifting cultivation	5.20	10000	1.00	52.00
6	Grasses in Pastures	prescribed	0.84	125000		24.80
7	Agr residue In fields	10% of total available				29.62
					Total	157.07
	Total biomass burnt =		426.06			

* Total available crop residue (Table 14) less fodder and residue burnt in fields

Sources:
Col(3): Ref.(24),(28)
Col(4): Ref.(17)
Col(8),(9),(10): Ref.(24)

Table 15. Estimation of agricultural residue available

(1) S.N	(2) Type of crop	(3) Straw-grain ratio	(4) Output(Mt) (1987-88)	(5) Annual availability(Mt) (1987-88)	(6) Used as fodder(Mt) (1987-88)	(7) Biomass burnt(Mt) (1987-88)
1	Rice	1.50	56.43	84.65	84.65	0.00
2	Wheat	1.48	45.10	66.74	66.74	0.00
3	Jowar	2.26	11.85	26.77	26.77	0.00
4	Bajra	2.19	3.28	7.19	7.19	0.00
5	Barley	1.58	1.59	2.52	2.52	0.00
6	Maize	2.08	5.63	11.71	11.71	0.00
7	Ragi	1.85	2.33	4.30	4.30	0.00
8	Millets	2.10	1.17	2.45	0.00	2.45
9	Gram	1.98	3.62	7.17	7.17	0.00
10	Tur	1.13	2.23	2.52	0.00	2.52
11	Other pulses	1.80	5.18	9.33	0.00	9.33
12	Groundnut	3.55	5.67	20.14	0.00	20.14
13	Sesam	3.55	0.56	2.00	0.00	2.00
14	Rape,mustard	3.55	3.37	11.96	0.00	11.96
15	Linseed	1.83	0.37	0.68	0.00	0.68
16	Castor	3.55	0.19	0.66	0.00	0.66
17	Potato	0.30	14.14	4.24	0.00	4.24
18	Cotton	7.55	1.09	8.25	0.00	8.25
19	Jute & mesta	1.37	1.22	1.67	0.00	1.67
20	Sugarcane	0.10	196.72	19.67	19.67	0.00
21	Coconut(.2kg/nut	0.20	7.56	1.51	0.00	1.51
	Total			296.15	230.73	65.42

Sources:
Col(3),(6): Ref.(23)
Col(4): Ref.(15)

Carbon dioxide (CO_2) emissions from deforestation

The world's forest's are vast storehouses or "sinks" for carbon. Worldwide loss of forest cover aggravates the greenhouse problem, by releasing this vast stock of carbon into the atmosphere as CO_2. The loss of a carbon sink due to deforestation is difficult to estimate because of the uncertainties regarding areas deforested and degraded, and the surface and soil carbon contents of various ecosystems. For India, if we consider the case where 50% of the plants in the afforested areas survive , the net deforestation for the period 1952-1988 works out to be 0.412 million hectares [18]. The emissions are calculated to be 0.59 Tg/yr (Table 18).

Table 16. Extent of deforestation from various activities

A. Forest area lost for various purposes between 1952-1980

	Activity	Period	Area lost/ diverted (m.hac.)
1	Agricultural activities	1952-80	2.623
2	Submergence due to river valley projects	1952-80	0.502
3	Industries & townships	1952-80	0.134
4	Transmission lines, roads	1952-80	0.061
5	Miscellaneous	1952-80	1.008
	Total		4.328

B. Forest land diverted for non-forest use since the enforcement of Forest (Conservation) Act, 1980

Year	Forest land diverted (hectares)
1980	negligible
1981	2672.040
1982	3246.540
1983	5702.010
1984	7837.590
1985	10608.070
1986	11963.110
1987	72780.050
1988	126242.980 *
Total	241052.390

C.	Total forest area under encroachment as on 1-1-1983	700632.620
D.	Cumulative deforestation from 1952-87 (m.hac) {total a+total b+c}	5.270

* Assumed to be equal to the annual average rate of growth for the period 1981-87

Sources : Ref.(18),(19)

Table 17. Area planted/afforested since the beginning of First Five Year Plan

(1) S.No.	(2) Plan period	(3) Area afforested plan period (m.hac)	(4) Cumulative area afforested (m.hac)
A. (i)	First	0.052	0.052
(ii)	Second	0.311	0.363
(iii)	Third	0.583	0.946
(iv)	1966-69	0.453	1.399
(v)	Fourth	0.714	2.113
(vi)	Fifth	1.210	3.323
(vii)	1979-80	0.222	3.545
(vii)	Sixth	4.650	8.195
(viii)	1985-86	1.521	9.716
B.	Cumulative area afforested till 1985-86 (m.hac) {A(i)to(vii)}		9.716
C.	Survival rate		50%
D.	Net area afforested (m.hac) {B*.5}		4.858
E.	Cumulative area deforested till 1987-88 (m.hac)		5.270
F.	Net deforestation (m.hac) {E-D}		0.412

Sources : Ref. (18), (19)

Table 18. CO_2 emissions from deforestation

(1) S.No.	(2) Variable	(3) Unit (range)	(4) World	(5) India
1	Acreage deforested	m. hac.	1792.00	0.41
2	CO_2 Flux	Tg C/yr	700.00	0.16
		Tg CO2/y	2566.67	0.59

Sources:
Col(5): Ref.(18)

Nitrous oxide (N_2O) emissions from forested lands brought under cultivation

These emissions are based on the new areas brought under cultivation. Globally, between the period 1965-84, annual incremental area brought under cultivation was 6.5 million hectares. In India the figure is 0.3 million hectares per annum [1].

The annual global flux from this source is estimated to be 0.4Tg N, the contribution from Indian soils is about 0.02 Tg N/yr or 0.03 Tg N_2O/yr (Table 19).

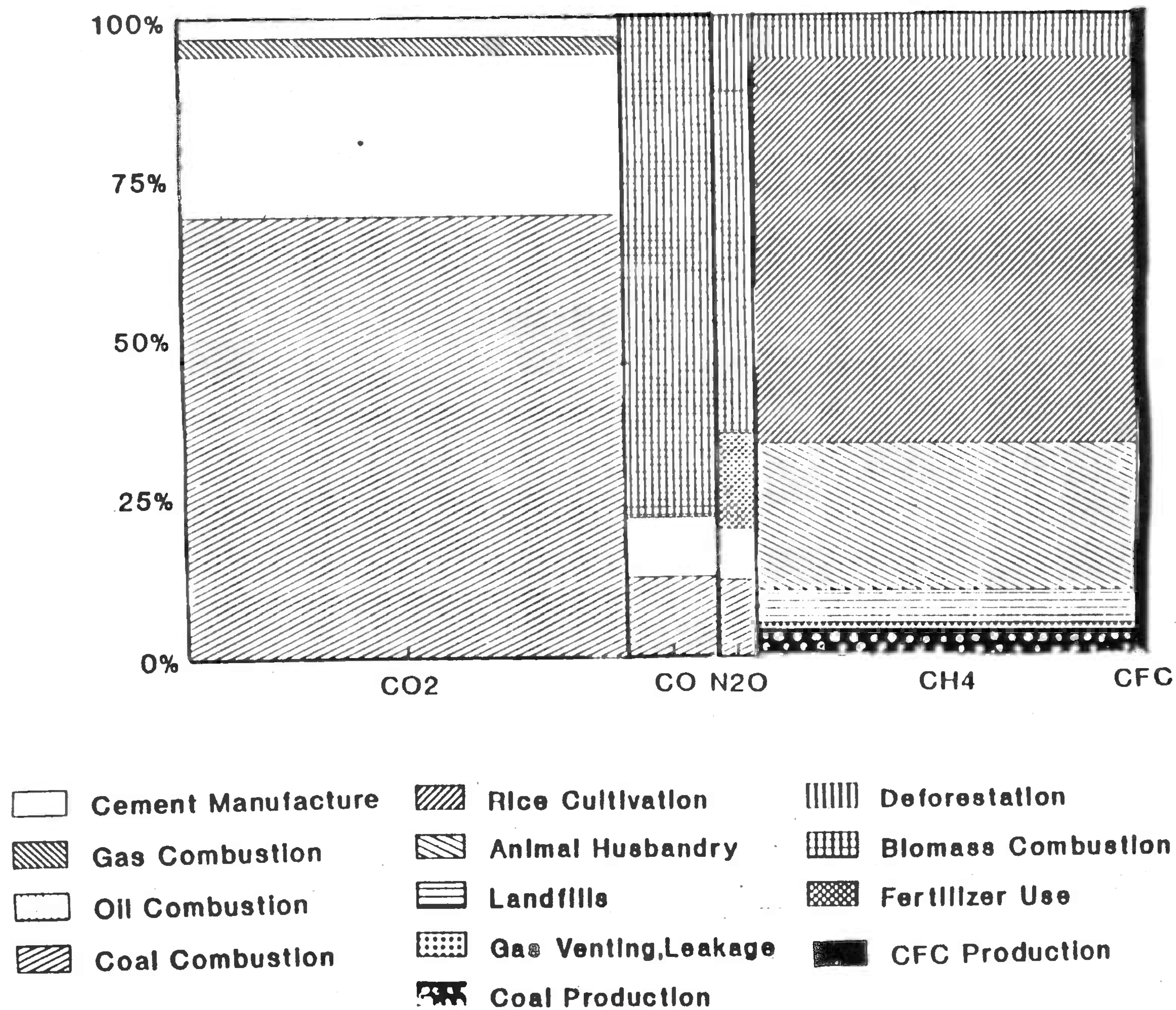
Table 19. N_2O emissions from forested land brought under cultivation

(1) S.No.	(2) Variable	(3) Unit	(4) World	(5) India
1	New area brought under cultivation (1965-1984)	m.hac/yr	6.50	0.30
			0.40	0.02
2	Nitrogen flux	Tg N/yr		
3	Nitrous oxide flux	Tg N2O/yr	0.63	0.03

CONCLUSIONS

The results of the above study are presented in the last three tables. Table 20 gives a quick overview of the total emissions of greenhouse gases from various activities in India. Based on the Global Warming Potential (GWP) (by wt) of each of the gases, the cumulative GWP of each gas from each activity and its percentage share is worked out in Table 21. India's contribution to global warming is calculated in Table 22 from India's emissions of greenhouse gases and the GWP of each gas. The GHG emissions for India, weighted by the GWP, amounted to 1225 Tg CO_2-equivalent in 1987 and, as a percentage of global emissions, stood at 3.84%. The main contributors to this were CO_2 and CH_4 with shares of about 46% and 40% respectively. It would, therefore, be relevant

Relative Contribution of Various Activities and Gases to Global Warming



for India to assign priority to these two gases, both in the context of global negotiations and in policies for reducing GHG emissions.

Table 20. Summary of estimates of anthropogenic emissions from India

Activities	CO2	CO	CH4	N2O	CFC's
I Energy	541.52	11.45	2.45	0.05	-
Coal production	-	-	2.17	-	-
Coal combustion	389.33	6.79	0.03	0.03	-
Oil combustion	138.01	4.65	0.02	0.02	-
Gas combustion, flaring	14.18	0.01	0.00003	0.00003	-
Gas venting, leakages	-	-	0.23	-	-
II Industry	18.77	-	2.18	-	0.01
Cement manufacture	18.77	-	-	-	-
CFC's	-	-	-	-	0.01
Landfills	-	-	2.18	-	-
III Agriculture & Forestry	0.59	41.35	43.94	0.21	-
Animal husbandry	-	-	11.05	-	-
Rice cultivation	-	-	29.44	-	-
Fertiliser use	-	-	-	0.04	-
Biomass combustion	-	41.35	3.45	0.14	-
Deforestation, landuse changes	0.59	-	-	0.03	-
TOTAL EMISSIONS(Tg)	560.88	52.80	48.57	0.26	0.01

Table 21. Global Warming Potential of the gases in India (Emissions per year x GWP(wt))

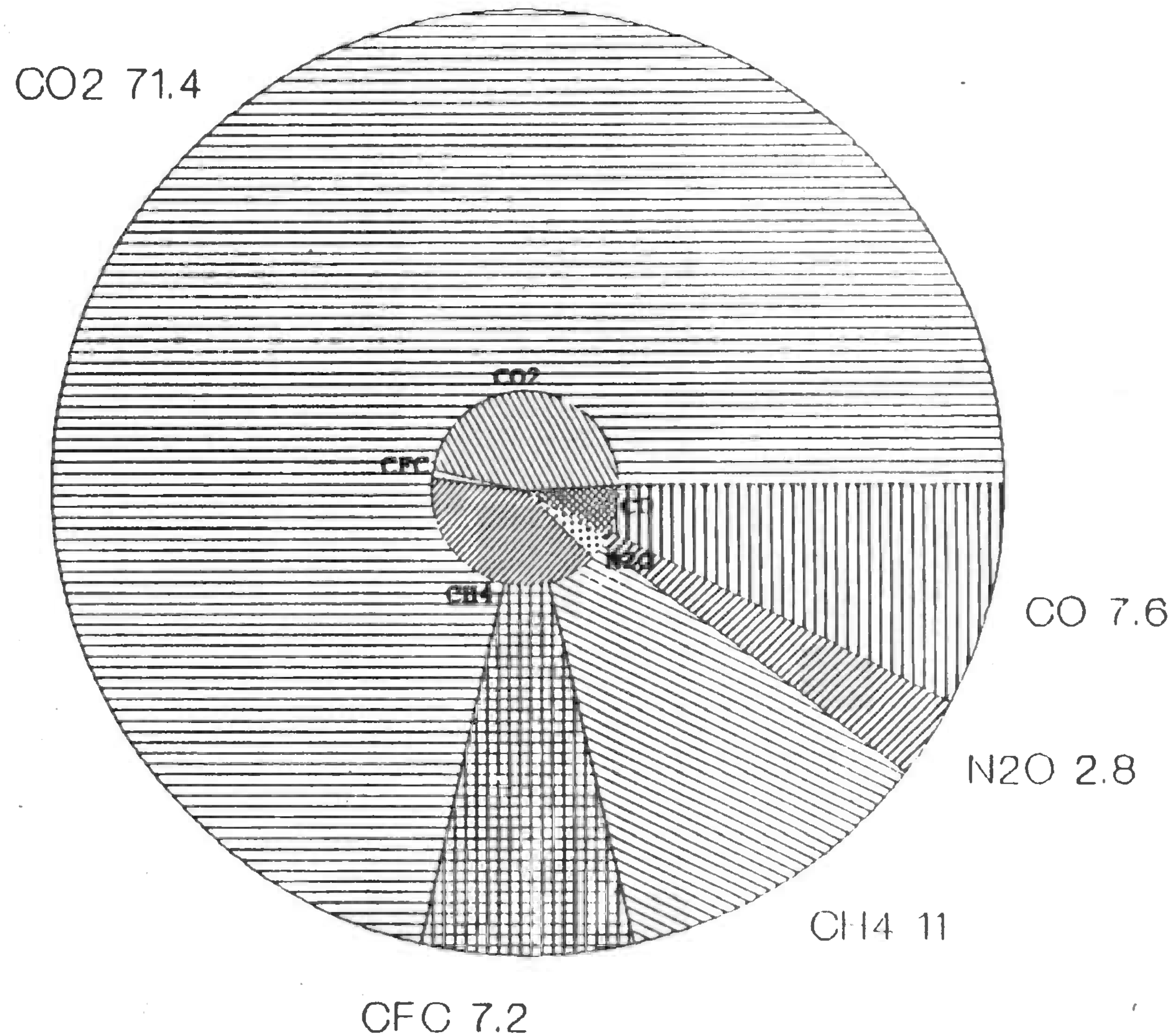
Activities	CO2	CO	CH4	N2O	CFC's	GWP-activity share	Percent Share
I Energy	541.52	25.19	24.50	9.01	-	600.22	49.02
Coal production	-	-	21.70	-	-	21.70	1.77
Coal combustion	389.33	14.94	0.30	5.40	-	409.97	33.48
Oil combustion	138.01	10.23	0.20	3.60	-	152.04	12.42
Gas combustion, flaring	14.18	0.02	0.00	0.01	-	14.21	1.16
Gas venting, leakages	-	-	2.30	-	-	2.30	0.19
II Industry	18.77	-	21.80	-	15.33	55.90	4.56
Cement manufacture	18.77	-	-	-	-	18.77	1.53
CFC's	-	-	-	-	15.33	15.33	1.25
Landfills	-	-	21.80	-	-	21.80	1.78
III Agriculture & Forestry	0.59	90.97	439.40	37.44	0.00	568.40	46.42
Animal husbandry	-	-	110.50	-	-	110.50	9.02
Rice cultivation	-	-	294.40	-	-	294.40	24.04
Fertiliser use	-	-	-	6.84	-	6.84	0.56
Biomass combustion	-	90.97	34.50	25.20	-	150.67	12.30
Deforestation, landuse changes	0.59	-	-	5.40	-	5.99	0.49
GWP-gas share	560.88	116.16	485.70	46.45	15.33	1224.51	100.00
Percent share	45.80	9.49	39.66	3.79	1.25	100.0	

* The GWP(wt) of CFC-11 has been taken as the GWP(wt) of the CFC's.

Table 22. Estimation of India's Contribution to Global Warming

Gas	World (Tg)	India (Tg)	GWP	World (GWP)	India (GWP)	India/World (%)	World Contribution To GW	India Contribution To GW
CO2	22718.10	560.88	1	22718.10	560.88	2.4689	0.7137	1.762
CO	1102.00	52.80	2	2424.40	116.16	4.7913	0.0762	0.365
CH4	349.00	48.57	10	3490.00	485.70	13.9169	0.1096	1.525
N2O	5.00	0.26	180	900.00	46.80	5.2000	0.0283	0.147
CFC's	1.77	0.01	1300	2301.00	13.00	0.5650	0.0723	0.041
Total								3.840

Shares in GWP
World-India (inset)



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FOREST BIOMASS BURNING IN INDIA

O.N. Kaul

INTRODUCTION

There seems to be growing scientific evidence that increasing atmospheric concentration of "Greenhouse Gases" (GHGs) will alter the global climate, thus threatening global security, the world economy and the natural environment. Various human activities are now increasing the concentration of greenhouse gases in the earth's atmosphere, thereby intensifying the "Greenhouse Effect" and causing "Global Warming". It has been estimated (Ahuja, 1989) that 22,718 Tg of CO_2 (1 Tg = 1 Teragram = 10^{12} gm), 1,102 Tg of CO, 350 Tg of CH_4, 5.0 Tg of NO_2 and 1.77 Tg of Chloroflourocarbons (CFCs), with 20% uncertainity, are being emitted annually, into the earth's atmosphere, globaly, from anthropogenic sources and 4% of these emissions originate from India excluding any contribution that may occur from tropospheric O_3 and some other trace gases like NO_x. This contribution could rise with increasing developmental activities in the country.

The contribution of various GHGs and policy sectors to global warming indicate (UNEP, 1989) that rising concentrations of atmospheric CO_2 are likely to be responsible for about 50% of global warming over the next several decades, the other half being due to other GHGs (CFCs, CH_4, O_3, N_2O, etc in that order). As regards the contribution of various policy sectors to global warming the greatest potential is from energy (49%) and industrial (24%) sectors but more than one-quarter (27%) of potential warming is from biological sectors of forestry and agriculture;

forestry contributing about 14% through forest biomass burning and deforestation.

Biomass burning results in the emission of all the four inorganic GHGs, namely, CO_2, CH_4, CO, and N_2O, the emissions of CO_2 contributing to greenhouse warming only to the extent that these emissions are in excess of that fixed in photosynthesis. Of the global emissions of various GHGs, from anthropogenic sources, mentioned in Para 1, 61% CO, 16% CH_4 and 44% N_2O is attributed to biomass burning for energy and non-energy related sources (Ahuja, 1989). Further, it is estimated that 6,800 Tg of biomass (dry matter) is burnt annually, world-wide, (Crutzen et al, 1979) of which about 496 Tg (7.3% of global) is burnt in India. Accordingly, the emissions of various GHGs like CO, CH_4, N_2O, from India, as Tg per year have been calculated to be of the order of 48.5, 4.1, and 0.2 respectively (Ahuja, 1989). These emissions have to be taken with necessary reservations as they are fraught with major uncertainities and externalities due to lack of information, data, and statistics on various aspects of biomass burning like areas burnt, biomass densities, fractions of biomass burnt, burning efficiencies etc., but all the same they are a pointer in the right direction, for taking any effective action that may be necessary.

An attempt has been made in the present paper to identify the various sources/activities of forest biomass burning in India, and thereby estimate the various types of forest biomass burnt annually, in recent years, in the context of estimation of emissions of GHGs. The estimates mentioned in this paper are at best only indicative of the nature and extent of the problem due to extreme paucity of information and data on the subject and uncertainity of certain parameters. As such they have to be taken with due reservations. Much better information and statistics are needed to make these estimates more realistic and dependable.

TERRESTRIAL BIOMASS AND CARBON FLUXES

The influence of terrestrial biomass on the atmospheric carbon cycle is potentially very large, though very difficult to estimate. With about 700 Pg (1 Pg = 1 Petagram = 10^{15} gm) present in the atmosphere as CO_2, 600 to 1000 Pg in the land biota and a world-wide carbon detritus pool estimated to be in the range of 700-3,000 Pg (Seiler and Crutzen, 1980) or even more (Table 1, Houghton and Woodwell, 1989), it is clear that carbon shifts in land biota and detritus pools can result in important changes of CO_2 in the atmosphere.

Table 1. Major carbon reservoirs of the World

Reservoir	Size of Reservoir (10^9 Metric tons)
World Vegetation	560
World Soils	1,500
Atmosphere	735
Oceans	36,000
Fossil Fuel Reserves	5,000 to 10,000

Some recent studies have shown that global terrestrial biomass is decreasing with time, mostly due to deforestation in tropical and subtropical regions, so that the biosphere, currently, is acting as a large net source of atmospheric CO_2. The release of CO_2 into the atmosphere has been estimated in recent years by several authors using different pathways and methods, which are, unfortunately, often not well documented and clear (Seiler, and Crutzen, 1980). It is also clear that there exist major discrepancies in the published net and gross carbon fluxes between the oceans, the biosphere and the atmosphere.

The reported net releases vary widely ranging from 0.5 Pg C to more than 8 Pg C per year, to which should be added the net input of 5.6 Pg C per year from burning of fossil fuels to get the total input of CO_2 into the atmosphere (Seiler and Crutzen, 1980). A recent estimate of annual carbon fluxes is given in Table 2 (Houghton and Woodwell, 1989) which indicates a net gain of 3.00 billion tonnes of carbon as CO_2 by the atmosphere, as a result of various removals and emissions.

Table 2. Annual carbon fluxes

Source	Removals of Carbon from atmosphere as CO_2 (10^9 Metric tons)	Emissions of Carbon into atmospher as CO_2 (10^9 Metric tons)
Photosynthesis	100	-
Respiration by plants	-	30
Soil respiration	-	50
Fossil fuel burning	-	5
Deforestation	-	2
Physicochemical processes at the sea surface	104	100
Total	204	207
Net gain to atmosphere ----- 3.0 billion tonnes		

SOURCES OF FOREST BIOMASS BURNING

The various sources/activities of forest biomass burning identified in the context of emission of GHGs are as follows:

- Fuelwood
- Shifting cultivation
- Forest fires
    - Unregulated fires
    - Prescribed burning
        - Natural regeneration
        - Protection fires
        - Plantations
- Forest encroachments
- Forest area lost
- Burning of grasses in forests
- Burning of forest litter

The above sources/activities identified are briefly discussed hereafter.

Fuelwood

In common with many developing countries, India, consumes energy in various forms ranging from electricity obtained from nuclear fuels to agriculture waste and animal dung. The most important commercial sources of energy are coal, oil and electricity;the details regarding production and consumption of these forms of energy being regularly recorded by the concerned agencies. The production and consumption data of the most significant sources of non-commercial energy sources (fuelwood, agricultural waste, and animal dung) are very scanty (except the recorded production from Government forests) and are derived by computations based on the quantity of energy required in the households, population growth, economic development and such other factors influencing the consumption of these forms of energy.

A considerable amount of forest biomass, in India, is annually burnt as fuelwood, the proportion of fuelwood, agriculture waste and animal dung in the total non-commercial energy sector being estimated to be 65%, 20% and 15% respectively (Anon., 1979). While the recorded removals from Government forests supply only a fraction of the fuelwood consumed in the country (about 25%), the bulk of the fuelwood supply comes from the so called "Unrecorded Sources" which include supply from private lands, gardens, trees around houses, shifting cultivation areas and the like. However, a large quantity of fuelwood is collected from the nearby forests, by the local population, as a matter of right and this removal does not find a record anywhere. Similarly, there is a lot of pilferage (illicit removal) from the nearby forests which meets a large part of the fuelwood needs of the neighbouring population and such removals also go unrecorded. In fact, most of the fuelwood being used in the rural areas is collected mainly from the nearby forests and people collect fuelwood from distant forests only when no firewood is available nearby.

Based mainly on per capita consumption, population growth, economic development as well as the availability of alternative sources of energy, various estimates of consumption/demand projections of fuelwood in India have been made by different agencies (Table 3) from time to time for the period 1953-54 to 2004-2005. While the figures in Table 3 generally indicate a substantial rise in the requirement of fuelwood in the country by the year 2000 and 2005, there is a great variation in the estimates projected in these studies. For example, the National Commission on Agriculture indicated the requirement for fuelwood in India for the years 1980, 1985 and 2000 as 123, 134.7 and 150 million tonnes (Anon., 1976). The report of the Working Group on Energy Policy has projected the demands of fuelwood as 139.7, 138.7, 134 and 111.9 million tonnes for the years 1982-83, 1987-88, 1992-93

Table 3. Consumption/Demand projections of fuelwood

Year	Estimates of Consumption/Demand Projections (Million Tonnes)						
	(5) (8) (13) (15) (30)	(4)	(12)	(15)	(18)	(14)	(34)
1953-54	86.3						
1960-61	99.6						
1965-66	109.3						
1970-71	117.9						
1975-76	133.1						
1980		123.0					
1982-83	139.7						
1985		134.7	120-130				
1987				157.0			
1987-88	138.7						
1991					306.5		
1992-93	134.0						
1996					342.8		
1999-2000						191.6	
2000		150.0					
2000-01	111.9						
2001					383.6		256.7
2004-05			300-330				

Note : Figures in brackets on top of each column indicate the references of the estimates.

and 2000-01 (Anon., 1979), the demand showing a decreasing trend because of the presumed availability of alternative sources of energy. A recent study of the Planning Commission (Anon., 1989) has placed the demand projections of fuelwood at 306.5, 342.8 and 383.6 million tonnes for the years 1991, 1996 and 2001. However, the Seventh Five Year Plan document of the Planning Commission has estimated the fuelwood requirement of 191.60 million tonnes for 1999-2000 (Anon., 1987). The Advisory Board for Energy has forcast the demand for fuelwood in the country as 300-330 million tonnes in 2005 (Anon., 1985 a).

With such large variations in consumption/demand projections of fuelwood presented in Table 3, it becomes necessary that these estimates are reconciled before a final set of figures is adopted for the present study. It is also to be noted that the fuelwood consumption in the country is going to rise, in the foreseeble future, atleast in the rural sector, due to the present energy crises and the difficulty of alternative sources of energy being available more freely and cheaply. Plant biomass would, therefore, remain a major source of energy in the near future.

In order, therefore, to obtain any dependable estimates of consumption/demand projections of fuelwood for different years, eight observations of consumption/demand projections in Table 3 (these observations were considered to be more realistic for various reasons including past consumptions) were plotted against the corresponding years and a regression worked out. The consumption/demand projections for different years were then calculated using the regression equation:

$$Y = -4268.58 + 2.228 \times X$$

where Y is the consumption/demand projection in million tonnes and X is the year of consumption/demand projection. The values so obtained are set out in Table 4 (Col.2) and range from 82.70 million tonnes in 1953 to 154 million tonnes in 1985, 187.42 million tonnes in the year 2000 and 198.56 million tonnes in 2005. These values of consumption/demand projections appear to be reasonably correct looking at past consumptions and the rate of growth and have been adopted in the present study.

Table 4 (Col.3) also indicates the quantity of fuelwood available for burning, on a dry weight basis, in different years from 1953 to 2005. The values range from 74.43 million tonnes in 1953 to 138.60 million tonnes in 1985, 168.69 million tonnes in the year 2000 and 178.70 million tonnes in 2005.

Table 4. Consumption/Demand patterns of fuelwood

Year	Consumption/Demand Projections (Million Tonnes)	Dry Weight (Million Tonnes)	Fuelwood Burnt (Million Tonnes)
(1)	(2)	(3)	(4)
1953	82.70	74.43	66.99
1960	98.30	88.47	79.62
1965	109.44	98.49	88.64
1970	120.58	108.54	97.69
1975	131.72	118.55	106.69
1980	142.86	128.57	115.71
1985	154.00	138.60	124.74
1990	165.14	148.63	133.77
1995	176.28	158.65	142.79
2000	187.42	168.69	151.82
2005	198.56	178.70	160.83

Notes: 1) Figures in Col.2 are those obtained from the regression equation.

2) Figures in Col.3 are dry weights of the figures in Col.2 which are on air dry basis having an average moisture content of 10%.

3) Figures in Col.4 are based on the assumption that the overall burning efficiency of fuelwood is 90%.

Though burning of fuelwood is almost complete, as a first approximation an overall burning efficiency of 90% could be assumed. The actual quantity of wood, therefore, burnt annually as fuel, in different years, is shown in Col. 4 of Table 4, the remaining quantity being left as Charcoal. In terms of million tonnes of fuelwood burnt/ to be burnt annually, in different years, the values respectively are 66.99, 124.74, 151.82 and 160.83 for the years 1953, 1985, 2000 and 2005.

Shifting cultivation

Shifting Cultivation (or Jhumming, as the practice is commonly known in India), a legacy from the neolithic period is practised in about 16 states of the country (being most prevelant in the seven Northeastern states and Orissa), with very deep roots and very wide ramifications, as the tribal group system of cultural and ethenic mores is typical of the area and has resisted change for a very long time. It is rooted in the cultural ethos of the tribal societies, and although their traditional economy has evolved to some extent, the constraints imposed by the environment and the increasing population combined with shrinking resources have invariably led to short term adaptations with possibilities of disaster in the long run.

In its simplest form the practice consists of clearing a forest area of its vegetation during the winter months of November - December and allowing the cut vegetation to dry up till March - April of the following year, when it is burnt in situ after making a fire line around the Jhum plot. This is followed by raising of agricultural crops in mixtures which are harvested sequentially as the crop matures. The Jhumed plot is then abandoned, and the cultivator moves to another plot during the next winter season for Jhumming, allowing the previous plot to regenerate to be Jhumed again after keeping it fallow for some years.

While clearing the land for Jhumming, the cultivator slashes down the undergrowth, bamboos and smaller trees, while larger trees may often be left behind, along with stumps of smaller trees due to difficulties of extraction because of the high labour input involved or to speed up fallow regeneration or provide shade to the crops grown. These larger trees may, therefore, remain on the Jhum plot through successive Jhum cycles till they are burnt in a Jhum operation or are extracted by the cultivator . In certain cases the slashing of vegetation may be partial in that the undergrowth is completely cut down and the very sparsely distributed trees may merely be topped along with their branches so that they are able to recuperate quickly during the fallow period when the second-growth vegetation comes up. Depending on the accessibility of the area, some timber, bamboos and fuelwood may be extracted by the cultivator, while clearing the plot for Jhumming, for his personal consumption and/or for export outside the village for monetary returns.

Adequate data about the extent of forest area affected by shifting cultivation or the annual area put under this practice are not available, in the absence of any regular surveys and transitory nature of the practice, except for very rough estimates mostly based on small samples and intellegent guesses. The earlier estimate (1956) places the annual area involved in shifting cultivation at 0.542 million ha and the number of tribal families affected at 529 thousand, with a population of 2.645 million (Kaith, 1958) or a mean family size of five. The later estimates made by various agencies, from time to time, are set in Tables 5.1, 5.2 and 5.3 and are discussed hereafter.

Tables 5.1, 5.2, and 5.3 present the extent of shifting cultivation, respectively, on an all India basis, for the Northeastern states (7 states) of the country and for Northeastern states and Orissa state together. It is observed that, on an all India basis (Table 5.1), the total area affected by shifting cultivation has increased by 81.2% (from 2.710 to 4.912 million ha) during the period 1956 to 1984-85. Correspondingly the annual area under this practice has also gone up from 0.542 to 1.000 million ha (84.5%) in the same period. The total population involved has increased by 17.6% from (2,645 to 3,110 thousand) for the period 1956 to 1983 with a corresponding increase in the number of familie, from 529 to 622 thousand (17.6%). As a result the area cultivated per family has also risen by 56.9%, form 1.02 to 1.60 ha between 1956 and 1983. In this analysis certain observations in Table 5.1 (Col.2), regarding the total area affected by shifting cultivation in different years have been excluded, for obvious reasons, particularly for the years 1977 and 1984.

The position with regard to extent of Jhumming in the Northeastern states, where it is most prevelant, is shown in Table 5.2 . While there are certain inconsistancies with regard to the estimates of total area affected by shifting cultivation, as well as the annual area under this practice (Cols. 2 and 3), made by various agencies for different years (these inconsistancies are bound to occur as the estimates are not based on any actual surveys but on rough intelligent guesses), generally, both the total area affected by shifting cultivation and the annual area have increased during the period 1956 to 1984-85. The annual area has increased by 41.8% from 0.273 to 0.387 million ha (Col. 3), while the total area affected has risen from 1.365 to nearly two million ha (46.5%) during the same period (Col. 2). Increasing trends are also observed in the total population involved in Jhumming as also the number of families (Cols. 5 and 6). While the total population has gone up from 1,249 to

Table 5.1. Extent of shifting cultivation in India: (All India)

Estimates for the Year	Total Area Affected by Shifting Cultivation (Million Hectares)	Annual Area Under Shifting Cultivation (Million Hectares)	Col (3) as % of Col (2)	Total Population Involved (000)	No. of Families Involved (000)	Mean Family Size	Area Cultivated per Family (HA)	No. Of Communities Practising Shifting Cultivation	Reference
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1956	(2.710)	0.542	20.0	2,645	529	5	1.02	109	(25)
1960-61	2.705	0.541	20.0	2,589	(518)	-	1.04	-	(2)
1977	9.470	-	-	-	-	-	-	-	(21)
1983	4.357	0.996	22.9	(3,110)	622	-	1.60	-	(9)
1984	6.770	0.990	14.6	-	-	-	-	-	(10)
1984-85	4.912	1.000	20.4	-	-	-	-	-	(17)

Note: (1) Figures in brackets are calculated values taking a mean family size of 5.
(2) Figures in brackets under Col.2 are calculated values taking a Jhum cycle of 5 years.

2,215 thousand (73.3% increase) during the years 1956 to 1983, the total number of families (Col.6) has increased by 77.2% (250 to 443 thousand) during the same period. The area cultivated per family (Col.8) seems to be almost constant, if not decreased (1956 to 1983), being around one hectare per family, even though there has been a population increase. This could be possible because of the land constraint and the fact that a number of schemes are presently in operation in the Northeastern states to wean away the people from this practice.

As Jhumming is also extensively practised in Orissa, Table 5.3 indicates the extent of this practice in the Northeastern states and Orissa together. Excluding the data for the years 1977 and 1984, an increasing trend is observed in the total area affected by shifting cultivation (Col. 2), annual area jhumed (Col. 3), total population and number of families involved (Cols. 5 and 6) and the area cultivated per family (Col.8), during the period 1956 to 1983 and 1984-85 ; the respective percentage increases being of the order of 110.2, 117.8 ,29.8, 29.8 and 66.7.

Table 5.2. Extent of shifting cultivation in India: (North-eastern States)

Estimates for the Year	Total Area Affected by Shifting Cultivation (Million Hectares)	Annual Area Under Shifting Cultivation (Million Hectares)	Col (3) as % of Col (2)	Total Population Involved (000)	No. of Families Involved (000)	Mean Family Size	Area Cultivated per Family (HA)	No. Of Communities Practising Shifting Cultivation	Reference
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1956	(1.365)	0.273	20.0	1,249	250	5	1.09	22	(25)
1960-61	1.360	0.272	20.0	1,258	(252)	-	1.08	-	(2)
1971	2.695	0.457	16.9	(2,125)	425	-	1.08	-	(31)
1974	2.696	0.455	16.8	(2,125)	425	-	1.07	-	(24)
1975	2.696	0.456	16.8	-	-	-	-	-	(3)
1975	7.341	-	-	-	-	-	-	-	(19)
1976	2.696	0.455	16.8	(2,460)	492	-	0.92	-	(4)
1977	7.341	-	-	-	-	-	-	-	(21)
1983	1.352	0.387	28.6	(2,215)	443	-	0.88	-	(9)
1984	2.800	0.416	14.9	-		-	-	-	(10)
1984	6.285	-	-	-	-	-	-	-	(19)
1984-85	1.908	0.387	20.3	-	-	-	-	-	(17)

Note: (1) Figures in brackets are calculated values taking a mean family size of 5.
(2) Figures in brackets under Col.2 are calculated values taking a Jhum cycle of 5 years.

The above percentage increases are significant, to be taken note of, when compared to percentage increases (mentioned earlier) on an all India basis and for the Northeastern states only, to indicate the substantial contribution of Orissa to Jhumming. For example, while the annual area under shifting cultivation, during the period 1956 to 1984-85, has increased by 84.5% and 41.8%, respectively, on an all India basis and for the Northeastern states, there has been a rise of 117.8% for the Northeastern states and Orissa put together. The same is the case with regard to the annual area affected by Jhumming as well as the area cultivated per family.

The data presented in Table 6, on the annual extent of and total area affected by shifting cultivation for the period 1956 to 1984-85, on an all India basis, Northeastern states and Northeastern states and Orissa together is also striking as far as the contribution of Orissa state is concerned. Of the One million ha (Col.2) under shifting cultivation in the country, in 1984-85, Northeastern states and Orissa together account for 91.7% of the area and the balance (8.3%)is contributed by the other eight states. Out of the 91.7% area under Jhumming in Northeastern states and Orissa, the Northeastern states account for only 38.7%, the remaining (53.0%) being contributed by Orissa, which is substantial. The same is the case with regard to the total

Table 5.3. Extent of shifting cultivation in India : (North-eastern states & Orissa)

Estimates for the Year	Total Area Affected by Shifting Cultivation (Million Hectares)	Annual Area Under Shifting Cultivation (Million Hectares)	Col (3) as % of Col (2)	Total Population Involved (000)	No. of Families Involved (000)	Mean Family Size	Area Cultivated per Family (HA)	No. Of Communities Practising Shifting Cultivation	Reference
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1956	(2.165)	0.433	20.0	2,249	450	5	0.96	42	(25)
1960-61	2.160	0.432	20.0	2,194	(439)	-	0.98	-	(2)
1977	9.000	-	-	-	-	-	-	-	(21)
1983	4.000	0.917	22.9	(2,920)	584	-	1.60	-	(9)
1984	6.509	0.946	14.5	-	-	-	-	-	(10)
1984-85	4.556	0.917	20.1	-	-	-	-	-	(17)

Note: (1) Figures in brackets are calculated values taking a mean family size of 5.
(2) Figures in brackets under Col.2 are calculated values taking a Jhum cycle of 5 years.

Table 6. Annual extent of shifting cultivation

Estimates for the Year	Annual Area Under Shifting Cultivation (Million Hectares)			Col (3) As % Of Col (2)	Col (4) As % Of Col (2)	Total Area Affected by Shifting Cultivation (Million Hectares)			Col (8) As % Of Col (7)	Col (9) As % Of Col (7)
	ALL INDIA	NE STATES	NE STATES & ORISSA			ALL INDIA	NE STATES	NE STATES & ORISSA		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1956	0.542	0.273	0.433	50.4	79.9	2.710	1.365	2.165	50.4	79.9
1960-61	0.541	0.272	0.432	50.3	79.8	2.705	1.360	2.160	50.3	79.8
1983	0.996	0.387	0.917	38.9	92.1	4.357	1.352	4.000	31.1	91.8
1984	0.990	0.416	0.946	42.0	95.6	6.770	2.800	6.509	41.4	96.2
1984-85	1.000	0.387	0.917	38.7	91.7	4.912	1.908	4.556	38.8	92.8

Note: NE states means Northeastern states.

area affected by this practice. The position being similar for other years also as far as the annual area and total area affected are concerned.

A perusal of Col.4 of Tables 5.1,5.2 and 5.3 shows that the total area affected by shifting cultivation, in a particular year, is generally five times the annual area (around 20%), which implies a disturbing shortening of the Jhum cycle (crop-fellow cycle) to 5 years only. It has been reported that this cycle, about 50 to 60 years back, was in the range of 30-40 years (Anon., 1976) or 20-30 years (ICAR, 1983). Table 7 sets the Jhum cycles for various states of the country, in the last four decades, as reported by different agencies, though locally the cycle may be as short as 3-6 years (ICAR, 1983) or even 2-3 years (Kaul, 1980), which precludes the necessary flexibility to allow the natural processes of recuperation to repair these damaged ecosystems. A Jhum cycle of 5 years has been adopted for the present study. This period is also reported by the Forest Survey of India in their surveys conducted in the Northeastern states (Anon., 1988).

While a large quantity of vegetation may be burnt annually in shifting agriculture, data on the total biomass burnt due to this practice are presently not available for India. Any estimates, therefore, made in this regard would only be educated guesses to be depended upon with caution. Most of the total area affected by Jhumming is under fallow regeneration and as mentioned earlier, about 20% of this area is annually cleared for cultivation. The land annually cleared for cultivation, having gone through several Jhum cycles earlier, is covered with second-growth vegetation and some older tree growth left over from earlier Jhumes. This second growth vegetation is mainly dominated by bamboos (and a few tree species) which continue to remain on the site as a pyric subclimax due to repeated cycles of Jhumming (burning). No new forest land is, however, allowed for Jhumming since 1980 with the passage of the Forest (Conservation) Act which prohibits diversion of forest land to non-forest uses.

Studies carried out on secondary succession, biomass, litter production and productivity in forest areas after Jhumming (Ramakrishnan and Toky, 1981 quoted by ICAR, 1983) indicate that the total inventory of the aboveground biomass increased linearly with age attaining a maximum value of 147.59 tonnes/ha (7.38 tonnes/ha/annum) in a 20 year fallow. The rate of accumulation of biomass increased upto 15 years of secondary growth reaching a maximum of 8.95 tonnes/ha/year and declined in a 20 year fallow.

Table 7. Shifting cultivation (Jhuming) cycle by states

State	Jhuming Cycle (Years)				
	(24)	(2)	(4)	(9)	(10)
	(A) <u>Northeastern States</u>				
Arunachal Pradesh	-	5	1-17	3-10	4
Assam	3-7	5	5-10	2-10	7
Manipur	15-20	5	6-8	4-7	6
Meghalaya	-	5	4-5	5-7	6
Mizoram	-	5	4-5	3-4	8
Nagaland	-	5	6-15	4-9	9
Tripura	8-10	5	4-5	5-9	8
	(B) <u>Other States</u>				
Andhra Pradesh	-	5	-	3	6
Bihar	8-10	5	-	5-8	6
Karnataka	-	5	-	-	-
Kerala	-	5	-	-	6
Madhya Pradesh	20 : 10-15 : 15-20 :	5	-	10-15	6
Maharashtra	2-3 : 16 :	5	-	-	-
Orissa	6-7	5	-	5-14	7
Tamil Nadu	3-6 : 6-8 : 2-3 :	5	-	-	-

Note: Figures in brackets on top of columns indicate the references.

Assuming a Jhum cycle of 5 years and adopting the above mentioned rates of accumulation of biomass (7.38 and 8.95 tonnes/ha/annum respectively at ages 20 and 15 years), the rate of accumulation of biomass at age 5 years comes to 3 tonnes/ha/annum through graphics. The total aboveground biomass at 5 years would, therefore, be of the order of 15 tonnes/ha. In another study, (carried out in Meghalaya), however, the total aboveground standing biomass in a 5 year second growth Jhum fallow is reported as 23 tonnes/ha (Toky and Ramakrishnan, 1983).

Forest Survey of India has been conducting a survey of forest resources of the Northeastern states for sometime past and some reports on the inventory of these states have already been published. Taking the inventory figures from these reports for second growth Jhum fallows (predominantly bamboo areas) for the states of Assam and Nagaland (Anon., 1982,1988), it has been estimated that the average total per ha aboveground biomass, on a dry weight basis, works out to 65.72 tonnes of which 20.72 tonnes is bamboo and 45.00 tonnes as tree biomass, bamboo biomass constituting 31.51% of the total aboveground biomass (Table 8).

Table 8. Aboveground biomass in Jhum areas

State	Aboveground Biomass (Tonnes/Ha Dry wt.) Tree Species	Bamboos	Total
Assam (Muli Bamboo areas)	43.68	11.69	55.37
Assam (Hill Jati Bamboo areas)	49.00	28.80	77.80
Nagaland	42.54	31.96	74.50
Weighted Average	45.00	20.72	65.72

Bamboo Biomass as % of total aboveground biomass = 31.51

There are, however, some major drawbacks in the data presented in Table 8. Firstly, that the age of the fallows is not known, though the sampled area is very large, and covers all age classes of Jhum fallow from 1 to 5 years and in some cases older Jhum fallows also. Secondly, a standing aboveground biomass of 65.72 tonnes/ha, of which tree species constitute 45 tonnes (68.49%) is much more than expected in a 5 years old second-growth Jhum fallow. It is, therefore, very clear that the tree biomass is from the older trees left over in the earlier successive Jhum cycles (this has been mentioned earlier also). It would thus be prudent to exclude the tree biomass from our calculations of biomass available for burning and take into account only the bamboo biomass of 20.72 tonnes/ha, plus the incremental biomass of the older trees.

Averaging the three values of per ha aboveground biomass (15, 23 and 20.72 tonnes) obtained from three sources quoted earlier, the average aboveground biomass/ha in Jhum fallows comes to 19.57 tonnes (or 20 tonnes). Giving an allowance of 3 tonnes/ha for the incremental biomass of older trees, the average aboveground biomass/ha in Jhum fallows would be of the order of 23 tonnes, which looks fairly reasonable and has been adopted for this study. This incremental biomass of 3 tonnes has been calculated on the assumption that the average annual wood production of Indian forests is 0.7 m^3/ha/year (Anon., 1987 a).

Accordingly, the aboveground biomass in areas put under shifting cultivation, annually, on an all India basis, during the period 1956 to 1985 is shown in Table 9 Col. 3, being of the order of 12.47, 12.44, 22.91, 22.77 and 23.00 million tonnes respectively for these five years.

Table 9. Total aboveground biomass

Estimates for the Year	Annual Area Under shifting Cultivation (Million Ha)	Aboveground Biomass (Million Tonnes)	Biomass Burnt (Million Tonnes)
(1)	(2)	(3)	(4)
1956	0.542	12.47	4.99
1960	0.541	12.44	4.98
1983	0.996	22.91	9.16
1984	0.990	22.77	9.10
1985	1.000	23.00	9.20

The fate of the standing biomass in Jhum areas is rather uncertain, both from the point of view of burning as well as utilisation. It has already been mentioned earlier that the larger trees on a Jhum may not be cleared and burnt for various reasons and that some biomass may be extracted for personal consumption and/or sale for monetary gains. As such the entire standing biomass on a Jhum plot is not cut and burnt. Further, because of climatic factor like high humidity and relatively short dry season in the shifting cultivation areas of the country, only part of the biomass gets burnt in the Jhum operation. Generally, however, bamboos, undergrowth, grasses and smaller trees get burnt along with dead organic matter on the forest floor (dealt with subsequently). It would, therefore, be a good guess to adopt a burning efficiency of 40% and accordingly, the quantity of biomass burnt, annually, for the period 1956 to

1985 in shifting cultivation areas is shown in Table 9 (Col.4), which ranges from 4.99 (1956) to 9.20 (1985) million tonnes.

Forest fires

Forest fires are one of the most potent source of damage to forests causing loss of standing crop and productive capacity of the soil/forest and destroying natural regeneration, protective, recreational and scenic values of the forest and wildlife. However, the ecological role of fires may be significant in that, much of natural regeneration in the country owes its existence to the burning of forests though lot of regeneration may be destroyed in the process.

Regulated or controlled burning is a very useful tool in forestry practices for the accomplishment of certain specific purposes. For example, the natural regeneration of teak (Tectona grandis), and sal (Shorea robusta), in their more moister regions of natural occurrence is intimately associated with controlled fires, which keep down the shrubs and weeds and reduce the depth of litter thus exposing the mineral soil to create the necessary seed bed conditions for germination and establishment of seedlings of the desired species. Delibrate and controlled burning is a regular feature in chir (Pinus roxburghii) forests to prevent occurrence of more destructive and accidental fires in the hot weather.

There are three types of forest fires most prevelant, namely, Ground Fires, Surface Fires and Crown Fires. Ground fires occur in the humus and peaty layers beneath the litter in undecomposed portion of forest floor with intense heat but practically no flame. Such fires are rather rare, and have been recorded occasionally in high level Himalayan fir and spruce forests. Surface fires, occur on or near the ground in the litter, ground cover, brushwood and reproduction and are the most common type in all fire-prone forests of the country. Crown fires, occur in the crowns of trees, consuming foliage and usually killing the trees and are met frequently in low level coniferous forests, in the Siwaliks, and the Himalayas. In India, there is a definite dry hot season before the monsoon, during which period most of the fires occur, even the wetter forests being prone to fire damage during this season.

There are three main causes of forest fires, i.e., natural, unintentional/accidental by man, and deliberate/intentional/incendiary due to man. Natural fires occur mostly due to lightning, rolling stones and rubbing of bamboos with each other. Unintentional/accidental fires occur due to careless throwing of match-sticks and burning cigarettes, carrying of naked fire by people passing through the forests and spread of fire from labour camps and recreation/picnic spots. Deliberate/intentional fires would include annual burning of fire lines in the forests or burning of slash for raising new plantations. Most of the forest fires can, however, be traced to the deliberate action of the local villagers who set fire to the forests for inducing luscious growth of grass for better grazing, and catching wild animals. Fires are also caused by local population for collection of minor forest products like honey, mahua (Madhuca longifolia),etc.

Unregulated fires: There are no statistics available, in India, on the occurrence of forest fires and the damage caused by such fires in terms of area and biomass burnt and the monetary losses caused, except for some very parfunctory attempts made in the past (Table 10). Even in these attempts, it appears that all the fires have not been reported and the information contained in Table 10 pertains to some significant fires only.

Table 10 shows the annual estimated record of reported forest fires in India with regard to the number of fires, area burnt and the damage caused by these fires in terms of monetary value for the period 1960-61 to 1987-88. Though no pattern is emerging from the figures presented in the table, it speaks of the dearth in collecting and collating data on forest fires in the country.

In the absence of any statistics on biomass burnt in these fires, an attempt has been made to calculate the quantity of aboveground tree biomass burnt from the monetary values in Table 10 (Col. 4). Adopting an average stumpage value of Rs. 1,500/- per m^3 of standing crop (which would be correct on an average basis looking at the number of species involved and their stumpage value), the calculated aboveground tree standing biomass for different periods, in m^3, is shown in Table 11 (Col. 3), in tonnes (air dry) in Col. 4 and on oven dry weight basis (in tonnes) in Col. 5. In arriving at figures in Cols. 4 and 5 it is assumed that one m^3 weighs 750 Kg (air dry) at 10% moisture content. Apart from the fact that there is an increasing trend in biomass burning in unregulated fires from 1985-86 to 1987-88, no other conclusions are possible from the scanty data in Table 11.

Allowing a burning efficiency of 30%, (as all the material does not get burnt and such fires are promptly attended to by the respective Forest Departments), the actual biomass burnt in unregulated fires varies from nearly 3,000 tonnes (Oven dry) in 1985-86 to over 9,000 tonnes in 1987-88.

Prescribed burning: Reference has already been made to the ecological role of forest fires in the form of Controlled Burning (regulated burning/prescribed burning) earlier. There are three main forms of controlled burning generally in vogue in the country, namely,controlled burning for natural

Table 10. Annual estimated record of reported forest fires in India

Estimates for the Period	Average Annual			Reference	Mid-point Year of the Period
	No.Of Fires	Area Burnt (000 Ha)	Damage Value (Million Rs)		
(1)	(2)	(3)	(4)	(5)	(6)
1960-61 to 1964-65	6407	534.0	0.201	(4)	1962
1968-69 to 1972-73	3424	258.9	94.393	(4),(22)	1970
1968-69 to 1977-78	1905	NR	NR	(29)	1972
1980-81 to 1984-85	3570	114.5	1.4	(15)	1982
1985-86	NR	985.8	21.987	(33)	1985
1986-87	NR	975.0	26.973	(33)	1986
1987-88	NR	1034.3	67.897	(33)	1987
1987-88	NR	54634.0**	NR	(28),(15)	1987

Note: (1) NR - Not reported.
(2) ** - Area subject to repeated annual ground fires.

regeneration, for protection (burning of fire lines) and for raising of new plantations. These are discussed hereafter.

(A) Natural regeneration: Controlled burning for purposes of natural regeneration is associated mainly with three species, i.e., teak, sal and chir. The total forest area in the country under these three species, respectively, is of the order of 9.77, 12.00 and 0.89 million ha (Anon., 1980). Based on the rotations of these species - teak, 60 years; sal, 100 years; and chir, 120 years - it is assumed that 2% of the area under teak (0.20 million ha), 1% of the area under sal (0.72 million ha), and 4% of the area under chir (0.04 million ha), giving a total of 0.36 million ha, is subject to annual burning for the purposes of natural regeneration.

As prescribed burning for purposes of regeneration is controlled and consists mostly of ground fires carried out during winter months, the material burnt is usually litter lying on the forest floor, grasses, shrubs and other undergrowth. These are being dealt with subsequently, as to the amount of actual biomass burnt in such fires.

(B) Protection fires: The Forest Departments of the various states carry out annual burning of fire lines, in the forests of the country, as a measure of protection against any unregulated fires which may cause damage to the forests. There is absolutely no information available as to the extent

Table 11. Aboveground biomass burnt

Estimates for the Year	Annual Monetary Loss (Million Rs.)	Aboveground Biomass m^3	Aboveground Biomass Air Dry Wt. (Tonnes)	Aboveground Biomass Dry Wt. (Tonnes)	Biomass Burnt (Tonnes)	Mid-point Year of the Period
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1960-61 to 1964-65	0.201	134	100	90	27	1962
1968-69 to 1972-73	94.393	62,929	47,196	42,476	12,743	1970
1980-81 to 1984-85	1.400	934	700	630	189	1982
1985-86	21.987	14,658	10,994	9,895	2,968	1985
1986-87	26.973	17,982	13,486	12,137	3,641	1986
1987-88	67.897	45,265	33,949	30,554	9,166	1987

Notes: (1) Figures in Col. 2 are from Table 10, Col.4
(2) Figures in Cols. 4 and 5 are based on one m^3 weighing 750 Kg, air dry, at 10% moisture content.

of fire lines burnt annually, in India, and much less on the quantity of biomass burnt in such fires. It would, however, be safe to assume that about 1% of the total forest area of the country (75.18 million ha - Anon., 1987, 1987 a, 1989 a) is under fire lines which would account for an area of about 0.752 million ha, being burnt annually.

Burning of fire lines being in the nature of controlled ground fires carried out during the cold season, the materials burnt usually consist of litter on the forest floor, grasses, shrubs and other undergrowth. These have been dealt with subsequently in terms of the actual biomass burnt.

(C) Plantations: It is customery to give a good hot burn, during the winter season, in all plantations areas prior to their sowing/planting in the succeeding planting season. After all the utilisable materials (timber, fuelwood, etc.) have been extracted from the area, the remaining small material and other debris is allowed to dry, when, later it is collected in heaps and burnt. This cleans up the area to facilitate various planting operations and keeps the area relatively free of weeds atleast for sometime.

While reasonably accurate statistics on the areas planted annually are available, there is no record of the biomass burnt in such fires, though these fires are essentially in the nature of ground fires where mostly litter, grasses, small material and other undergrowth gets burnt.

Table 12 shows the area afforested during the successive Five Year Plans from 1951 to 1986 (Anon., 1987), indicating that a total of 11.478 million ha have been planted during this period, with an increasing rate of afforestation from 0.052 million ha (1951 - 1956) to 1.762 million ha (1986-87). The average annual area afforested has also risen from 0.0104 million ha during the period 1951 - 56 to 1.762 million ha in 1986-87. It must, however, be mentioned here that of the total area afforested annually, over 50% is planted under various development programmes of farm forestry, agro-forestry etc. where plantation areas are not burnt prior to planting operations. Consequently the planting areas subject to pre-planting burning would get reduced and is shown in Col. 4 of Table 12.

As only litter, grasses, small material and other undergrowth gets burnt in these controlled prescribed fires, the amount of biomass burnt is being dealt with subsequently.

Forest encroachment

Attempts to encroach upon Government forest lands for cultivation has been a regular feature since independance till before the enforcement of the Forest (Conservation) Act, in 1980, which prohibits diversion of any forest land for non-forest purposes. With the growth of population, the demand for land for agriculture also increased with the

Table 12. Progressive afforestation through successive plan periods

Period/ Year	Total Area Afforested (Million Ha)	Av. Annual Area Afforested (Million Ha)	Annual Area Subject to Burning (Million Ha)	Mid-point Year of the period
(1)	(2)	(3)	(4)	(5)
1951-56	0.052	0.0104	0.0052	1953
1956-61	0.311	0.0622	0.0311	1958
1961-66	0.583	0.1166	0.0583	1963
1966-69	0.453	0.1510	0.0755	1967
1969-74	0.714	0.1428	0.0714	1971
1974-79	1.221	0.2442	0.1221	1976
1979-80	0.222	0.2220	0.1110	1979
1980-85	4.650	0.9300	0.4650	1982
1985-86	1.510	1.5100	0.7550	1985
1986-87	1.762	1.7620	0.8810	1986
Total	11.478			

result that as many as 2.623 million ha of forest lands were officially diverted for agriculture during the period 1951 - 1980, in addition to many hectares of un-occupied non-forest Government lands, (Anon., 1987 a).

Encroachments on Government forest lands are generally made by people who live in the vicinity of the forest or forest dwellers as they are popularly known. Forest dwellers are mostly tribals who prefer forest lands for cultivation for two reasons. Firstly, forest lands are taken to be more fertile than other un-occupied Government lands and secondly, these lands are in the vicinity of their habitations. Owning agricultureal lands not only satisfies the tribal's economic and social needs but also his emotional feelings.

Forest encroachments could be considered a form of shifting cultivation, practised by the local population who encroach upon forest lands for cultivation, with the difference that once the cultivator has cleared and burnt the land for growing agriculture crops, he takes to permanent agriculture on the same plot of land rather than move from one plot to another as done in the case of Jhumming. So the land once occupied by the cultivator is lost to forests and remains permanently under agriculture.

It has been estimated that nearly 700,633 ha of forest land were under encroachment since 1951 to 1982 (Anon., 1987); the average annual forest area under encroachment being of the order of 21,895 ha (21,900 ha).

Though a large quantity of vegetative growth may be burnt in the areas encroached annually, for permanent agriculture, there is no information presently available as to the amount of biomass burnt in such encroachments. However, taking foret encroachments to be a form of shifting cultivation, it is assumed that the aboveground biomass in these encroached areas would be of the same order as for the jhummed plots, i.e., 23 tonnes/ha. Accordingly, the total biomass available for burning, annually, would be 503,700 (21,900 X 23) tonnes.

As in shifting agriculture, so also in case of encroachments, only a part of the biomass gets burnt and generally, bamboos, grasses, undergrowth and smaller trees get burnt along with dead organic matter lying on the forest floor (dealt with subsequently). A burning efficiency of 40% (as in the case of Jhumming) has, therefore, been adopted, and accordingly the total biomass actually burnt, annually, is of the order of 201,480 tonnes.

A part from the GHGs emissions that may be caused as a result of burning in such encroachment areas, these areas are permanently lost as forest carbon sinks unlike shifting agriculture, where forest regrowth is allowed to come in after one year of Jhumming. How far this loss of vegetative carbon sinks is compensated by the new plantations that are being raised, annually, in the country is hard to predict, at this stage.

Forest area lost

The future demands of various goods and services on our forest ecosystems would primarily be influenced by the increase in population and economic growth though in case of fuelwood consumption, urbanisation, availability of alternative fuels more freely and cheaply and the energy crises would continue to have a significant effect. The impact of dynamic population growth arises the need for increased resources and the competition for land becoming more intense, resulting in the detrimental effect of population increase on these ecosystems.

Table 13.1 indicates the forest area lost for various purposes during the period 1952 to 1980 (prior to the passage of Forest (Conservation) Act, 1980) while Table 13.2 shows the extent of diversion of forest land for non-forestry purposes from 1980 to 1987 (Anon., 1987). It will be observed that the forest area lost for different purposes during the period 1952 to 1980 (Table 13.1) is the tune of 4.328 million ha, with 0.155 million ha having been lost annually, on an average. The largest forest area (2.623 million ha or over 60% of the total) has been lost to agriculture and the balance to other uses.

The total forest area diverted for non-forest uses from 1952 -1987 is of the order of 4,442,809.41 ha (4.443 million ha) (Tables 13.1 and 13.2) which accounts for a yearly average area of 0.127 million ha having been diverted for non-forestry purposes during this period. There have, however, been no official diversions for agricultural purposes after 1980 when the Forest (Conservation) Act was passed. It has also been reported that an area of 0.19 million ha has been deforested during the period 1981-83 to 1985-87 amounting to an annual loss of 47,500 ha (Anon., 1989).

It must be mentioned here that generally, in all cases of diversion of forest lands for non-forestry uses, all usable materials in the form of timber, poles, firewood etc. are extracted from the area prior to the land being put to such non-forestry purpose for which it was diverted. Consequently, there is very little biomass left in the area and as a rule, these areas are not burnt prior to their non-forestry use except, may be, in case of agriculture where the land has to be free of all debris etc. In such cases, burning would be confined to grasses, shrubs and other undergrowh, besides litter on the forest floor. This is being dealt with subsequently under litter burning, as to the amount of actual biomass burnt in such fires.

The most significant effect of the diversion of forest lands for non-forest uses, is actually the reduction of forest Carbon sinks, rather than emission of any GHGs into the atmosphere except for agriculture where the diverted forest area may be burnt for preparing the land for agriculture crops. Once forest areas are diverted for non-forestry uses like the ones mentioned in Table 13.1, there is a permanent reduction in the forest carbon sinks. How far the carbon balance is maintained by raising of new plantations, annually, in the country could only be guessed.

Table 13.1. Forest area lost for various purposes from 1952 to 1980

S.No.	Purpose	Area Lost (Million Ha)	Av. Annual Area Lost (Million Ha)
(1)	(2)	(3)	(4)
1.	Agricultural activities	2.623	0.094
2.	Submergence due to river valley projects	0.502	0.018
3.	Industries and townships	0.134	0.005
4.	Transmission lines,roads etc	0.061	0.002
5.	Miscellaneous uses	1.008	0.036
	Total	4.328	0.155

Table 13.2: Forest area diverted for non-forestry uses from 1980 to 1987

Year	Forest Land Diverted (Ha)
1980	Nil
1981	2,672.04
1982	3,246.54
1983	5,702.01
1984	7,837.59
1985	10,608.07
1986	11,963.11
1987	72,780.05
Total	114,809.41

Burning of grass in forests

Reference has already been made to the burning of grasses in forest and plantation areas due to shifting cultivation; unregulated fires; prescribed burning in natural regeneration areas, protection fires and in plantations; forest encroachments and forest areas diverted for agriculture. The areas annually burnt in different periods for the above sources/activities of forest biomass burning have also been mentioned earlier.

It has been reported that the productivity of grass in forest areas is generally higher than in other grass producing areas (barran and uncultivated land, permanent pastures and grazing land, culturable wastelands and fallow lands) and that the production of dry grass generally varies from 0.5 to 6.0 tonnes/ha/year; the average grass yield from forest areas and other grass producing areas being taken to be about 3 and 1.5 tonnes/ha/year respectively (Anon., 1985).

Adopting an average annual yield of 3 tonnes/ha for forest areas, the aboveground grass biomass in the areas annually burnt with regard to the various sources/activities of forest biomass burning (shifting cultivation etc) is given in Table 14 (Col. 3).

Allowing a burning efficiency of 40% for shifting cultivation areas, encroachment areas and forest land diverted for agricultural purposes; 30% for areas burnt in unregulated fires; and 50% for areas where burning is prescribed (natural regeneration, protection fires and plantations); the aboveground grass biomass actually burnt in these areas is indicated in Table 14 (Col. 4).

With increasing area under shifting agriculture, unregulated fires and plantations, the aboveground grass biomass actually burnt has increased from 0.650 to 1.200 million tonnes (1956-1985); from 0.481 to 0.931 million tonnes (1962-1987) and from 0.008 to 1.322 million tonnes (1953-1986), respectively, for the above mentioned three activities of forest biomass burning. As the area burnt, under natural regeneration, protection fires, encroachments and forest lands diverted for agriculture, is assumed to be constant, the aboveground grass biomass actually burnt has also remained static, being to tune of 0.540, 1.128, 0.026 and 0.113 million tonnes, respectively.

Table 14. Aboveground grass biomass

Year	Annual Area Burnt (Million Ha)	Aboveground Grass Biomass (Million Tonnes Dry Wt.)	Biomass Burnt (Million tonnes)
(1)	(2)	(3)	(4)
		(A) Shifting Cultivation	
1956	0.542	1.626	0.650
1960	0.541	1.623	0.649
1983	0.996	2.988	1.195
1984	0.990	2.970	1.188
1985	1.000	3.000	1.200
		(B) Unregulated Fires	
1962	0.534	1.602	0.481
1970	0.259	0.777	0.233
1982	0.114	0.342	0.103
1985	0.986	2.958	0.887
1987	1.034	3.102	0.931
		(C) Natural Regeneration Areas	
Annual	0.360	1.080	0.540
		(D) Protection Fires	
Annual	0.752	2.256	1.128

		(E) Plantations	
1953	0.0052	0.016	0.008
1963	0.0583	0.175	0.088
1976	0.1221	0.366	0.183
1982	0.4650	1.395	0.698
1986	0.8810	2.643	1.322
		(F) Encroachments	
Annual (1951-1980)	0.0219	0.066	0.026
		(G) Forest Area Diverted to Agriculture	
Annual (1952-1980)	0.094	0.282	0.113

Burning of forest litter

Burning of forest litter in forest and plantation areas due to different sources/activities of forest biomass burning (shifting cultivation; unregulated fires; prescribed burning in natural regeneration areas, protection of forests from fire damage and in plantations; encroachment of forest lands, and forest areas diverted for agriculture) has already been referred to earlier. The areas annually burnt in different periods for the sources/activities just mentioned have also been reported earlier.

The position with regard to data on biomass, productivity and litter production in Indian Forests is no better than many other tropical countries, in that very little data exist on the subject and whatever is available is rather fragmentary. Data are, however, available in the form of yield and volume tables for a large number of species (both for natural forests and plantations). It is only during the last two decades that studies of limited nature on biomass, productivity, litter production and nutrient cycling in the various forest ecosystems of the country, both in natural forests and plantations, have been taken up. Kaul (1973), has made a comprehensive review of these studies upto 1973, though some studies have been undertaken thereafter also.

A literature review of the various studies carried out on litter production in Indian forests, indicates that, on an average litter production in tropical deciduous forests of the country is of the order of 7,000 Kg (7 tonnes)/ha/annum, (Kaul, 1973), the rate of decomposition of litter being very fast, it being difficult to demonstrate the presence of a humus layer.

Assuming an average annual litter production of 7 tonnes/ha, the litter biomass in the areas annually burnt due to various sources/activities of forest biomass burning (shifting cultivation etc) is given in Table 15 (Col. 3).

Adopting a burning efficiency of 40% for shifting cultivation areas, forest areas encroached, and forest lands diverted for agriculture; 30% for areas burnt in unregulated fires; and 50% for prescribed burning areas (natural regeneration, protection fires and plantations); the litter biomass actually burnt in these areas is shown in Table 15 (Col. 4).

As in the case of grass burning, the litter biomass actually burnt has also increased with increasing area under shifting cultivation, unregulated fires and plantations, the increase being, respectively, from 1.518 to 2.800 million tonnes (1956-1985); from 1.121 to 2.171 million tonnes (1962-1987); and from 0.018 to 3.083 tonnes between 1953 and 1986. The actual litter biomass burnt in the areas burnt under natural regeneration, protection fires, encroachments and forest lands diverted to agriculture has remained constant for obvious reasons of the annually burnt areas remaining the same.

Table 15. Litter production

Year	Annual Area Burnt (Million Ha)	Litter Biomass (Million Tonnes Dry Wt.)	Litter Burnt (Million tonnes)
(1)	(2)	(3)	(4)
		(A) <u>Shifting Cultivation</u>	
1956	0.542	3.794	1.518
1960	0.541	3.787	1.515
1983	0.996	6.972	2.788
1984	0.990	6.930	2.772
1985	1.000	7.000	2.800
		(B) <u>Unregulated Fires</u>	
1962	0.534	3.738	1.121
1970	0.259	1.813	0.544
1982	0.114	0.798	0.239
1985	0.986	6.902	2.071
1987	1.034	7.238	2.171
		(C) <u>Natural Regeneration Areas</u>	
Annual	0.360	2.520	1.260

	(D) Protection Fires		
Annual	0.752	5.264	2.632
	(E) Plantations		
1953	0.0052	0.0364	0.018
1963	0.0583	0.4095	0.205
1976	0.1221	0.8547	0.427
1982	0.4650	3.2550	1.625
1986	0.8810	6.1670	3.083
	(F) Encroachments		
Annual (1951-1980)	0.0219	0.1533	0.061
	(G) Forest Area Diverted to Agriculture		
Annual (1952-1980)	0.094	0.658	0.263

Conclusions

Summarising the results obtained for individual sources/activities of forest biomass burning (presented in earlier tables), an attempt has been made to arrive at the total quantity of forest biomass actually burnt in the country during 1980s (1985-1987) due to various sources/activities of forest biomass burning in India. The results are presented in Table 16.

Table 16. Total quantity of biomass burnt annually during 1985-87

Source/Activity	Biomass burnt annually during 1985-87 (Million Tonnes)
(A) <u>Tree Biomass Burnt</u>	
Fuelwood	124.740
Shifting cultivation	9.200
Unregulated fires	0.009
Prescribed burning	-
Encroachments	0.202
Forest areas diverted for agriculture	-
(B) Burning of grasses	5.260
(C) Burning of litter	12.270
Total	151.681
Carbon = 151.681 X 0.45 =	68.26 Million tonnes

It is observed (Table 16) that a total of 151.681 million tonnes of forest biomass (dry weight) was burnt annually during the period 1985-1987, the major contribution of 88.44% (134.151 million tonnes) being from tree biomass, followed by burning of litter (12.270 million tonnes - 8.09%) and grasses (5.260 million tonnes - 3.47%). The total amount of carbon involved for emission of GHGs would be to the tune of 68.26 (151.681 X 0.45) million tonnes.

The above estimates are of best only indicative of the nature and extent of the problems created by forest biomass burning with regard to emission of GHGs and have to be taken with due care, in view of the extreme paucity of data and uncertainities involved. As more and adequate statistics and data are made available, more realistic and dependable estimates could be concluded.

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IMPACT OF GLOBAL WARMING ON INDIAN AGRICULTURE

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INTRODUCTION

The objective of this study is to determine the effect on agriculture in India of global warming due to increase in atmospheric levels of greenhouse gases such as CO_2, methane and fluorinated hydrocarbons.

It has been predicted that the concentration of the greenhouse gases will double in the next thirty or forty years and cause an increase in temperature of 2.0 to 4.0°C. It has also been predicted that there will be considerable changes in rainfall in different regions of the globe. Increase in CO_2 and temperature and change in rainfall patterns will have a marked effect on agriculture which will be different for different regions and different crops.

An assessment of the impact of global warming on Indian agriculture will be of relevance for agricultural planning. The selection or development of plant varieties suitable for the altered global climate conditions will be a priority area of research.

This report deals with the following aspects of global warming in relation to Indian agriculture.

The effect of increase in greenhouse gases on global climate, especially changes in temperature and rainfall, according to different computer general climate models, is discussed in Section I.

The literature on the effects of increase in CO_2 and temperature, change in water availability or combination of these three factors on the yield of different crops, based on different crop growth simulation models is surveyed in Section II.

These results may not, however, be directly applicable to India in view of several distinctive features of Indian agriculture. These are discussed in Section III.

It is essential that the impact of climatic changes should be studied with specific reference to India as a basis for future planning. Initially this study will be taken up for rice. The specific features of rice and its cultivation in India are discussed in Section IV. These studies can then be extended to other crops to get an overall picture of the possible changes in agriculture due to future climatic changes and the policy decisions and planning required to deal with such changes.

Section I

The increase in atmospheric concentrations of greenhouse gases (CO_2, methane and fluorinated hydrocarbons) has aroused widespread concern. It has been predicted that these gases will increase in the next thirty to forty years to a level corresponding to a doubling of the present concentration of CO_2. General circulation models have been used to predict how climate will change as a result of the increase in greenhouse gas concentrations in the atmosphere. Inspite of some differences and uncertainties, these models predict that in the next forty years the earth's surface temperature will increase by 1.5° to 4.5°C; increase in rainfall especially in the higher latitudes and a lesser rainfall in a few regions; reduction in sea ice at the polar regions and increase in sea level; submergence or salination of coastal areas; and increase in the flow of some rivers due to increase in rainfall or melting of snow.

Section II

Several studies were undertaken to determine the effect of climatic factors such as increase in levels of CO_2, temperature and altered precipitation or a combination of these factors on agriculture. Plants have been exposed to these climatic factors at different stages of development such as germination, shoot development, flowering and grain filling and the effect on yield of biomass and grain was determined.

Effect of carbon dioxide (CO_2): Plant responses to increased CO_2 were found to vary with the plant type, depending on whether they belong to the C_3 group (wheat, rice, legumes, oil seeds, cotton) or C_4 group (sugarcane, sorghum or maize). The C_3 species show greater CO_2 assimilation, growth and yield in response to CO_2 enrichment as compared to the C_4 species. According to one survey, CO_2 enrichment caused an increase in economic yield of mature agricultural crops by 26% and that of immature shoot dry weight by 40%. C_3 crops in general showed a mean yield increase of 36% in response to CO_2 enrichment. A decrease in transpiration of 34% or more was found among species exposed to CO_2 doubling, in both C_3 and C_4 species. This may lead to a decrease in water requirements.

Effect of temperature: A study of the effect of temperature on rice yield showed that increase in temperature leads to a reduction in duration of growing season and a decline in productivity. Other workers have predicted lower wheat and rice yields taking into account only temperature. However other studies indicate a yield increase due to CO_2

enrichment at higher temperatures.

Effect of CO_2 and temperature and water availability: Computer model simulation studies conducted recently take into consideration both increased CO_2, temperature and altered water availability (i.e. dryland and irrigated conditions). The conclusions were: altered temperature would play a significant role in the higher latitudes; yield under irrigated conditions would show far less variability; positive effects of CO_2 would compensate for yield decreases caused by higher temperature, especially for maize.

Section III

An assessment of the impact of global climatic change on Indian agriculture must take into consideration, the features unique to this country which are: dependence of agriculture in most regions on monsoons; low level of agricultural inputs such as fertilizers and pesticides; low level of technology; large margin between actual and potential yields for most crops; the need to increase production to meet the foodgrain requirements of a rapidly growing population; multiple cropping in many parts of the country.

Inspite of Indian agriculture being less sophisticated than that practiced in Western nations, the agricultural infrastructure is strong. It is supported by a large group of agricultural universities and research institutions, availability of a wide range of germplasm of most crops, extension services and All India Coordinated Projects for the major crops grown in India. This should facilitate identification of varieties suitable for altered climatic conditions.

A large area is dependent on the monsoons, but temperature is only one of about sixteen factors affecting the onset of the South East monsoon. The effect of global rise in temperature on monsoons is difficult to predict at present with existing models. The results obtained elsewhere cannot be extrapolated to Indian conditions and necessitate a detailed study of Indian agriculture.

The response of plants to changes in temperature and CO_2 is dependent also on the nutritional status and availability of water. Some of the predictions made with crop growth simulation models are based on growth under optimum conditions and may not be relevant to conditions in several parts of India.

Though foodgrain production should nearly double within a few decades to meet the requirements of the increase in population, current yields are only half or one third of potential yields. There is a considerable scope for increase in production even in the existing technology. The extent of irrigation and the inputs of fertilizers will also show marked increase in the next two decades. These should be taken into account in assessing the impact of global warming on agriculture which is influenced by these factors.

Section IV

Rice occupies the largest area under agriculture in India, and rice and wheat are the most important foodgrains grown in the country. It is cultivated in most parts of India under a wide range of climatic and soil conditions. It is grown both in rainfed and irrigated areas with very heavy inputs of fertilizers and pesticides or with very low inputs. It is also grown in coastal areas which may be subject to sea level rise and increase in salinity.

The impact of global warming will be studied initially for rice. On the basis of the results obtained with rice, this study may be extended to other major crops to assess the effect of global climatic changes on agriculture.

The effect of agriculture on greenhouse gas emission particularly of methane, CO_2 and oxides of nitrogen; the effect of global warming on sea rise and the resultant loss of land and increase in salination, and the effect on forestry will not be dealt with in this chapter since these are being dealt with separately.

SECTION-I

Future Climate

A panel of experts convened by the National Academy of Sciences (National Research Council, U.S.A.) in 1987, made the following predictions regarding future climate and its probability. Their predictions were based on the available general circulation models.[1]

Global Mean Surface Warming (very probable). A doubling of atmospheric carbon dioxide or its radiative equivalent resulting from all the greenhouse gases,would lead to "long term global surface warming in the range of 1.5 to 4.5 °C ."

Global Mean Precipitation Increase (very probable). It is expected that an increased heating of the earth's surface would increase evaporation leading to greater global mean precipitation. Some regions would instead register decreases in rainfall.

Polar Winter Surface Warming(very probable). Polar surface air may be warmed by as much as three times the global average, due to a reduction in sea ice.

High Latitude Precipitation(probable). Average annual precipita-tion in the higher latitudes would increase.

Large Stratospheric Cooling. Fluorinated hydrocarbons and nitrogen oxides would cause reduction of the ozone concentration which would reduce ultraviolet radiation and reduce heating in the stratosphere. On the other hand increasing concentrations of greenhouse gases would increase radiation of heat from the stratosphere. Both these factors would reduce temperatures within the upper stratosphere. Rise in Global Mean Sea Level. The thermal expansion of sea water and melting of land ice is likely to lead to an increase in sea level.

The climate models indicate lesser warming in the tropics as compared to the global average. But different general circulation models are not in agreement regarding both temperature and precipitation changes.

Table 1. General Circulation Model Predictions of Globally averaged Climate change Due to Doubled CO_2

Model	Surface air temperature increase (°C)	Precipitation increase (%)
GFDL	4.0	8.7
GISS	4.2	11.0
NCAR	3.5	7.1
OSU	2.8	7.8
UKMO	5.2	15.8

Source : Karl et al.(1989). Climate variations of the past century and the greenhouse effect (A report based on the First Climate Trends Workshop) Rockville, MD: National Climate Programme Office/NOAA.[27]

Using general circulation models Manabe and Wetherald (1980) examined the effect of a doubling of CO_2 content in the atmosphere. It was found that this CO_2 doubling led to a general warming of the troposphere.

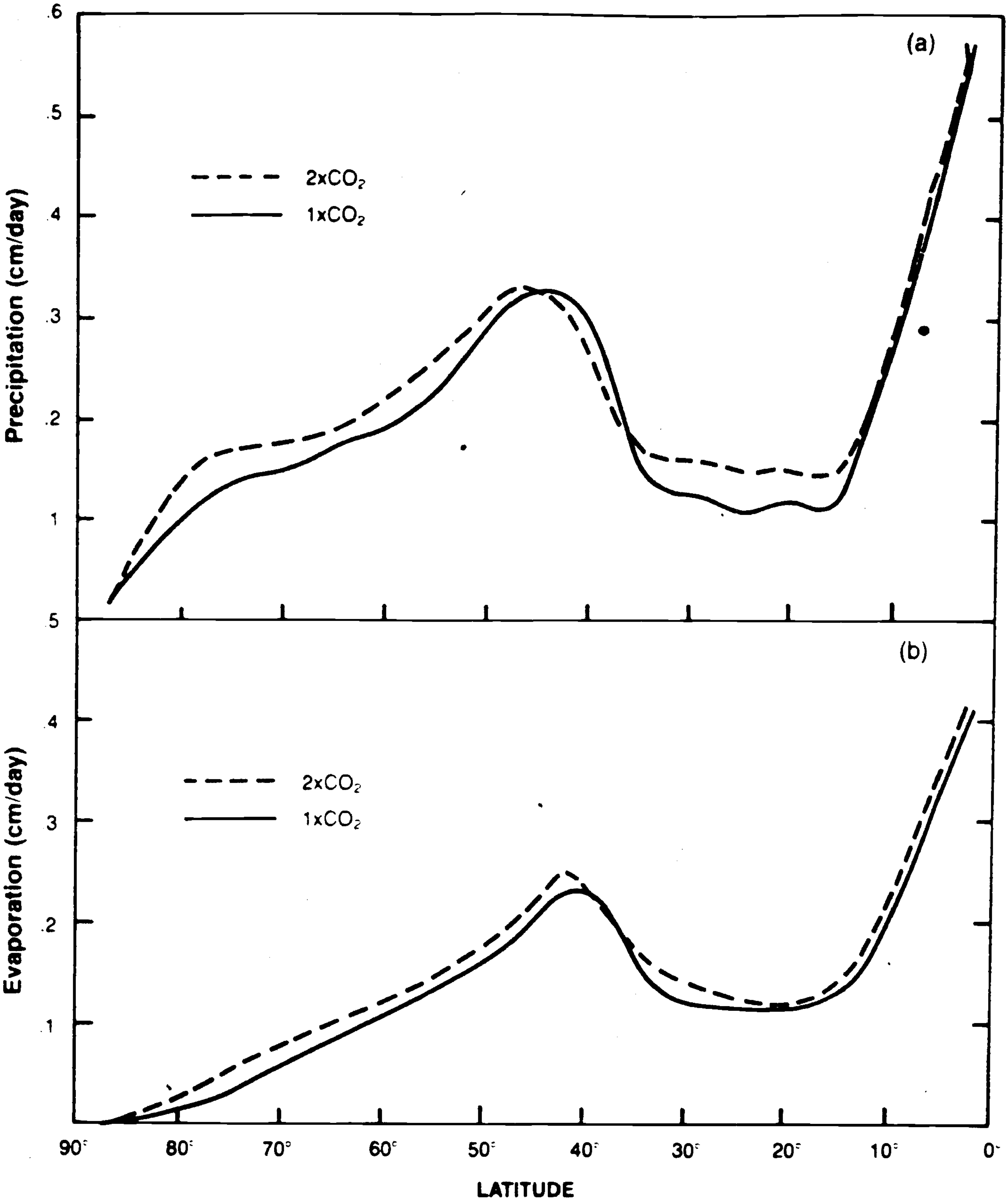


Figure 1. Zonal mean values of precipitation (a) and (b) evaporation for ambient levels and doubling the CO_2 content (adapted from Manabe and Wetherald, 1980).

The temperature increase in the lower latitudes (0-20°) is around 2°C. The higher latitudes (50-90°) experience 4-8°C rise in surface temperature.

The effect of such a doubling on the zonal - mean values of precipitation and evaporation was also studied. Their model suggested that :

1. negligible increase in precipitation in the lower latitudes (0-13°)(Figure 1)
2. slight increase in precipitation between the latitudes (14-36o)
3. decrease in precipitation between latitudes (37-47°)
4. higher latitudes of 47-90° show a substantial increase in precipitation primarily because of largescale poleward movement of water vapour.

The effect on evaporation rate was a uniform increase for all latitudes.

Thus predictions range from a general increase in tropical summer rains to an increased intensity of rainfall within normal rainy period. Some predictions visualize shifts both in onset and duration of rains.

India, which is in the tropical and sub-tropical regions is affected by variability in annual rainfall due to the vagaries of the monsoon. Increased temperature is only one of several variables, which determine the onset and duration of the monsoons and the regional and total precipitation. These have not been considered by the existing models. In India, river sources include montane glaciers and snowfields whose meltwater discharge would occur earlier in response to warming. The effect of global warming on melting of snow and changes in rainfall in the catchment areas on river flow needs to be determined.

Though the predictions of the model contain many uncertainities, they still serve to indicate future scenarios and are only tentative. Consensus exists that a significant change is likely to occur in the 21st century itself. The next forty to fifty years are likely to register an increased warming of 1.5 to 4.5 °C and changes in precipitation in several regions.

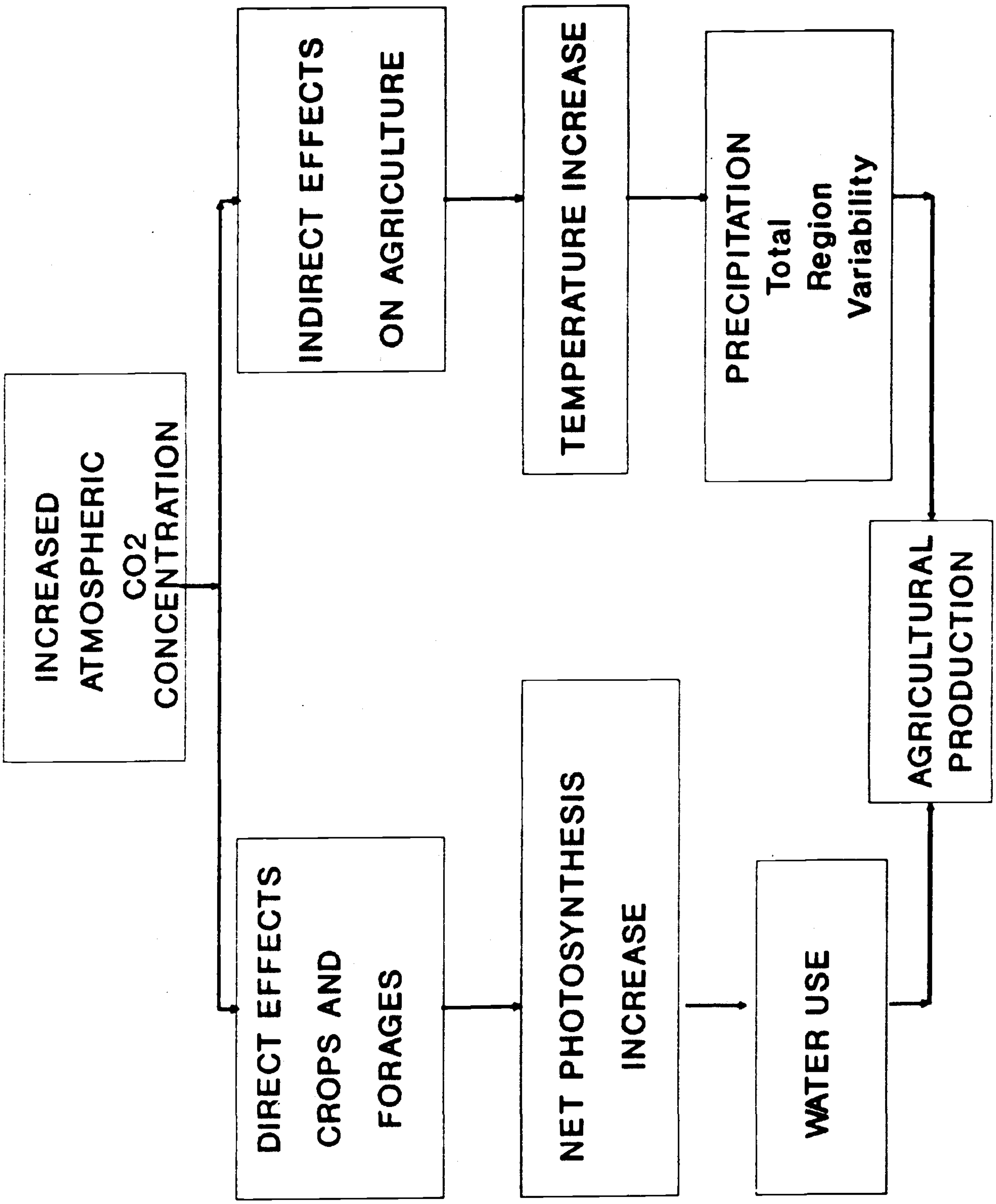


Figure 2. Schematic diagram showing direct effect on CO_2 on plants and indirect effect on plants via climate.

SECTION. II

Sensitivity of Agriculture to Global Climate Change

Agriculture in the broadest sense includes all land based and biomass producing activities such as cropping, animal husbandry and forestry. Model predictions indicate an increase in temperature ranging from 1.5 to 4.5° C due to a 300 ppm increase in atmospheric carbon dioxide concentration. This increase in temperature is likely to affect the entire biosphere, though to a different extent in different regions. The rate of climate change would be critical in influencing the ability of ecosystems to adapt to such a change.

The following alterations due to global climatic change may have an impact on agricultural production due to changes in:

i) concentrations of atmospheric carbon dioxide

ii) temperature

iii) water availability and seasonal distribution of rainfall at regional level.

The schematic diagram given on the opposite page illustrates the nature of potential impact on agriculture.

Changes in the length of the growing season, altered plant growth rates and altered yield are among other important changes which may occur.

The effect of most of the above factors, especially the effect of carbon dioxide and temperature on plant growth has been extensively studied. It is known on the basis of several experiments that crops in controlled environments will

Table 2. Examples of C_3 and C_4 crops

C_3	C_4	Food Crop
X		Wheat
X		Rice
	X	Maize
X		Potato
X		Barley
X		Sweet Potato
X		Cassava
X		Soyabean
X		Grapes
	X	Sorghum
	X	Canesugar
	X	Millets
X		Oats
X		Tomato
X		Banana
X		Beetsugar
X		Oranges
X		Coconut
X		Rye
X		Cotton seed oil
X		Watermelon
X		Apples
X		Cabbage
X		Yam
X		Peanut
X		Onion
X		Beans
X		Peas
X		Mango
X		Sunflower seed

Source : FAO Production Yearbook, 1988
Adapted from version in[2].

respond positively to increased concentrations of carbon dioxide.

Plants have been classified into three major types on the basis of their CO_2 fixation mechanisms: C_3, C_4 and CAM (Crassulacean Acid Metabolism). In Table 2 major C_3 and C_4 crops are shown. [2] At least 95% of the world's biomass as well as as most crop species belong to the C_3 category. Of these, the best studied are soyabean (C_3, broadleaf species), wheat (C_3, grass), maize (C_4, grass) and to a lesser extent rice (C_3, grass). CAM plants are adapted to arid conditions and are of relatively minor economic importance. The most important C_3 crops for India are rice, wheat, legumes, oil seeds and cotton; and important C_4 crops are sugarcane, sorghum and maize.

Studies on the effect of higher CO_2 concentrations on crops were first made in France, as early as 1902. Since then, a large number of crops have been tested and all show a positive response to increased carbon dioxide levels. Earlier experiments were mainly done using horticultural crops grown under favourable conditions of soil,water and nutrients. This trend has now shifted towards the major agricultural crops, growing under controlled field conditions. Experiments have been also conducted to understand the interaction between CO_2 enrichment and water availability, nutrient stress, altered light and temperature conditions. Environmental Protection Agency (EPA), USA has sponsored research on yield of major crops, such as wheat, soyabean and maize under both dryland and irrigated conditions.

Both the results of a)literature surveys and b)computer modelling studies are discussed below.

a) Literature Survey

An evaluation of 770 observations, from about 140 reports, published during a 64 year period was conducted by Kimball in 1983.[3] He reviewed studies of CO_2 enrichment on agricultural yield and biomass production of 38 agricultural crops and 18 other species.

He concluded that CO_2 enrichment increased the economic yield of all mature agricultural crops by 26 per cent and immature shoot dry weight by about 40 percent. C_3 crops showed a mean yield increase with CO_2 enrichment of 36 per cent.

Both C_3 and C_4 crops showed a decrease in stomatal conductance of 40 per cent. Increased photosynthetic rate per unit leaf area could in turn lead to an increase in leaf level Water Use Efficiency.(WUE) If the leaf area index is low it would lower the amount of water used by the crop and reduce irrigation requirements. The experimental data reviewed also showed that young plants were stimulated more as compared to mature plants by increased CO_2 levels. CO_2 enrichment at different phases of the crop's lifecycle produced different responses depending on the phase. Table 3 gives the responses of crops to increased CO_2 levels. [4]

Table 3: Response of crop plants to an increase in CO_2 concentration above current ambient level.

Process	Knowns	Uncertainties	Unknowns
Leaf Photosynthetic Rate	Increases in all plants on first exposure. C_3 respond more than C_4. Response follows law of diminishing returns with little further response after 1000 ppm.		Magnitude of response for some crop species.
Inhibition of Photosynthesis by Source-Sink Imbalance	Response occurs in many species.	Response is somewhat correlated with starch accumulation.	Mechanism underlying response. Magnitude of response under various conditions.
Leaf Transpiration Rate	Decreases in all plants. C_4 plants respond more than C_3.	The reduction in transpiration rate reduces latent heat loss and increases temperature.	Stomatal mechanism giving response. Magnitude of response under various environmental conditions.
Leaf Anatomical and Biochemical Adaptation	Leaf area, weight per unit area, thickness and number of mesophyll cell layers increase in many species.	RuBP carboxylase activity is reduced in some species. For practical purposes, counteracting responses cancel and adapted leaves have photosynthetic rates similar to unadapted. Some studies show a higher carbon exchange rate for leaves adapted to high CO_2.	Mechanisms underlying responses.
Canopy Leaf Area	Usually increases.		Magnitude of interactions between CO_2 and other environmental and crop variables.
Canopy Photosynthetic Rate	Similar responses as leaf photo-synthetic rates.	Response can be predicted from a knowledge of how leaf photosynthetic characteristics vary with previous light exposure.	Magnitude of response for some crop species.
Canopy Transpiration Rate	Decreases after canopy closes. Response before canopy closure depends on counteracting effects of decreased stomatal conductance and increased canopy leaf area.		Whether response can be predicted from knowledge of how leaf charac-teristics vary with depth in canopy. Magnitude of response under various conditions.
Carbon Partitioning Among Organs	Proportion of carbon going to roots and stems is increased in many but not all species.		Mechanisms of response. Magnitude of response under various conditions.
Stem Growth	Stem height increases in many species	Volume and/or density of wood increases in woody species.	Magnitude of response in species where stem is harvested.
Root Growth		Number of active root axes and hence total root length increases.	Magnitude of response and whether it affects amount of soil water available to plant.
Branching, Flowering, and Fruiting	Initiation and/or retention of these organ is increased in many species.	Development of organs is generally slightly earlier.	Mechanism underlying response. Magnitude of response under various conditions.

Process	Knowns	Uncertainties	Unknowns
Canopy Water-Use Efficiency	Increase in C_3 and C_4 plants. Increase in photosynthesis or yield contributes more than reduction in transpiration.		Magnitude of response under various conditions.
Fruit and Seed	Increases number and/or size of fruits and seeds.	No significant change in seed analysis.	Magnitude of response under various conditions.
Yield	Very variable, depending on harvested parts and on other environmental conditions. Increases 32% on average between 330 and 600 ppm for plants in favourable conditions.		Many of the mechanisms that determine yield.
CO_2XLight Interaction	Photosynthetic rate and absolute dry weight gain respond more to high CO_2 in high light in most species, but there is still a small response in low light in C_3 species.		Magnitude of response for some crop species.
CO_2 Concentration X Temperature Interaction	Extremely high or low temperatures limit source or sink strength and limit response to CO_2.	High CO_2 allows okra to survive low temperatures that would otherwise kill it, and allows grape to tolerate high temperatures.	Magnitude of response for most crop species.
CO_2 Concentration X Soil Water Availability	Transpiration rate is reduced in high CO_2 (after canopy closure) and plants need less water.	Plants maintain high turgor pressure. Relative yield response to CO_2 is greater at low soil water availability.	Many of the mechanisms involved. Magnitude of response.
CO_2 Concentration X Mineral Nutrients	Relative response of C_3 species to CO_2 is generally, but not always, less in nitrogen deficiency. In legumes, nitrogen fixation keeps pace with carbon fixation.	Potassium shortage inhibits any response to CO_2. Nitrogen shortage inhibits response of C_4 species to CO_2.	Magnitude of response for most crop species.
CO_2 Concentration X Salinity		Relative response to CO_2 is higher in saline conditions.	Magnitude of response for most crop species.
CO_2 Concentration X Gaseous Pollutants	In C_3 species, high CO_2 reduced the effect of pollutants because stomatal conductance is reduced.	In C_4 species, SO_2 damage is worse in high CO_2.	Mechanism in C_4 species response. Magnitude of response for most crop species and pollutants.

Source: Acock, Basil and Allen, L. Hartwell. Jr. "Crop responses to elevated carbon dioxide concentrations." In: Strain, Boyd. R and Cure, Jennifer, D; (eds) Direct Effects of Increasing CO_2 On Vegetation. Washington, D.C.; U.S. Department of Energy. DOE/ER-0238. pp. 85,86,87.

Cure conducted survey of literature on 10 crop species at doubled CO_2 levels. [5] The combined effects of CO_2 enrichment, water stress, nutrient stress, temperature and light were also considered.

The response of Carbon Exchange Rate, a carbon assimilation variable, to doubled CO_2 was greater for short term studies than for long term acclimated plants. The carbon assimilation variable values for the C_3 species indicate that the C_3 grasses such as wheat may respond less strongly to increased CO_2 levels than the broad leaved species such as cotton and soyabean.

Table 4. Average crop response from doubling ambient CO_2
(Abridged from Cure, 1985) (Numerical values represent percent change from ambient condition)

Response Category	Wheat	Barley	Rice	Corn	Sorghum	Soyabean	Alfalfa	Cotton	Sweet Potato
Biomass Accumulation	+31	+30	+27	+9	+9	+39	+57	+84	+59
Conductance	-22	-52	-33	-37	-27	-31	---	-15	---
Transpiration	-17	-19	-16	-26	-27	-23	---	-18	---
Yield	+35	+70	+15	+29	---	+29	---	+209	+83

<u>Source</u>: Modified from original in Cure, J.D. "Carbon dioxide doubling responses : A crop survey." In :Direct Effects of Increasing Carbon dioxide On Vegetation. Washington,D.C. :U.S. Department of Energy. DOE/ER-0238. p.105. [5]

Biomass Accumulation: The effect of CO_2 doubling on biomass accumulation is higher for C_3 crops as compared to C_4 species in agreement with the lower carbon assimilation response for C_4 species.

Harvest Index and Yield: The effect on wheat and soyabean yields were similar to those on biomass accumulation, although data for C_3 grasses was scarce and variable.

Soyabean was one of the species for which the Harvest Index (ratio of grain weight to total plant weight above ground) decreased consistently with increasing CO_2 levels. The results indicate the need for examining the efficiency of carbohydrate partitioning during reproductive growth.

Conductance and Transpiration: Decreased stomatal conductance was observed with increased CO_2 levels. This was true of both C_3 and C_4 species, although, some studies indicate a greater stomatal sensitivity of C_4 species as compared to C_3 species. A decrease in stomatal conductance does not necessarily lead to a decrease in transpiration of the same magnitude. This is so because as the stomata close in response to increased CO_2 levels and transpiration falls, temperature within the leaf rises, in turn stimulating transpiration.

CO_2 enrichment under varying conditions of water, nutrient, light and temperature was studied in terms of their interaction.

Water Stress: Predictions of future climate envisage altered precipitation patterns and also altered water availability. As far as crop water use is concerned the increased leaf canopy area resulting from high CO_2 concentrations may compensate for the lowered conductance under the same conditions. An increase in leaf canopy area resulting from high CO_2 concentrations may or may not aid in water conservation. Continued low water availability is likely to lead to low leaf water potential. There are a few instances of some species having adapted to low moisture availability by forming osmotically active solutes which aid in maintaining turgor under the above conditions. The effectiveness of such an adaptation would however, depend on the rate and magnitude of global climate change.

Nutrient Stress: Nutrient stress is capable of limiting the effect of CO_2 enrichment on plants. During experiments on soyabean and two weed species grown at increased CO_2 levels in varying dilutions of Hoagland's solution leaf area increased only under high nutrient supply. Low nutrient conditions led to lowered leaf expansion in turn leading to accumulation of carbohydrate (resulting from assimilation) even under present CO_2 levels. Thus increased levels of CO_2 would increase carbohydrate accumulation unless there is simultaneous enhancement of the root's absorption efficiency or external nutrients are made more easily available to the plant. Nutrient uptake would have to be on par with carbon fixation so that carbon assimilation is not inhibited.

Light and Temperature: The data available shows no consistency as far as the influence of light on the carbon assimilation variables or on the growth of the species studied. It was found that at higher temperatures the response to CO_2 was greater as compared to that at lower temperatures. At high temperatures and high light intensities, the carbon assimilation variables and biomass accumulation response to CO_2 were higher in comparison to the values obtained at low light intensities and the same high temperature.

Given the scarcity of quantitative data, it would be difficult to make definite predictions, but some of the results that emerge from this survey are:

i) Only soyabean and wheat have been extensively studied; more work is needed on other crop growth responses.

ii) C_3 plants showed a greater increase in both carbon assimilation and growth as compared to C_4 species in response to increased CO_2.

iii) A uniform decrease in transpiration of approximately 34 per cent across all species was observed in response to CO_2 doubling.

iv) Responses under controlled conditions are likely to be better than those obtained under field conditions, reducing the validity of the application of the former to actual yields.

b) Computer model studies

The Environmental Protection Agency (EPA) initiated studies on climate change caused by the greenhouse effect, [6] using output from the general circulation models viz. Geophysical Fluid Dynamics Laboratory (GFDL), Goddard Institute for Space Studies (GISS) and the Oregon State University climate models. These studies used i) a doubled CO_2 scenario ii) a transient scenario representing the period of transition to a future climate and iii) an analog scenario of the 1930's period which was warm.

The potential impact of climate change on agriculture was studied using the general circulation model output in combination with crop growth simulation models. These crop growth simulation models aid in predicting growth components and yield for various crops such as soyabean, wheat, rice. They have been used and validated in varying environments in different parts of the world. The EPA study covered the Great Lakes, Eastern USA and Great Plains. Using the weather scenarios generated by the climate models and baseline observed weather data, an attempt was made to simulate crop production under both normal and altered climates. An effort was also made to forecast yield under both dryland and irrigated conditions.

Ritchie ran both the CERES Maize and SOYGRO models for rainfed and irrigated conditions for the Great Lakes region. [7] The findings were:

i) The principal causes of altered yields were rainfall and temperature.

ii) The yield decreases predicted for irrigated conditions was less than those for rainfed conditions.

iii) Irrigation water needed for optimal yield was related to amount of rainfall in the growing season. Water requirements increased as much as 90% under the extreme GFDL conditions, in comparison to the baseline weather.

iv) The duration of the crop's life cycle was reduced by an increase in temperature in a number of instances.

The model was also modified to incorporate increased photosynthesis and reduced transpiration due to increased CO_2. Direct effects of CO_2 caused an increase in crop yield vis a vis weather effects alone for both crops at all locations. There were instances where direct CO_2 effects overcame weather related losses.

Peart et al ran similar simulations for soyabean and maize for South Eastern U.S.A. using baseline weather and yield data for about 19 sites, both in rainfed and irrigated conditions. [7] The findings were:

i) Under the GISS scenario climatic variables caused a 25 per cent yield decrease for rainfed soyabean; and a yield decrease of as much as 73 per cent under the GFDL scenario.

ii) For rainfed yield of maize, decrease for the GISS scenario was 8 per cent which went upto as high as 65 per cent under the more extreme GFDL scenario.

iii) Altered yield resulted for soyabean, but not maize on incorporating equations for increased photosynthesis and reduced transpiration. Both climate and direct effects brought about a 14 per cent yield increase for soyabean.

iv) Irrigated conditions could overcome the weather related losses in yeild.

Another crop simulation study for wheat and corn in the Central and Southern Great Plains of the US was run by Rozenweig. [7] The study showed that :

i) Decrease in duration of crop life cycle for wheat and corn caused a decline in yield.

ii) As in the first study quoted above, yield was found to be less variable under irrigated conditions.

iii) The direct effects of CO_2 were incapable of overcoming the climatic variables in a dryland condition simulation, under the GFDL scenario.

iv) Planting wheat cultivars with lower vernalization requirements, lower photoperiod sensitivity and longer grainfilling periods and altering planting dates helped only at some locations.

In conclusion some of the overall findings from the study are:

i) Agriculture in the higher latitudes would be affected primarily due to the altered temperature.

ii) Yield variability was far less for irrigated conditions underlining the need for increasing acreage under irrigation.

iii) The direct effects of CO_2 could overcome only partially the yield decreases caused due to altered climate, especially for maize (a C_4 plant).

There have been very few such studies in India. In a study of the effect of increasing temperature on estimated rice yields, increasing mean daily temperature was found to result in decreasing the period from transplantation to maturity, but was accompanied by a decline in crop yields. [8] Yield of rice is also closely dependent on total radiation and minimum temperature from flowering to ripening.

Sinha (1989) has predicted a decline in both rice and wheat productivity in response to a 2° C rise in temperature. The decrease in yield for Punjab and Haryana would be approximately 0.75t per hectare for rice in the event of a 2°C rise in temperature and 0.45t per hectare yield decline in wheat for an increase in temperature of 0.5°C. Studies on the regional impact of global warming on Punjab and Haryana would be of greater significance on overall foodgrain production.

This is especially significant in view of the fact that future

Table 5. Expected changes in major river systems affected by carbon dioxide induced climatic change

River System	Location
A Rivers experiencing decreases in flows	
River System	**Location**
Hwang Ho	China
Amu Darya	Soviet Union
Ayr Darya	Soviet Union
Tigris-Euphrates	Turkey, Syria, Iraq
Zambezi	Zimbabwe, Zambia
Sao Francisco	Brazil
B Rivers experiencing some flow and storage loss	
River system	**Location**
Congo	Central Africa
Rhone	Western Europe
Po	Western Europe
Danube	Eastern Europe
Yangtze	China
Rio Grande	United States Mexico
C Rivers experiencing increases in flows	
River system	**Location**
Niger	Africa
Chari	Africa
Senegal	Africa
Volta	Africa
Blue Nile	Africa
Mekong	Indochina
Brahmaputra	South Asia

Source :Roger Revelle, 'Carbon dioxide and world climate, 'Scientific American, Vol 247.1982.pp.753-759. [10]

agricultural production must feed the world's growing population estimated to be about 10.5 billion by 2075. [9]

Inspite of a steady increase in global production and consumption of grain, regional food shortages continue to occur due to climatic variability and socioeconomic factors. Technological advances such as high yielding varieties and irrigation systems have reduced the extent of crop yield dependence on weather, although even today, it still constitutes an important factor in agricultural productivity. The 1988 US drought shows the close link between agriculture and climate. The failure of the monsoon in 1987, caused a shortfall in agricultural production in India, Bangladesh and Pakistan.

Another area of major concern is the sensitivity of marginal agricultural lands. Some of the rainfed croplands in tropical Africa, S. Asia and S.America are undergoing extensive deserti-fication and lowering productivity. It is to be seen how an altered climate would affect such areas.

In terms of water resources, changes are expected in the flow of the major river systems,which support agriculture extensively (Table 5). [10] Alterations either in flow or storage capacities of these river systems would affect both surface and underground flow and may even cause flooding. However, data regarding India are scarce.

Sea level rise, an associated impact of climate change, would not only cause flooding of low lying coastal agricultural regions, but also alter quality of water resources due to salination. These results indicate that global warming will have an effect on agriculture. But they cannot be extrapolated to India directly and more detailed studies are needed to determine future trends in this country. While increase in CO_2 concentration will be nearly the same in all parts of the globe the extent to which changes in temperature, rainfall, river flow and sea rise will affect India in different regions and for different crops remains to be determined. Some of the climatic and other variables which are likely to change due to global warming and affect agriculture directly or indirectly are listed in Table 6 on next page.

This clearly demonstrates the nature of potential impact due to global warming on agriculture. Our study is restricted to the effects of CO_2, temperature and water availability on agriculture. There are several special features of Indian agriculture which distinguish it from agriculture in other countries and which are relevant to such studies. These are discussed in the next chapter.

Table 6 : Climatic and other variables likely to change due to GHW and components of resource base and production environment of agriculture to be most affected by the change .

Major Components of physical resource base and production environment.	CLIMATIC AND OTHER VARIABLES						
	Temperature	Solar Radiation	Precipitation	Soil moisture	Run-off	Evapo-transpiration.	Atmospheric Humidity.
1. Moisture Regime			:		:	:	
2. Length of growing season			:	:	:		:
3. Micro-Climatic stress	:	:	:	:	:	:	:
4. Frequency of aberrant weather	:	:					
5. Seasonality	:	:	:				
6. Disease/pest complex	:	:	:	:			:
7. Bio-mass productivity potential	:	:	:	:		:	:
8. Photosynthesis pattern	:	:		:		:	:
9. Plant-input interaction		:		:		:	
10. Chemistry of soil	:	:	:	:	:		
11. Soil erosion hazard		:		:			

SOURCE : Jodha, N.S. 1988.
Potential strategies for adapting to greenhouse warming : Perspective from the developing world.
In Easterling, W. and Rosenberg, N. (eds)
Greenhouse Warming : Abatement and Abatement Resources for the future.
Washington D.C. [26]

Section III

Special Features of Indian Agriculture

1. Economy

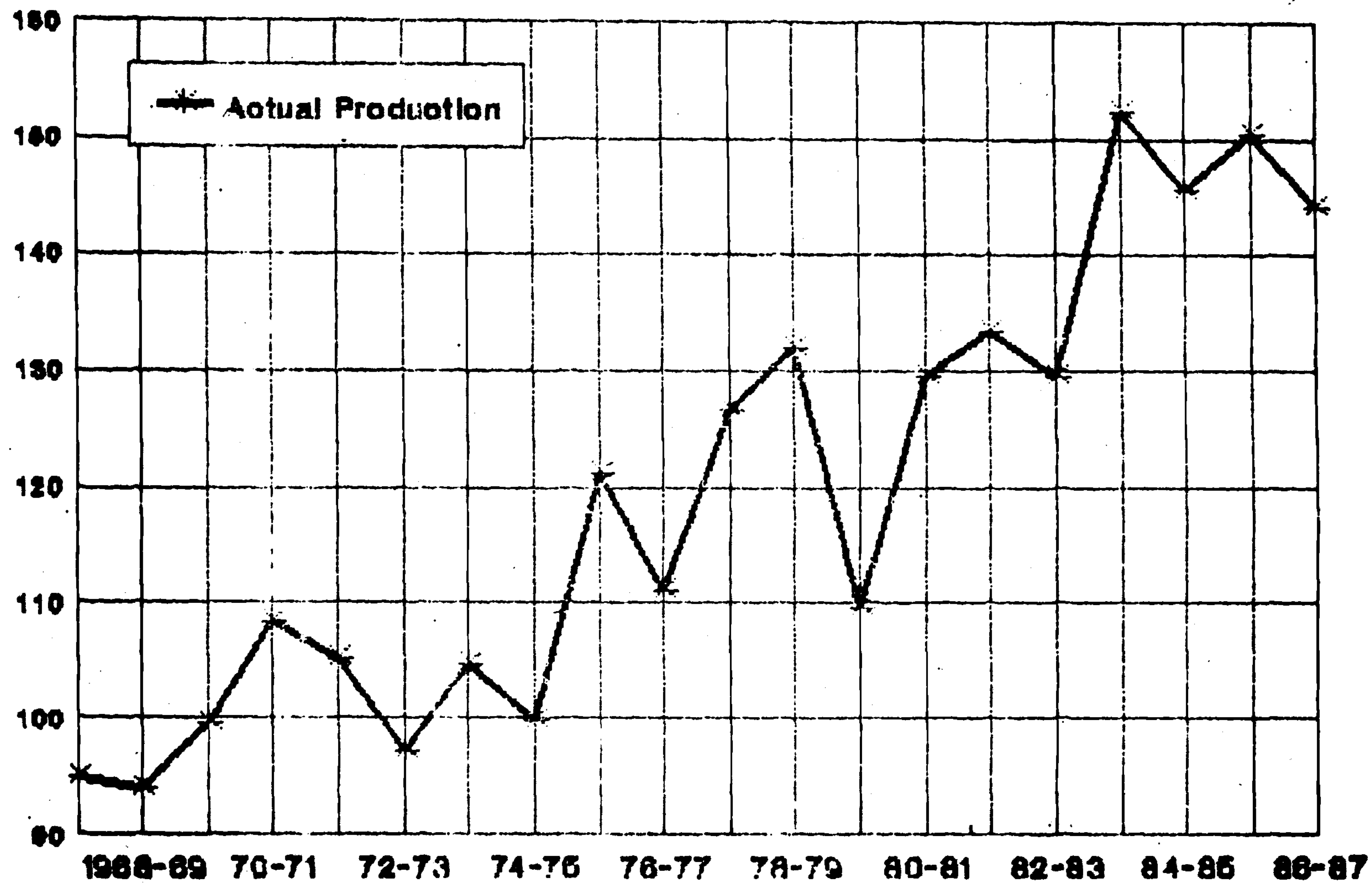
Our economy is agriculture based and agriculture serves as the major source of income, employment and sustenance for the bulk of the population. Its contribution to the Gross National Product is over 30 per cent. In 1981, out of a population of 685 million, 41.6% workers were cultivators and 24.9% were agricultural labourers. The value of exports based on agriculture in 1985-86 was 30% that of total exports.[12] The quantum of agricultural exports at present is about half that of manufactured goods. The impact of global warming on agriculture is therefore, of basic importance to the economy.

2. Irrigation

Although irrigation is important in many regions, agriculture is primarily dryland/rainfed. Dryland farming continues to be practised in 70 percent of the cultivated area amd 10.2 crore hectares out of 14.2 crore hectares are rainfed. 80-90 percent of the rainfall received in the country is concentrated in the four monsoon months, and is due to the Southwest Monsoon. The erratic and unpredictable nature of the monsoon in turn leads to a reluctance amongst farmers to invest in inputs such as seeds, fertilizers and plant protection measures.

Watershed development (piece of land that drains at a common point) has been considered a suitable approach for the development of dryland areas. Many states and Union

TOTAL FOODGRAINS - ALL INDIA PRODUCTION
MILLION TONNES



Source: Ministry of Agriculture [12]

FIGURE [redacted] 3

Territories have identified about 13,472 microwatersheds covering an area of about 10 million hectares for systematic development.[13] This would include rainwater management, land development, increased use of fertilizers, improved seeds of drought resistant varieties, forest and fruit tree plantation and other related activities. By 2010, an irrigation potential of 113.5 mha is expected to be developed.

It should be noted that the adverse affect of higher temperature is much less under irrigated than rainfed conditions. The projected inrease in irrigation in India should be considered when assessing the effect of global warming on agriculture.

3. Land Utilization

At present, the average per capita land availability is 0.23 hectares. The per capita availability of land is expected to be hardly 0.15 hectare at the beginning of the next century. Food, fibre and other requirements of over 100 crores of human beings and fodder and feed needs of over 50 crores of farm animals, must be met in an ecologically sustainable manner. This will require intensive cultivation techniques, larger inputs of fertilizers, pesticides and other agrochemicals. These may increase greenhouse gas emission (methane from rice) and influence plant response to the higher CO_2 concentration.

4. Foodgrain production

Food grain production, in 1988-89, was estimated to be 170 million tonnes.[25] Of this, rice production was 70 million tonnes and wheat was 54 million tonnes. This achievement was due to the use of high yielding varieties of seeds, increased fertilizer usage, weed management, timely plant protection measures and efficient use of water. The goal at the end of the Eighth plan, is to reach a food grain production of 206 to 210 million tonnes. Meeting this goal would require additional area under cultivation and irrigation, increased fertilizer consumption and an increase in acreage under high yielding varieties. All these factors will influence global warming and the response of agriculture to it.

5. Fertilizer

The fertilizer consumption per hectare of agricultural land for India in 1985-86 was 47 kg/hectare compared to 380 kg/hectare for Japan. Annual consumption increased from one lakh tonnes in the 1950s to about 50 lakh tonnes by 1980. The target for 89-90 is 14 million tonnes. The per hectare consumption of NPK increased from 0.6 Kg in 1950 to 50 Kg by 1987-88. In 1985, 53% of the gross cropped area consumed 75% of the total fertilizer. Punjab, Tamil Nadu and Andhra Pradesh used 159, 96 and 79 kg/ha respectively whereas Madhya Pradesh, Orissa and Rajasthan used only 12 to 18 kg/ha.[14] Fertiliser tends to be overused especially in areas of assured irrigation, and for cereals, cotton and sugarcane. Soil testing aids in determining use of fertilizers in order to obtain the most economic returns.

The relatively low level of fertilizer use compared to that in western countries, Japan, and China as well as the projected increase in fertilizer production must be kept in view while assessing the effect of global warming. As indicated earlier, the stimulating effect of higher CO_2 levels on yields will be less if there is a deficiency of plant nutrients. It will also be seen that an effect of global warming and CO_2 increase in Punjab and Haryana would be of greater significance on overall foodgrain production than in other areas using low levels of fertilizers and low yielding varieties. Studies on the regional impact of global warming are therefore essential.

6. <u>Land Holdings and Technology</u>

Land holdings are categorized into the following groups

(i) marginal (less than 1 hectare)

(ii) small (1-2 hectares)

(iii)semi medium (2 to 4 hectares)

(iv) medium (4 to 10 hectares)

(v) large (10 and above hectares)

In the 1980-81 agricultural census, marginal holdings with less than 1 hectare land accounted for a little over 56 percent of the total holdings. Average size of marginal land holdings in 1980-81 was 0.39 hectares. Due to the small size of the holdings the total marketable surplus with an average farm family of five to six would be limited. There is a ceiling on farm land holdings which varies with the state and depends on whether the land is irrigated or rainfed, but the ceiling is generally less than 20 hectares. Large farms of hundreds or thousands of hectares such as those in many other countries are unknown in India.

The technology in most regions is relatively simple and lacks the sophistication and mechanization found in western countries. The scope for improving technology for efficient water management, pest and disease control measures, plant nutrient application and use of certified high-yielding seeds is very large. These changes will influence the impact of global warming as well as the measures required to counter adverse effects due to it.

7. Cropping Pattern

Land under high yielding varieties during the period 1987-88 for paddy was 21 million hectares. The same acreage was occupied by wheat, for the same period.

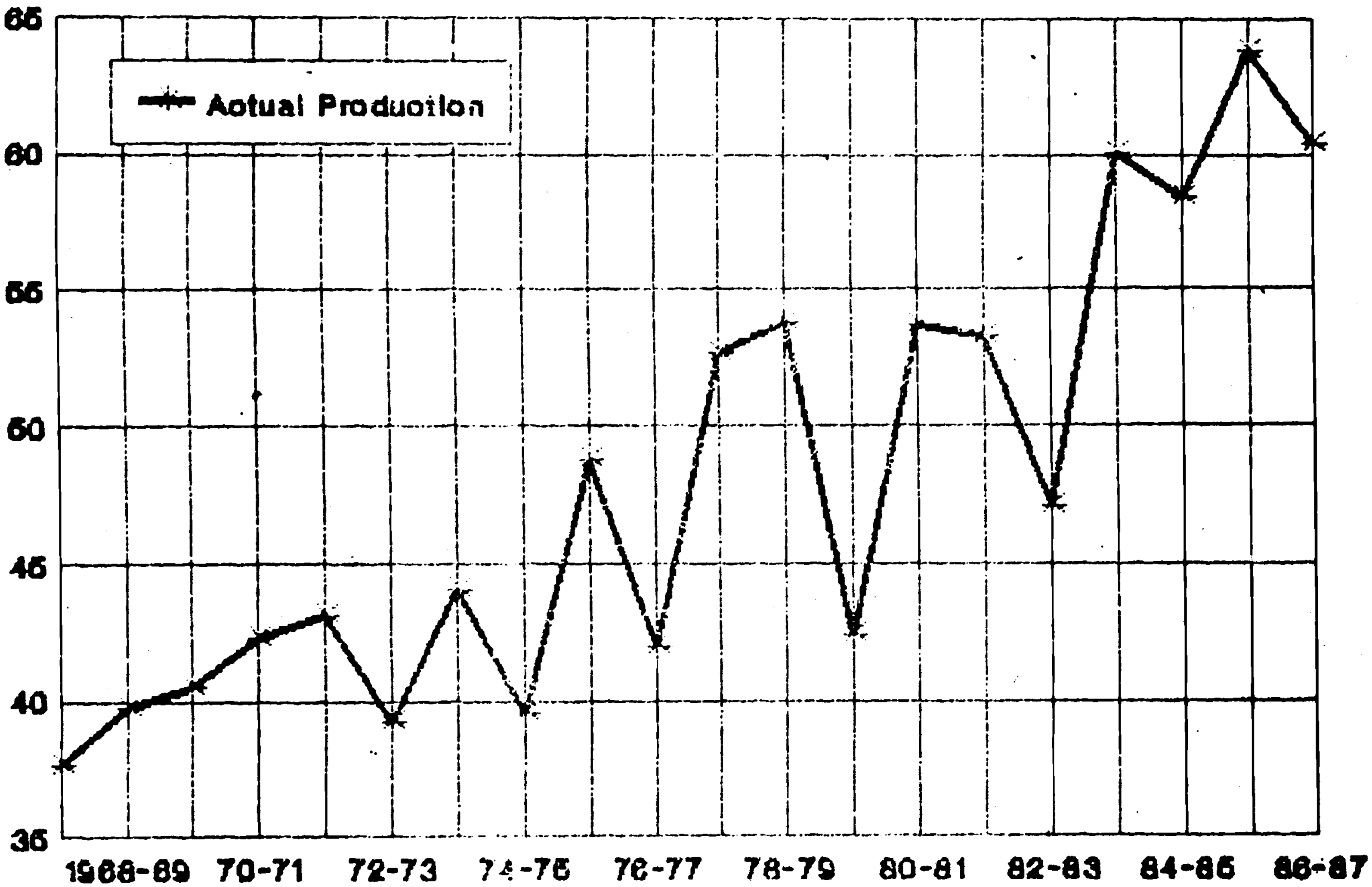
For the year 1984-85 total foodgrains occupied 72 per cent area cropped area. Cereals acreage was 59 per cent, rice 23 per cent and wheat 13 per cent of the total.

There are two main crops kharif and rabi with a third crop in several regions in summer. Major kharif crops are rice, jowar, bajra, maize, cotton, sugarcane, sesame and groundnut. The major rabi crops are wheat, jowar, barley, grain, linseed, rapeseed and mustard. Rice, maize and groundnut are grown in the summer season also. Multiple cropping is practised in many parts of India.

A reduction in the growing season due to elevation of temperature which has been predicted by computer models, may lead to lower yields because of shorter grain filling period. But in India, short duration crops are in demand and reduction of growing period may facilitate multiple cropping.

FIGURE 4

RICE - ALL INDIA PRODUCTION
MILLION TONNES



Source: Ministry of Agriculture [12]

Section IV

Crop under study : Rice (<u>Oryza sativa</u> L.)

1. Rice is grown from 8°N latitude to 34°N latitude in India. In the world rice cultivation extends from 39° S latitude (Australia) to 50°N latitude (China).

Table 7. All India area, production and yield of rice

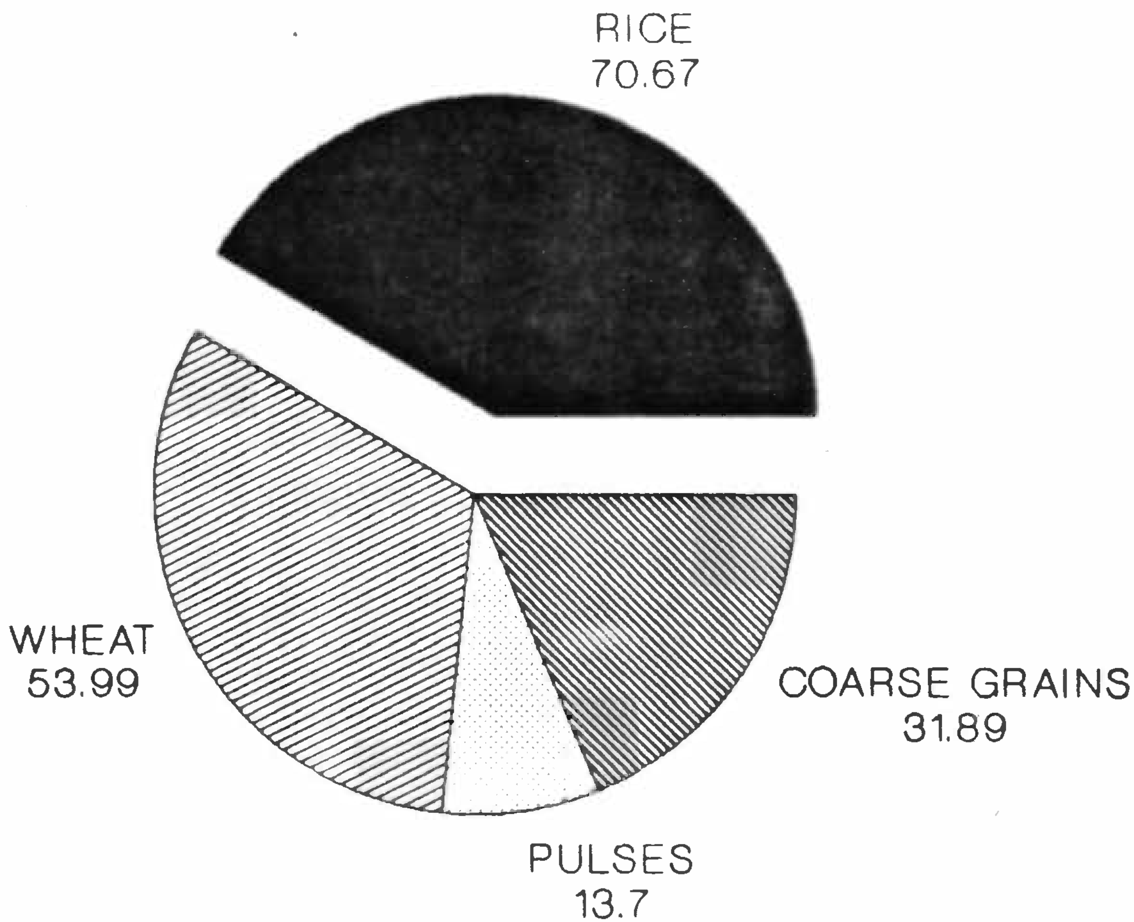
YEAR	AREA (M. HECTS)	PRODUCTION (M. TONNES)	YIELD (KGS/HECT)	% COVERAGE UNDER IRRIGATION
1949-50	30.52	23.54	771	32.3
1950-51	30.81	20.58	668	31.7
1951-52	29.83	21.30	714	31.7
1952-53	29.97	22.90	764	32.3
1953-54	31.29	28.21	902	33.6
1954-55	30.77	25.22	820	34.4
1955-56	31.52	27.56	874	34.9
1956-57	32.28	29.04	900	35.4
1957-58	32.30	25.53	790	36.4
1958-59	33.17	30.85	930	36.3
1959-60	33.82	31.68	937	35.8
1960-61	34.13	34.58	1013	36.8
1961-62	34.69	35.66	1028	37.5
1962-63	35.69	33.21	931	37.4
1963-64	35.81	37.00	1033	37.1
1964-65	36.46	39.31	1078	37.3
1965-66	35.47	30.59	862	36.5
1966-67	35.25	30.44	863	37.9
1967-68	36.44	37.61	1032	38.6
1968-69	36.97	39.76	1076	38.4
1969-70	37.68	40.43	1073	38.2
1970-71	37.59	42.22	1123	38.4
1971-72	37.76	43.07	1141	37.2
1972-73	36.69	39.24	1070	39.1
1973-74	38.29	44.05	1151	38.4
1974-75	37.89	39.58	1045	38.8
1975-76	39.48	48.74	1235	38.7
1976-77	38.51	41.92	1088	38.4
1977-78	40.28	52.67	1308	40.2
1978-79	40.48	53.77	1328	41.6
1979-80	39.42	42.33	1074	42.8
1980-81	40.15	53.63	1336	40.6
1981-82	40.71	53.25	1308	41.6
1982-83	38.26	47.12	1231	41.7
1983-84	41.24	60.10	1457	42.1
1984-85	41.16	58.34	1417	43.0
1985-86	41.14	63.83	1552	
1986-87	40.77	60.42	1482	
1987-88	38.32	56.43	1473	
1988-89	NA	70.67	NA	NA

<u>Source</u> : Ministry of Agriculture.[12]

Economic Survey.1989-90.[25]

FIGURE 5

Rice production vis-a-vis other foodgrains



Production in million tonnes for 1988-89

source Economic Survey 1989-90

2. Area under rice cultivation, in India, for 1987-88 was 383 lakh hectares and for wheat cultivation 226 lakh hectares. Production for the same period for rice was 564 lakh tonnes and for wheat 450 lakh tonnes and yield was 1,473 kg per hectare for rice, and 1,995 kg per hectare for wheat. [13] It is evident that although acreage under rice cultivation is larger as compared to wheat, yield per hectare is less for rice. Rice production for 1988-89, vis a vis other foodgrains is on the opposite page.

3. Paddy is the dominant crop of both the East and the West Coast which are included under Agroclimatic zones 11 and 12. [15] The productivity of rice in these regions is likely to be affected by a potential sealevel rise, which could lead to flooding/salt water intrusion reducing fertile agricultural land.

   It is not only grown under sealevel in Kuttinad in Tamil Nadu but in parts of Jammu and Kashmir at altitudes of 1,979 metres. It can be grown under upland conditions, under moderately submerged conditions and in 1.5-5 m water.

4. One third of the fertilizer produced in India is used for the paddy crop. However, rice growing conditions are conducive to rapid loss of applied nutrients, particularly of Nitrogen (N). Rice growing areas are often deficient in N. Among the nutrients N is the most important element particularly when N responsive varieties are grown. The economic optimum dose of N for the new rice varieties is 80-90 kg/ha during kharif and 100-120 kg/ha during the rabi. [16] Deficiency of boron, zinc and other

micronutrients has been shown in several regions, especially with high yielding varieties.

5. Water requirement for rice is greater than that for any other cereal crop of similar duration. The percentage of irrigated area to total area under rice cultivation for India was 43 per cent in 1984-85 and 74 per cent for wheat.[12] Paddy and wheat account for the bulk of the irrigated area under cereals.

6. One of the major sources of potential methane production is rice production. According to German researchers from the Fraunhofer Institute for Atmospheric Environmental Research increasing production of rice could increase methane production by about 2% per year. This would be expected to have a direct impact on global warming as a single methane molecule heats up the earth's atmosphere approximately 25 more times efficiently than a molecule of carbon dioxide. The extent of methane production would depend upon whether the soil is acidic or alkaline.

7. Rice being fairly tolerant grows normally in soils upto 6mm hos/cm conductivity as compared to other crops whose yield is affected by salinity levels above 4mm hos/cm conductivity.[16] It is to be seen how the crop withstands higher salinity levels in the event of a sealevel rise.

8. Rice is a suitable crop to study because it represents a broad class of crops (C_3 grass crop) and is a major foodgrain crop having second largest annual production in the world for cereals. [17]

Physiology of Rice

Some of the physiological features of rice which could have an impact on its future yield are discussed below. [18]

1. Rice is adapted to a range of 25° C to approximately 35° C of the ambient air temperature. Sato (1970) observed that high temperature treatment upto 35° c day and 30° C night did not promote maximum photosynthesis. [18]
2. The short rice varieties and even the semi dwarf varieties are known for their higher storage capacity. Storage capacity for carbohydrate is affected by the spikelet number and is determined prior to grainfilling (Matsushima 1965, and Evans 1972). [18]
3. Rice varieties show a negative correlation between plant height and harvest index. According to Athwal (1971), IR 8, a semi dwarf variety, has a harvest index value of approximately 1.0 while Peta a tall variety and its parent has a value of 0.5. [18]
4. The stomatal frequency of rice varieties, in particular indica varieties, is high. This would influence gaseous pollutant and carbon dioxide enrichment interaction. [18] However pest resistant varieties have a lower stomatal frequency.
5. Gas diffusion resistance of the rice leaf is low which would lead to a high rate of transpiration. In the event of an altered soil water availability, this would be of importance. [18]
6. The photosynthetic response of crops including rice were studied by Iyama and Murata in 1961. It was determined by the ability of the crop to keep water in the leaf blade against a soil moisture deficit. It was found to be greatest in this order. Wheat > Soyabean > Rice. [18]

Previous Research On Rice

Some of the work on the effects of CO_2 and temperature on rice is summarized below:

1 Effect of CO_2 enrichment before and after flowering on yield

Rice plants subjected to carbon dioxide enrichment in field enclosed chambers ,thirty days before flowering increased grain number per unit land area and increased grain weight.(Cock, J.H.,S.Yoshida 1973) [19] The increase in grain yield obtained over the control was 30 per cent. (Yoshida,S.1973) [22]

The increase in yield was directly proportional to the dry matter increase after panicle initiation. (Cock,J.H.,Yoshida,S.1973)[19] Enrichment for a period of ten days at the rachis-branch differentiation stage increased grain yield by ten per cent, this increase being mainly due to increased grain number. CO_2 enrichment for two weeks from reduction division to flowering had no effect on grain yields.

Enrichment thirty days after flowering had no effect on grain number, but led to an increase in filled grain percentage and grain weight. (Cock, J.H.,Yoshida,S. 1973) [19] Thirty days of CO_2 enrichment after flowering led to an increase in grain yield of ten per cent over the control due to increase in grain weight and filled grain percentage.(Yoshida, S. 1973) [22]

It is evident from the above experiment that grain number per unit land area is more limiting to grain yield than grain filling. (Yoshida, S.1973) [22]

2. Effect of various carbon dioxide concentrations on growth and dry matter production.

In an effort to understand the effects of various concentrations of carbon dioxide on growth and dry matter production, rice plants at the 5-7 leaf stage were exposed to carbon dioxide within growth chambers. High carbon dioxide concentrations did increase plant height and even leaf area (although response was not significant) and decreased transpiration. It also caused an increase in tillering, dry weight (Net Assimilation Rate) and increased dry matter distribution to the roots and less to the leaves. (Imai, K., Y. Murata 1978). [20]

Rice plants subjected to doubled CO_2 during vegetative growth phase showed an increased number of tillers, leaf area and dry weight. There was a large increase in root weight. Yield increased by 23-72% under high CO_2 due to an increase in grain number per panicle rather than in grain weight. [24]

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The interaction between atmospheric carbon dioxide concentration and nitrogen nutrition on dry matter production of crop seedlings was studied by Imai and Murata, in 1979.[21] It was found that higher carbon dioxide concentrations promoted dry matter production for rice and this effect was increased by higher N levels due mainly to the increased leaf area of tillers. There was no alteration in the response of Net Assimilation Rate (NAR) to the carbon dioxide concentration by nitrogen levels in the soil.

The promotion of dry matter growth rate was far greater in C_3 species under both low and high light intensities,owing to the larger response of NAR in these species. High light intensity did not promote carbon dioxide enrichment in C_3, unlike in the C_4 species.

The carbon dioxide enrichment effect on both C_3 and C_4 species was enhanced by the high temperature owing mainly to increase in NAR and partly due to leaf expansion. The carbon dioxide enrichment effect was greater in C_3 as compared to C_4 species under both low and high temperatures. (Imai,K.,Y.Murata. 1979). [21]

3. <u>Effect of solar radiation and temperature on rice yield</u>

Seshu and Cady, 1984 have discused the response of rice yields to solar radiation and temperature.[8] The results showed that an increase in mean daily temperature leads to decrease in the period from transplantation to maturity, accompanied by a decline in crop yield. According to them yield of rice is dependent on total radiation and minimum temperature from flowering to ripening.

4. <u>Effect of high CO_2 and temperature on growth and yield.</u>

Rice exposed to CO_2 doubling at two temperature regimes viz 28/21°C, day/night temperature and 33/26°C day/night temperature. It was found that a higher response was obtained at high CO_2 at 33/26°C than at 28/21°C. Some of the effects of exposure to doubled CO_2 at high temperature were advancement of flowering, increased panicle weight, increased root weight and increase in total dry matter production.

In conclusion the available data indicate that rice yields are likely to increase in response to increased CO_2 concentration. This would be dependent on adequate fertilizer and water availability. Increase in temperature would have an adverse effect on yield. There is uncertainty regarding the effect of increase of both CO_2 levels and of temperature on rice yields.

The actual effect on rice yield in different regions would be determined by i)increase in CO_2 ii)increase in temperature iii)increase or decrease in water availability. Different rice varieties and regions must be considered while examining potential yield alterations.

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SEA LEVEL RISE, MARINE ENVIRONMENTS AND HYDROCARBON DEVELOPMENT ACTIVITY

Ligia Noronha

INTRODUCTION

The purpose of this report is to raise some issues for coastal zone management given a backdrop of a potential Sea level rise (SLR). It discusses the issues involved in the decision to have an economic activity in an ecosystem deemed valuable in the context of a sea level rise. The coastal area selected for attention here is Southern Cambay region, one which is considered relatively vulnerable to SLR, the coastal activity being planned is hydrocarbon development and the marine environment upon which the effects are being assessed are the lowlying wetlands of this region, namely, mangrove swamps and marshes. The rationale for choosing this particular environment for attention is that they have an important role in stabilizing the coastline, dissipating wave-energy and controlling floods, all impacts expected to be aggravated by global warming and sea level rise. For a developing country, where the resources to adopt technical responses to hold back the possibility of a rising sea many years on is financially and politically difficult, a prudent use of natural resources that have a role to play in mitigating the effect of a potential SLR as a first response, is both a sensible and a responsible action to undertake. The rationale for choosing hydrocarbon development activity as the economic activity that modifies this environment is that it exemplifies an economic activity with immediate benefits, and thereby highlights the dilemma confronted by decision-makers between decisions which involve short term benefits as against those with longer term benefits. The considerable economic attractiveness of indigenous hydrocarbon development implies that ecological considerations and environemntal hazards tend to play an insignificant role relative to other considerations such as foreign exchange, economic returns and security of supply.

The central issue being raised here is one of assessing the value of preserving a marine environment as against the value of developing it for some coastal use. For coastal zone management it is necessary not only to have the social and the economic details of the use planned but also the general and the detailed information of the marine environment being impinged upon. This necessarily calls for an interaction of two sections in society: the socio-political and the economic on the one hand and the scientific community on the other. In India, most planning has been in the context of the set of concerns of one group or the other, little communication is evident between the two groups. Thus, hydrocarbon policy in India has been dominated by oil technocrats, politicians and economic advisors. Environmental concerns have not been on the decision agenda of any of these communities, in part because the polity in general lacked environmental consciousness. As the irreversibility of development decisions is beginning to become more clear, as people are becoming increasingly concerned not only with intragenerational equity in employment, income distribution and access to energy, but also with intergenerational equity in resource availability and the rights of future generations to natural environments, such concerns are coming to influence the political agenda.

THE SEA LEVEL RISE PHENOMENON

The projected increase in global warming by the middle of the next century ranges from 1.5° - 4.5°C. This range of increase in global temperatures has led to a number of model estimates of expected sea-level rise resulting from a thermal expansion of sea water, the melting of glaciers and polar ice. [1] The best known projections are the two by the National Academy of Sciences in 1983 and 1985 and those of the US Environmental Protection Agency in 1983 and in 1986. Tables I and II below give these estimates by causes and by years.

Table I. Scenarios of future SLR by years (in centimetres)

Scenario	Year 2000	2025	2050	2075	2100
-(EPA 1983)					
High	17.1	54.9	16.7	211.5	345.0
Mid-range High	13.2	39.3	78.9	136.8	216.6
Mid-range Low	8.8	26.2	52.6	91.2	144.4
Low	4.8	13.0	23.8	38.0	56.2
(EPA 1986)					
Low	3.5	10.0	20.0	36.0	57.0
High	5.5	21.0	55.0	191.0	368.0

Sources: See Table II.

Table II. Estimates of future SLR for the year 2100 (in centimetres)

Study	Causes				
	Thermal Expansion	Alpine Glaciers	Greenland	Antarctica	Total
NAS[1] (1983) (For 2085)	30	12	12	70	-
EPA[2] (1983)	28-115	--	--	--	56-345
NAS[3] (1985)	--	10-30	10-30	-10-+100	50-200
EPA[4] (1986)	28-83	12-37	6-27	12-220	57-368

Sources:

1 R. Revelle. 1983 'Probable Future Changes in Sea Level Resulting from Increased Atmospheric Carbon Dioxide' in Changing Climate, Washington D.C., National Academy Press.

2 J.S. Hoffman, D. Keyes, J.G. Titus, 1983. Projecting Future Sea Level Rise: Methodology, Estimates to the Year 2100 and Research Needs. Washington D.C. US EPA.

3 M.F. Meir et al. Glaciers, Icesheets and Sea Levels. Washington D.C., National Academy Press.

4 J.S. Hoffman, J. Wells, J.G. Titus, 1986. 'Future Global Warming and Sea Level Rise' in G. Sigbjarnarson (ed) Iceland Coastal and River Symposium. Rejkjavik/Iceland: National Energy Authority.

From the point of view of policy responses to sea level rise, however, the rise in eustatic sea level is just one of the processes that contributes to the rise in the level of the sea relative to land. What is essential to note is the relative mean sea level change at a particular location. This is the difference between the eustatic rise and any local change in land elevation brought about by glacial rebound, or by compaction and subsidence resulting from mineral and/or ground water extraction and drainage. Thus, the relative rise in sea level will vary between regions of the world dpending on these local factors. The impacts of a sea level rise will also vary depending on the particular characteristics of the region and of the coast. These impacts will depend not only on local geomorphological factors, but also on the climatic fluctuations and the coastal practices of the region. In sum, while the eustatic rise in sea level is uniform, the rises in relative sea level and the consequent impacts are essentially regional or location specific. The choice of responses will also necessarily have to be location and resource specific given the variations in these effects, in the socio-economic characteristics of the region and in the response capabilities of nations.

Effects of a Sea Level Rise (SLR)

The effects of SLR can be classified into four broad categories: (1) Physical (2) Ecological/environmental (3) Socio-economic and (4) Legal/institutional. The primary effects of rising sea levels will be increased coastal flooding, erosion, storm surges and wave activity. Already existing vulnerability to flooding and storm surges could be aggravated by (1) erosion (2) higher water levels that would provide storm surges with a higher base to build upon and (3) higher water levels that would decrease natural and artificial drainage [2]. Increased or decreased sedimentation could result from changes in river flow rates. These primary effects would lead to a loss of ecosystems such as wetlands, loss of coastal vegetation and habitats, salt intrusion into groundwater systems and the loss of cultivable land. Such changes would translate into socio-economic effects: on human health, on loss of structures and property, loss of recreational beaches, increased flood insurance costs, loss to coastal communities from tourism and nearshore fishing, etc. These, in turn, have legal and institutional implications for coastal zone management practices, for taxation and legislation and for the delimitation of national boundaries. Chart 1 below broadly summarises these effects.

CHART I: EFFECTS OF A SEA LEVEL RISE

PHYSICAL →

- INCREASED FLOOD DAMAGE
- STORM SURGES
- SHORELINE EROSION
- INCREASED SEDIMENTATION
- CHANGES IN RIVER FLOW RATES
- HIGHER WAVE ACTIVITY
- INCREASED LAND SUBSIDENCE

ECOLOGICAL/ ENVIRONMENTAL →

- LOSS OF COASTAL WETLANDS
- SALT WATER INTRUSION
- EVAPORATION OF SOLAR PONDS
- LOSS OF COASTAL VEGETATION
- LOSS OF COASTAL HABITATS
- LOSS OF CULTIVABLE LANDS
- LOSS OF NON-COMMERCIAL BIOMASS

SOCIO-ECONOMIC →

- LOSS OF HUMAN SETTLEMENTS
- LOSS OF STRUCTURES, PROPERTY
- LOSS TO COASTAL COMMUNITIES
- LOSS OF LIFE FROM INCREASED & SUDDEN STORM SURGES
- CHANGED SET OF ECON. ACTIVITIES
- INCREASED FLOOD INSURANCE COSTS
- LOSS OF SOCIAL AMENITIES, e.g. BEACH USE
- INCREASED FLOOD CONTROL COSTS

LEGAL/ INSTITUTIONAL →

- CHANGE IN CZM PRACTICES
- NEW ORGANIZATIONS TO HANDLE SLR
- IMPACT ON TAXES, LAWS
- DELIMIT. OF MARITIME BOUNDARIES

SEA LEVEL RISE AND COASTAL ZONE MANAGEMENT

A rise in sea levels thus represents a potentially massive set of impacts on existing coastal economic, social, and environmental systems. In a developed country the impacts of a SLR can be countered by choosing among a number of alternative options. In a country such as India, a variety of constraints makes it difficult to adopt speedy responses to calamities and losses. In general a 'wait and see' approach to a SLR could involve grim consequences as the cost of future action when the problem does occur could prove prohibitive. India is witnessing a rapid increase in coastal activities. The trend toward urban and industrial concentration along coastal regions in developed ocuntries is also evident here. It becomes imperative, therefore, to allow for the impacts of SLR in planning for such activities in order to reduce the future costs of redeploying productive resources once applied to the inundated land and to prevent the destruction of coastal resources that may be vital in a strategy to protect the coast against erosion.

In order to do this one needs to have a broad definition of coastal zone that allows for a comprehensive assessment of the impacts of a rise in sea level on coastal uses. The coastal zone is understood here not simply as an interface between the lithosphere, atmosphere and the hydrosphere at the shoreline, but rather as a tripartite physical division comprising:

(1) the <u>hinterland zone</u>, landward of the highest tide level

(2) the <u>littoral or nearshore zone</u>, comprising both beach or intertidal zone between the extreme tide limits and the transient breaker or surf zone

(3) the offshore zone, extending from the seaward edge of the breaker zone to the depth at which waves first cause sediments on the seabed to move landward. [3] Figure 1 illustrates this definition.

Such a classification becomes of importance because SLR can impact resources and uses in all 3 zones. However, uses and activities on urban waterfronts and backbeach areas which support/accommodate activities of high economic value will tend to attract more attention from planners and decision-makers than the nearshore and offshore zones. However, as mentioned earlier, the natural resources and systems, and their commercial exploitation, in these two zones may be of vital importance in understanding the impacts of and planning responses to a SLR and hence the need to highlight their role in coastal zone management and planning.

The mangrove swamps and the marshes of the intertidal zone play a vital ecological role as they: (1) stabilize the coast by trapping bottom sediment (2) form nurseries, spawning and feeding grounds for crustacea, molluscs, etc., (3) dissipate wave-energy and act as buffer zones that protect not only the coastline but the more vulnerable ecosystems, e.g. coral reefs.

Quite apart from their role as coastal stabilizers and buffer zones, these ecosystems have very high productivity which enables them to support large artisanal and commercial fisheries. On an average, gross primary productivity in marine habitats is much higher than in terrestrial habits as is evident in Table 3.

Figure 1. The Coastal Zone: A Tripartite Region

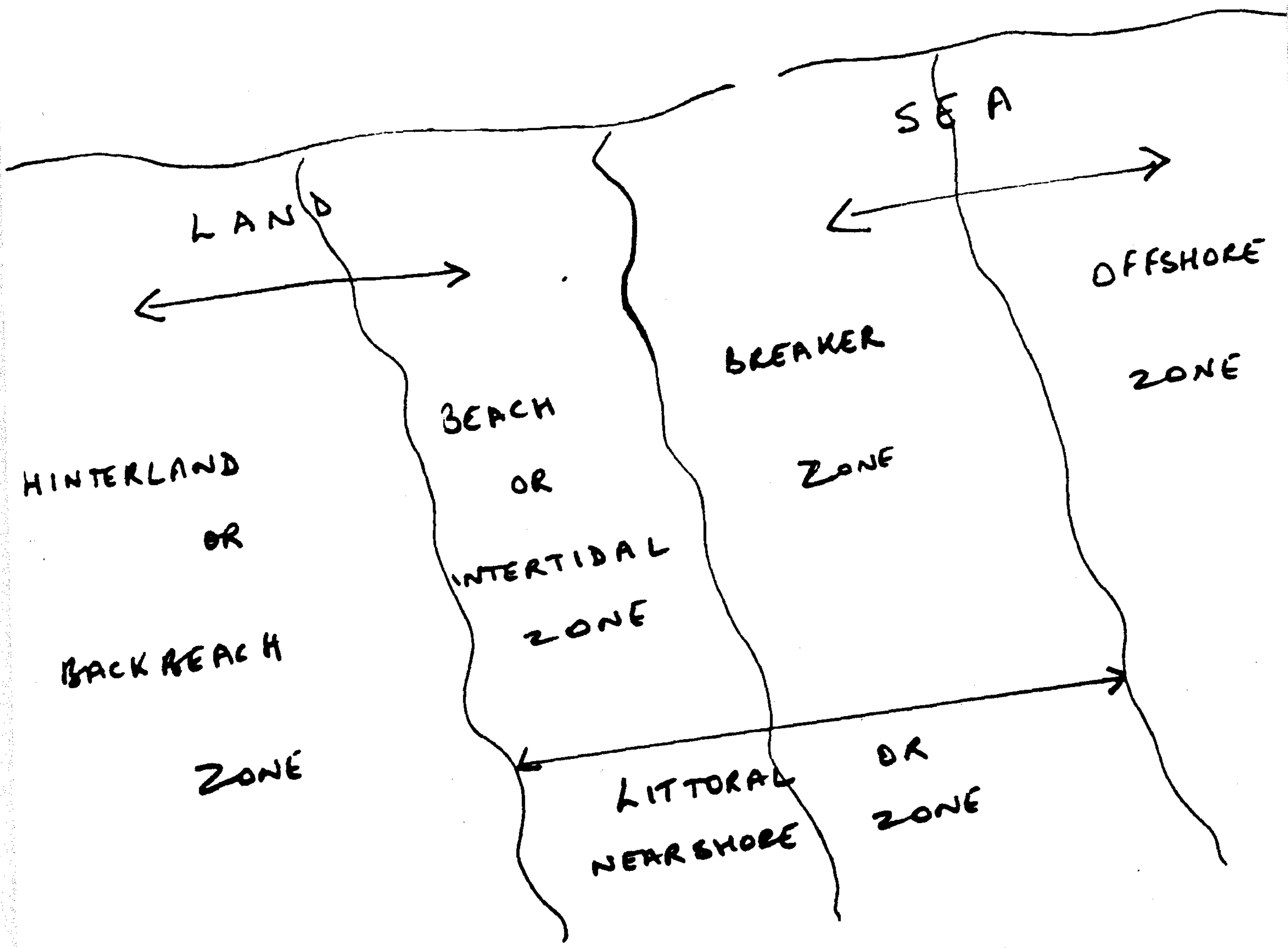


Table 3. Average gross primary productivity in terrestrial and marine habitats

($gCm^{-2}yr^{-1}$)

Mangrove forest	2300-50[illegible]
Tropical seagrass beds	4650
Coral reef	4200
Tropical algal communities	3836
Sugan cane fields	3450
Sewage treatment ponds	1800
Kelp beds	1750
Estuarine benthos	1320
Temperate algal communities	920
Conferous Woodland	800
Deciduos Woodland	785

Source: Table 1, UNEP Regional Seas Report and Studies No.73, Ecological Interactions between Tropical Coastal Ecosystems, UNEP 1985.

It has been argued, however, that the ability of mangroves and other marine ecosystems to support large fisheries may not be a direct result of their plant components, but also of their ability to stabilize the physical environment, providing refuge and contributing to the detrital food chain which helps maintain ecosystem stability. [4]

Thus, marine environments have a vital role to play not only in the support of commercial and artisanal fisheries, but also in reducing the vulnerability of the coastline to erosion, storm surges and coastal flooding. As a case in point is the extensive damage caused in 1961 by Hurricane Hattie, blowing at 200 m.p.h. and raising seas 15 feet higher than normal. The interesting fact, however, is that while the natural cays of the British Honduras were relatively undamaged, the planted cays were extensively damaged. [5]

The point being stressed here is that ecosystems occurring in the intertidal zones are valuable environments from a commercial and a non-commercial point of view. They will play an important role in reducing the vulnerability of an area to SLR and its impacts. They, therefore, need to be taken into account when alternative development opportunities are being considered.

There is also need to classify coastal activities according to their relation to the coast. A useful classification is given by M.J. Clark. [6] He distinguished between 'land-based' and 'water-based' activities and further classifies 'land-based' into (1) <u>Coast-dependent</u>, e.g., ports, beach-based recreation, etc. (2) <u>Coast-preferring</u>, e.g., tourism, coastal residential development, etc., and (3) <u>Coast-independent</u>, e.g., defence or industry not linked with the sea. 'Water-based' activities include navigation, recreation, defence, economic exploitation of fish, minerals, aquaculture, etc. Chart II gives some examples of coastal uses that can be broadly categorized under these heads. Such a classification can be of practical value in a management strategy for hazard reduction or development control since preference in zone delimitation or permit allocation will be given according to the dependence of the user on the particular zone. [7] It is also necessary to see how vulnerable a particular use is to the impacts of a SLR so that this information along with the site characteristics needed by a particular activity can help the planner to make the selection of areas to accommodate development activities.

There are two aspects to coastal zone planning here:
(1) to assess which areas should be allowed to develop, which should have limited development, which should be sterilized, which should be armoured by structural defences and which should be upgraded because of already existing conditions that increase its vulnerability to SLR, and
(2) to assess which coastal activities are more vulnerable to a SLR and hence the need to have research and further thinking on the adaptive options that can mitigate this vulnerability.

Chart II: Main activities found in coastal zones

1. Land-based	
A. Coast dependent	- Ports & Harbours - Oil terminals - Paper & Pulp mills - Metalurgical plants - Fish processing - Power plant
B. Coast preferring	- Urban commercial & Residential Development - Tourism & Beach recreation - Agriculture
C. Coast independent	- Defence - Any other industry not dependent on the sea
2. Water-based	- OTEC - Mining for aggregates, placers - Navigation - Naval Defence - Water sports - Fishing - Mariculture - Dredging & Land reclamation

A SLR may/will, as already discussed, create the following physical changes: in shoreline profile, beach conditions, sediment transport, water circulation, wave conditions, tidal ranges and in the amount of light that reaches the sea bed. These physical changes will cause changes in properties of sea water and the coast, such as, salinity, turbidity, temperature, dissolved oxygen, nutrient flows, erosion, deposition, flora and fauna, primary productivity, estuarine and deltaic ecosystems. These in turn will affect particular coastal uses. The relationship between such environmental changes and the alternative uses is brought out by Matrix I below. These relationships along with the classification in Chart II can then be used as inputs in a management strategy for controlled coastal development, which incorporates probable SLR impacts. For example, in a coastal area prone to erosion and which is vulnerable to a greater erosion from SLR, the policy would be to avoid siting an activity that although coast-dependent is especially vulnerable to coastal erosion, and opt instead to site those activities that are amenable to adaptation or retreat if the erosion is serious enough to warrant it.

What the above discussion points to is the interactive nature of the process: Some coastal uses are impacted by potential SLR; other coastal uses reduce the environmental quality and thereby expose the area and the uses to greater vulnerability from SLR impacts. What is required, therefore, is a methodology to assess the impacts of development activities being planned for areas with potential vulnerability to SLR. In the section that follows such an approach has been detailed with an example from the Indian context.

MATRIX 1:
RELATION BETWEEN ENVIRONMENTAL EFFECTS FROM SLR AND COASTAL USES

Marine environmental effects resulting from SLR \ Uses of coastal areas	Urban Develop.	Tourism	Ports + Harbours	Power Stations	Comm. Fishing	Mariculture	Agriculture	Desalination	Sea-salt Ponds	Paper + Pulp	Navigation
SALINITY			X	X	X	X	(X)	X	X		
TURBIDITY		X		X	X	X		X	X		
TEMPERATURE		X	X		X	X		X			
DISSOLVED O_2					X	X					
NUTRIENTS		X			X	X		X	(X)		
FLORA & FAUNA	(X)	X	X	X	X	X		X	X		X
PRIMARY PRODUCTIVITY		X			X	X		X	X		
EROSION	X	X	X		X	X					X
DEPOSITION & ACCRETION		X	X		X	X					X
SUBMERGENCE OF WETLANDS		X			X	X	X			X	

x - Major impacts
(X)- Minor impacts

Source: Adapted from GESAMP Reports and Studies No. 11, 1980, Matrix 3.

THE PROBLEM IN THE INDIAN CONTEXT

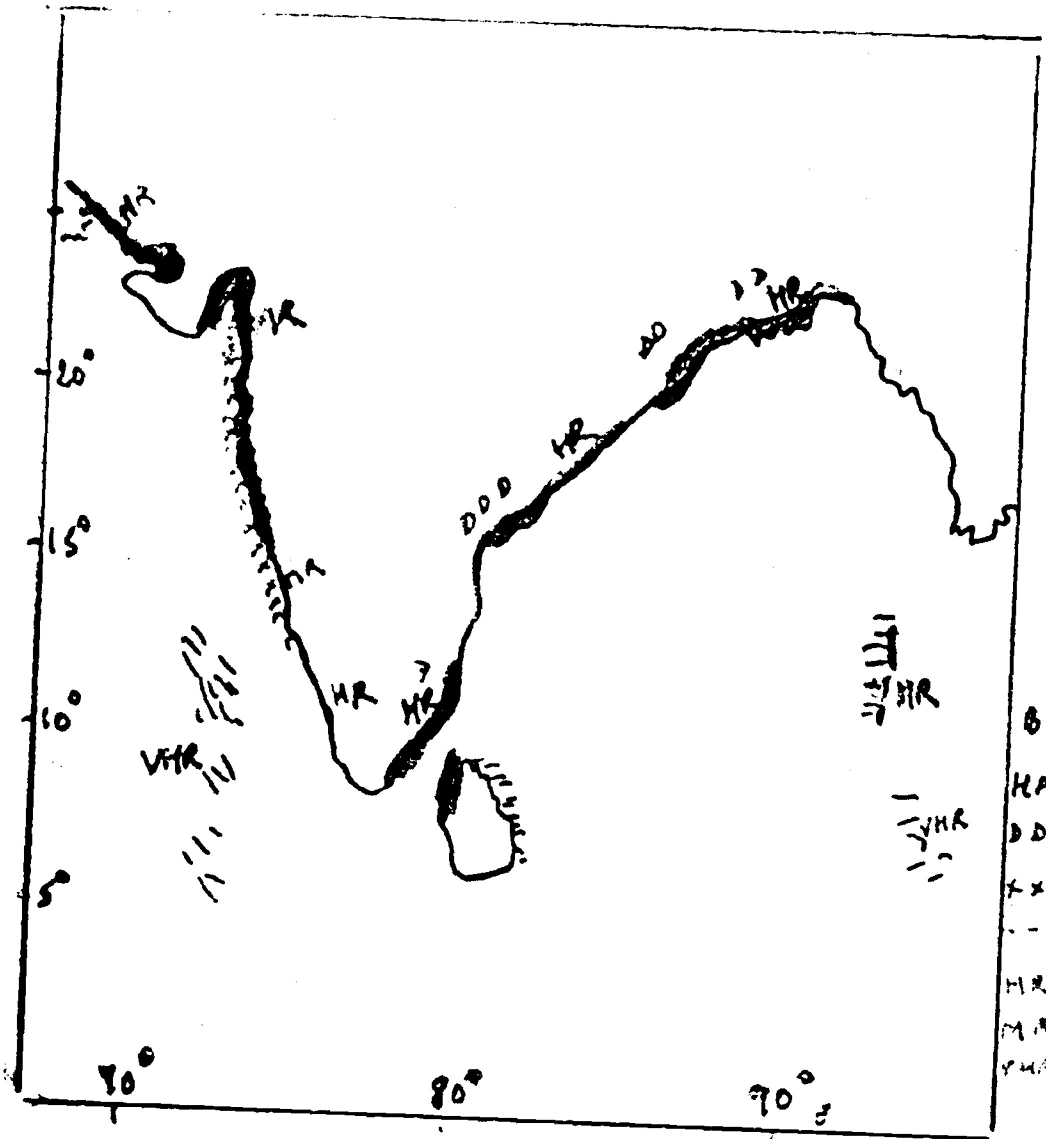
India has a coastline of about 6000 km., its peninsular shape jutting into the Indian Ocean. The western coastline has a wide continental shelf with an area of about 310,000 sq. km., nearly twice that of the eastern shelf. The eastern shelf is considered to be narrowest opposite the confluence of the Krishna and the Godavari rivers. The coastlines are of six types [8] a barrierless shore of emergent aspect between the Ganges and the Godavari; an emergent shore with offshore bars between the Krishna and Cape Comorin, a rocky submergent shore in Karnataka and Maharashtra, a marshy, lowland shore in Cambay, and a compound shore in Kerala and parts of Kathiawar which have an offshore coast of bars and a landward shore of lagoons. Beaches occupy 55% of Indian shores.

The eastern shore of India is rich in deltas formed by the rivers Ganga, Godavari, Krishna, Mahanadi and Cauvery. Most of these regions have large deposits of clay and mud and are very marshy areas, e.g., the deltas of the Ganga, Godavari and the Krishna. The area between Mahanadi and Godavari is occupied by sandy beach zones and is marked by a wall-like straightness of shoreline. The eastern coast is more vulnerable to tropical storms and to coastal flooding. This is especially so in the northern region. Expectations are that with a global warming and sea level rise this region will experience increased vulnerability to tropical storms and storm surges and to greater inundation. [9]

The south-western portion of India has discontinuous, and in stretches no sandy beaches. Instead it has well developed offshore bars and lagoons. [10] This area is lashed by the south-western monsoons which result in considerable erosion and denudation of headlands. The existing erosion in these parts is expected to aggravate with SLR. The ria shore is found in the area between 13 and 16° N and is marked by inlets, pocket beaches and creeks. Littoral concrete or beach rock occurs between Malvan and Kutch. The estuarine shore is most prominent on the western coast. Major estuaries are found in the Gulf of Cambay, making the Cambay region an area of mud flats and marshes.

India has extensive mangrove swamps, 80% of which are in West Bengal and the Andaman and Nicobar Islands. The balance is found in Gujarat, Maharashtra and Goa. Map I gives the distribution of some of these ecosystems and their relative vulnerabilities to SLR.

A number of these ecosystems are threatened by the uses to which the coastal area is put. Some of the mangrove forests, for example, are subject to outright decimation and the area is converted to residential or commercial areas; others are exposed to an exploitation of their products at a pace greater than their ability to renew themselves; yet others gradually lose their ability to maintain themselves because of coastal activities that result in an interference into the hydrological and littoral processes that govern their formation and continuation. An example of the latter is the development of oil and gas provinces that occur in such areas. It is this last, least obvious, impinging on the marine environment that is elaborated below:



BOLD - MANGROVE FORESTS
HATCHED - CORAL REEFS
DD - DELTAS
xxx - RIAS + ESTUARIES
-- - MAJOR ESTUARIES
HR - HIGH RISK
MR - MEDIUM RISK
VHR - VERY HIGH RISK

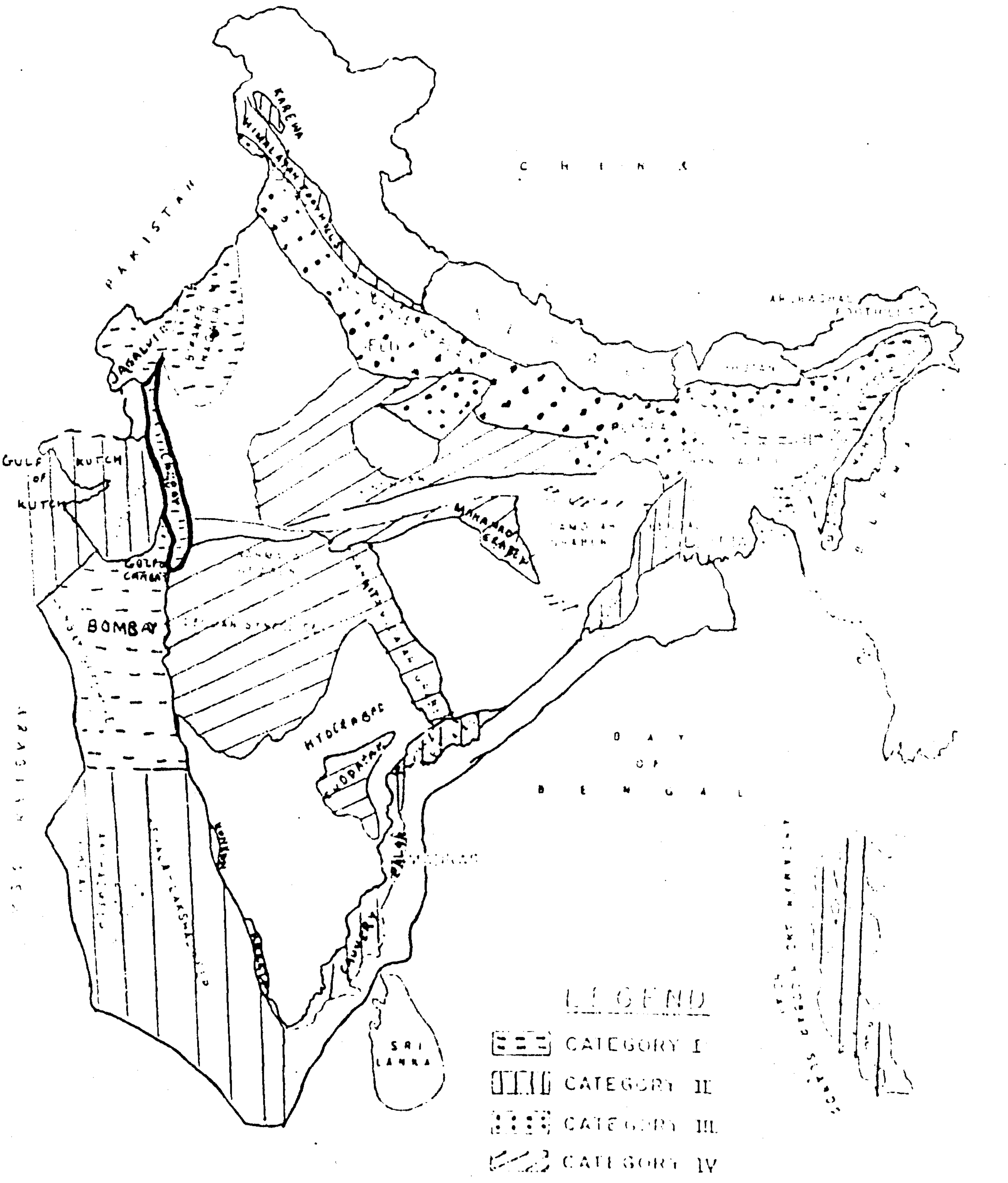
MAP I : ECOSYSTEMS + AREAS VULNERABLE TO SLR (RELATIVE VULNERABILITIES)

SOURCES [11]

MAP II ecological MAP OF CAMBAY BASIN

SOURCE [12]

SEDIMENTARY BASINS OF INDIA



As on 1.1.87, prognosticated resources in India were assumed to be 17 billion tonnes of oil and oil equivalent gas. Of this 60% were in Category I basins, 30% in Category II basins and 10% in Category III basins. Of this only about 25% have been converted into established reserves and 25% of that are what is known as proven reserves. Of the explored basins, Category I basins - Cambay, Upper Assam and Bombay Offshore - are the most explored, its established reserves representing over 95% of the total established reserves. The Cambay basin is a rich hydrocarbon province. The Cambay Shale, Kalol and Tarapur Shale formations are major source rock units and Ankleshwar is one of the major onshore oil producing fields in India. Maps II and III indicate its location. The Cambay basin is marked for even more intensive exploration activity in the VIII plan with about 22% of the total metreage planned for drilling being in this one basin. A sizeable part of this will be in the Southern Cambay region. This is also the region of some of the major estuaries in India - those of the Narmada and the Tapti rivers - and is an area of dense lowlying marshes and mangrove swamps. Oil and gas activities can modify these environments considerably, for they imply the need to dig canals for access to drilling sites, for purposes of navigation and the laying of pipeline routes. Canals that are dug perpendicular to the waterflow tend to impound water and reduce the sediment availability downstream. Canals dug parallel to the waterflow tend to lessen freshwater retention time and enable greater saltwater intrusion. [13] Moreover, subsidence due to subsurface withdrawal of oil and gas increases the risk of inundation of these areas from a SLR.

To these causes of wetland loss directly attributable to hydrocarbon development may be added sediment deficit that occurs for other reasons and reduces the ability of the swamps to maintain themselves.

A reduction of sediment load can occur because of (1) dredging for land-fill purposes or for mineral gain or in the interests of shipping and navigation. Increased depths in the area deredged could lead to increased wavelengths inshore of the dredged site, increased breaking waveheights, increased wave energy and accelerated erosion. [14] (2) the damming of the rivers that carry suspended load to the swamps as has been the case of the damming of the Mississipi River and the Louisiana wetlands. Large scale river development projects are being considered for these parts and it is important that the environmental parameters involved be considered prior to any action being taken. Thus, it is essential to assess the interaction of the effects of the various coastal uses with the marine ecosystem in order to gauge the cumulative nature of these effects on the ecosystem and monitor their implications to the area in the event of a sea level rise. Given this interaction between coastal uses and marine ecosystems, it is necessary to have a methodology in place that will assess the impacts of planned development activities already undertaken. Figure II is a schematic representation of such a method. Each of the loops in the figure will be discussed in detail.

The Planning Loop

Oil and gas projects in India are subject to the same type of techno-economic studies required for other public sector projects. The main elements of such a study are:

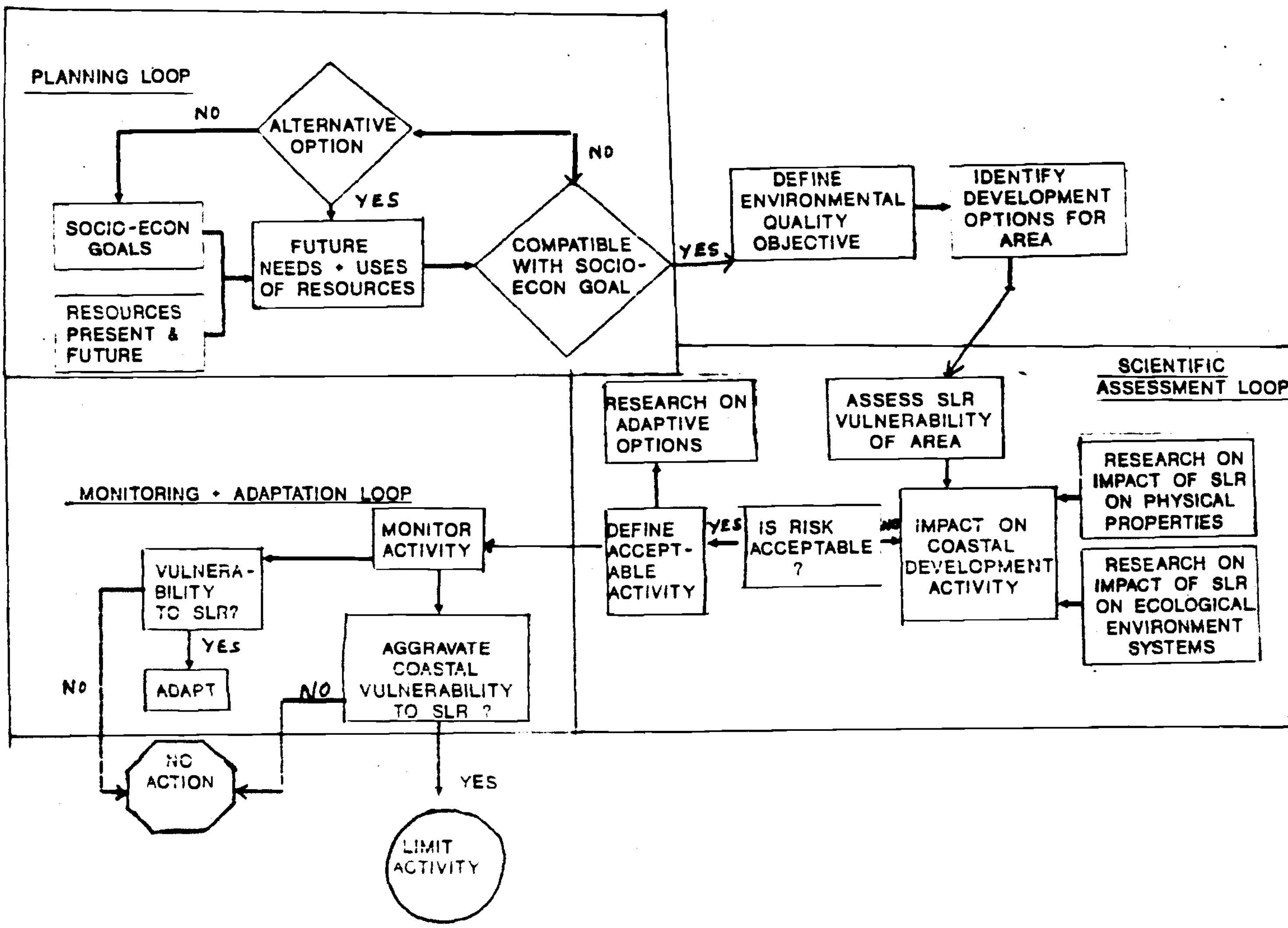


Figure. II: Methodology to assess and monitor impacts of development activities being planned or sited in coastal areas.

(Adapted from UNEP Regional Seas Reports and Studies No.80, Figure I, p.5.)

(1) the need for the project in terms of the overall demand and supply situation for oil/gas within a particular time frame

(2) the technical parameters that will allow the targets to be met

(3) the facilities available for production, downstream processing, refining capability, fractionation

(4) the estimates of capital cost, the component of foreign exchange in total costs and its phasing over the project period

(5) the internal rate of return that the project would generate using the DCF technique.

Having carried out the techno-economic study, the project proposers have then to submit an environment impact statement (EIS). In general, the need for oil is of such overriding importance that such as EIS is no more than a formality and is treated more as an appendage to the techno-economic report rather than of central concern to its feasibility.

The approach being advocated here is that this shift in emphasis occur, so that environmental implications of proposed development activities be central to the decision made. For this the socio-economic goals associated with the project need to be assessed <u>alongside</u> the present and the future needs of the marine resources that are being modified by such an activity. That is, the focus should be not the proposed activity but the natural environment and the choice to be made would then be between preserving the environment as it is or modifying it to accommodate the development activity.

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Following Fisher et al, the problem is then one of a choice of that mix of preservation and development that is optimum, i.e., that which maximizes the peresent value of net social returns from the area. [15] This will call for a maximization of the sum of flows of expected net social benefits at a particular time from X units of preserved area and Y units of developed area minus the 'social overhead' capital investment cost of transforming the land from preserved to developed. The sum is then discounted over time to yield present values. [16] This is subject to the constraints that the mangrove area in question is fixed, that the values of the services are affected by past decisions and actions, that development is a dynamic and an irreversible process and that while the benefits of development for hydrocarbon activities are likely to decrease over time as the oil or gas is depleted, the benefits from perservation are likely to increase. [17] The latter could happen, for example, if the services provided by the area have no good substitutes amongst produced goods or because as the sea level rises its value as a coastal stabilizer becomes increasingly necessary.

The net benefits from oil and gas development are relatively straightforward to assess. The valuation exercise will need to consider the revenues from production minus the cost of capital equipment, costs of operation, the direct and the indirect employment effects and the savings in foreign exchange and possibly security of supply considerations. The net benefits from preservation and the cost involved in transforming the mangrove area to a drilling and development site proves much more difficult because valuation here involves accounting for goods and services that are both marketed and non-marketed. Chart V below summarizes some of the goods and services that would typically have to be considered in assessing the loss of value from a mangrove forest. [18].

Chart V: The valuation of a mangrove forest

Valuation of Goods and Services

Marketed	Non-marketed
1. Loss of value of charcoal, timber, poles	1. Loss of medicinal uses of mangrove produce
2. Loss of value of commercial crabs, crustacea, molluscs	2. Loss of fuelwood and fodder for domestic use
3. Loss of man-hours P.A. of those who derived livelihood from sale of major produce	3. Loss of non-commercial biomass which support populations of commercial fish
4. Increased flood control costs	4. Loss of recreational fishing & holidays
	5. Loss of buffer zones
	6. Loss of protection against erosion & flood damage

The estimation of losses of the non-marketed goods and services calls for considerable ingenuity. Some of these goods and services can be valued using proxy prices, others by getting users to place a value on them. Two approaches, most used, in this connection are the "related-market approach" and the "contingent valuation approach". [19] The former is based on the linkages between environmental assets and market related private goods and services. [20] The 'contigent valuation approach' is survey based. People are asked how they would value environmental goods, say a beach, if a market or some other form of payment existed.

A step prior to such valuation is the need to have some baseline studies in place that will enable an identification of what are the resources at risk from such development. For this there is need for the involvement of the scientific community to develop resource inventory maps and to identify the various types of vulnerabilities that such resources may be exposed to in the context of the development of oil and gas. The combination of skills of both communities will then allow for a social cost benefit analysis in which environmental parameters are explicitly accounted for.

The Scientific Assessment Loop

If the planning exercise allows some development to occur, this does not imply that the responsibility to the environment is over. Sea level rise and its impacts is a phenomenon shrouded with uncertainty. It is, therefore, necessary to continue scientific research on the degree of vulnerability of the area to SLR and in turn this impact on the coastal development being planned. This calls for research on the impacts of SLR on the physical and ecological properties of the marine system. If the risk is an acceptable one, then the activity planned and the modification of the environment should be allowed. If the risk is an unacceptable one, then it would be more prudent to forego the short term benefit of oil and gas for the longer term benefits of having the mangrove swamps in place, to provide the services that it does.

Monitoring and Adaptation Loop

If, for example, oil and gas is allowed to develop in this environment, then it is necessary to monitor the activity for its vulnerability to SLR and for its effects on the natural environment. That is, does the activity aggravate the vulnerability of the area to SLR? For example, if the withdrawal of oil or gas is greatly increasing compaction and subsidence of the area, then it is increasing the area's vulnerability to inundation if the sea level rises. This will then call for a limit to be placed on the activity or on the pace at which it is occurring. On the other hand, if the activity itself is vulnerable to SLR, it will call for some adaptive option, either of a technical or an institutional kind.

Types of Adaptive Options

One can identify three main categories of responses to the SLR problem. These could be titled : (a) Biological (b) Technical (c) Institutional. Biological responses would concentrate on developing alternatives to lost or threatened resources and habitats or on enabling the development of species that are more tolerant to the changed environment.

The emphasis in this set of responses would be to assist the ecological systems to adapt to an environment that changes faster than their natural ability to adapt to it. Technical responses are essentially engineering solutions and involve the building of structures that will protect the coast from submergence and overtopping. Such responses involve both 'hard' and 'soft' engineering options. Dikes, groynes, bulkheads, etc. are examples of the former. Beach nourishment is an example of the latter. The third category of responses is institutional. As information about SLR increases, coastal users and uses are allowed to respond to the potential threats either naturally or by the use of legal and policy means. For example, in an interesting study of the various approaches to accomodate the landward migration of US wetlands, Titus examines the following among other policy options :[21]

1) the purchase of all the coastal lowlands that might be inundated
2) the prohibition of any development in these lands
3) 'presumed mobility', i.e., a legal mechanism to ensure that the land is abandoned if and when the sea level rises enough to abandon it. This approach has two options : (a) prohibit bulkheads, i.e., no interference with private activities today but explicitly notify property owners that as the sea level rises, they will not be allowed to construct bulkheads to protect their properties. (b) Leases, i.e., no interference with private owners today but convert property rights of current owners to long term leases which expire after a period of time or conditional leases which expire whenever the sea level rises enough to

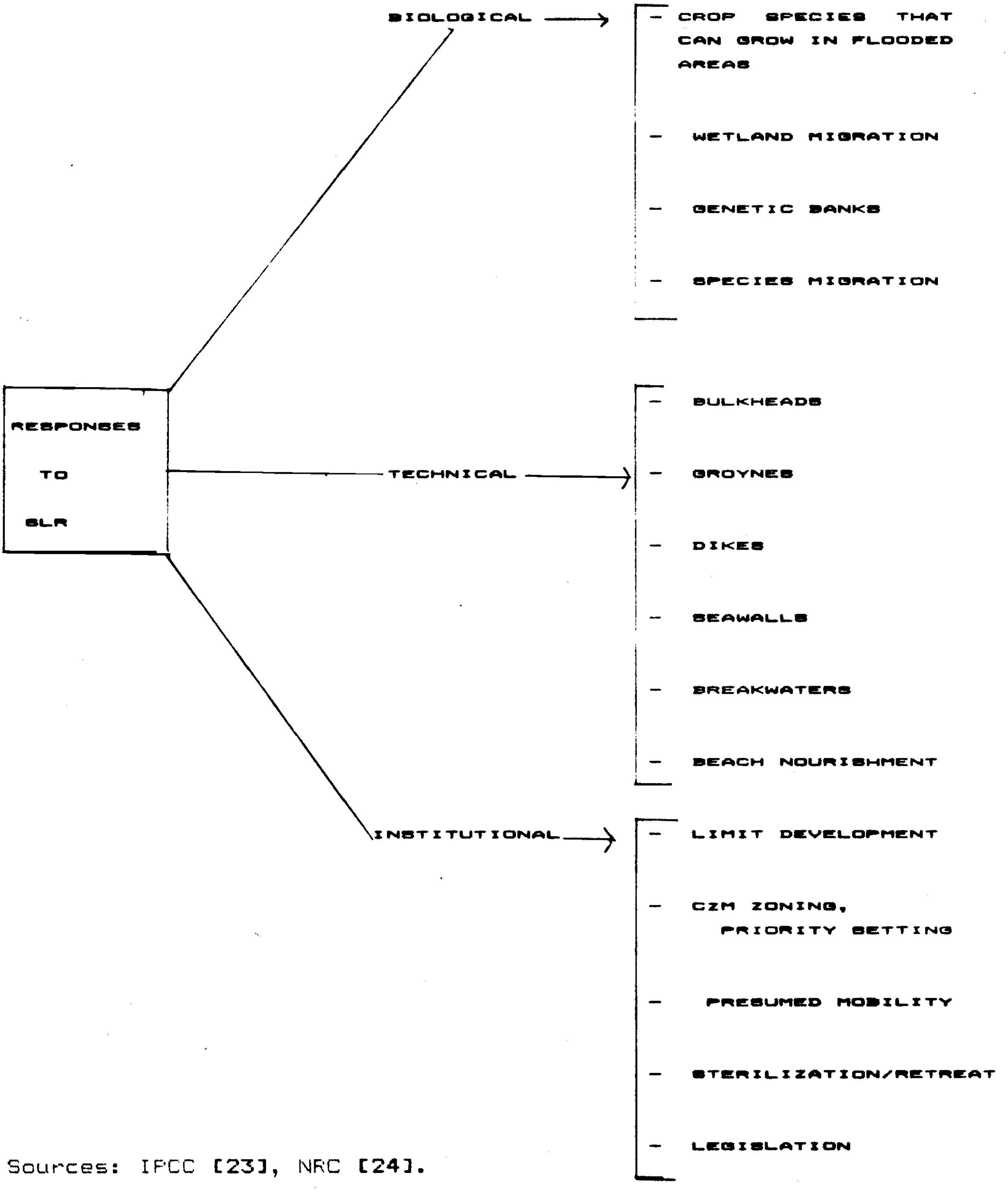
inundate property. Chart IV lists some of the adaptive responses in summary form.

However, the adoption of adaptive responses presupposes that some scientific assessment of the rate and the magnitude in mean sea level is already available. This will then enable an assessment of the physical and the biological effects and the economic vulnerability of a particular location to SLR and the extent of exposure of coastal communities to the threat. Having done this one can proceed to an estimation of adaptive responses that represent the least cost option. To do this will require a consideration of the relative costs of each option and the capability within the country to implement the response. In general, the main strategies available to a government are :

1) no protection,
2) retreat from area and relocation of economic activity
3) adoption of some form of structural protection
4) adaptation to the changed environment.[22]

Responding to SLR presents the decision-maker with an intricate set of policy issues and choices. The first issue of concern is the uncertainty involved with the question of SLR. Not only is there considerable controversy surrounding the timing and the magnitude of SLR, but there is also uncertainty with regard to whether the sea level will actually rise or fall. That there is need for increased information to reduce uncertainty is not in question; what is at issue is how much information is necessary before action is initiated and what will be the costs of strategies that involve no action in advance of sufficient information and

CHART IV: ADAPTIVE RESPONSES TO SLR



Sources: IPCC [23], NRC [24].

those strategies that undertake action ahead of information. Also what will be considered 'sufficient' information? Is there some amount of irreducible uncertainty that should be acceptable in decision-making? The problem is essentially a thorny one, made more difficult for a developing country because the cost of not holding back the sea can prove more burdensome than for the developed countries. On the other hand, to initiate action ahead of sufficient information will involve the tying up of scarce resources in projects of less immediate and possibly no relevance at all as compared to the country's immediate development needs. To justify such projects to a polity concerned with its immediate needs rather than those that may emerge 100 years on will prove a difficult political exercise.

Assuming that initiating a response is possible, the question is one of whether the nation has the capability to implement the response. It is clear from the discussion in this paper that there are various stages in the adoption of a response :

(1) the scientific assessment of the problem for the country in question
(2) the identification of potential effects of the projected SLR
(3) the undertaking of research on the various adaptive options
(4) choosing between alternative responses
(5) implementing the response.

All this calls for a number of capabilities - a scientific and technological capability, an institutional capability, a financial capability and a managerial and organizational capability. A number of developing countries may be short of all these, while others, such as India, may have some of these but not the others. This, therefore, calls for assistance from the more developed countries not only to identify the problem but to ensure that where the problem exists, suitable responses can be undertaken.

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THE CONTRIBUTION OF CFC EMISSIONS IN INDIA TO GLOBAL WARMING

Dr. Ajay Mathur

INTRODUCTION

Chlorofluorocarbons (CFCs) have already been subject to international restrictions through the Montreal Protocol due to their ozone depleting potential (ODP). Together with other ozone depleting substances (ODSs), they are now in the process of being phased out worldwide.

The global warming potential of ODSs is also large: typically 15,000 to 20,000 times that of CO_2. It is now clear that the ODP of CFCs has already initiated their phase out. Consequently, no separate action needs to be undertaken under the global warming purview. However, the level and timeframe of the phaseout depends on many factors: availability of substitutes, availability of financial resources, and changes required in infrastructure. In fact, India has not yet signed the Montreal Protocol because of these uncertainities. India takes the position that the incremental costs to the economy due to the phaseout must be borne by the countries that are responsible for the emission of CFCs. According to best estimates, the largest emissions are from the USA (29%). The other developed free-market economies account for another 41%, the USSR and the East Bloc for about 14%, and all the developing countries for about 16%. India's share is about 1% of the worldwide total.

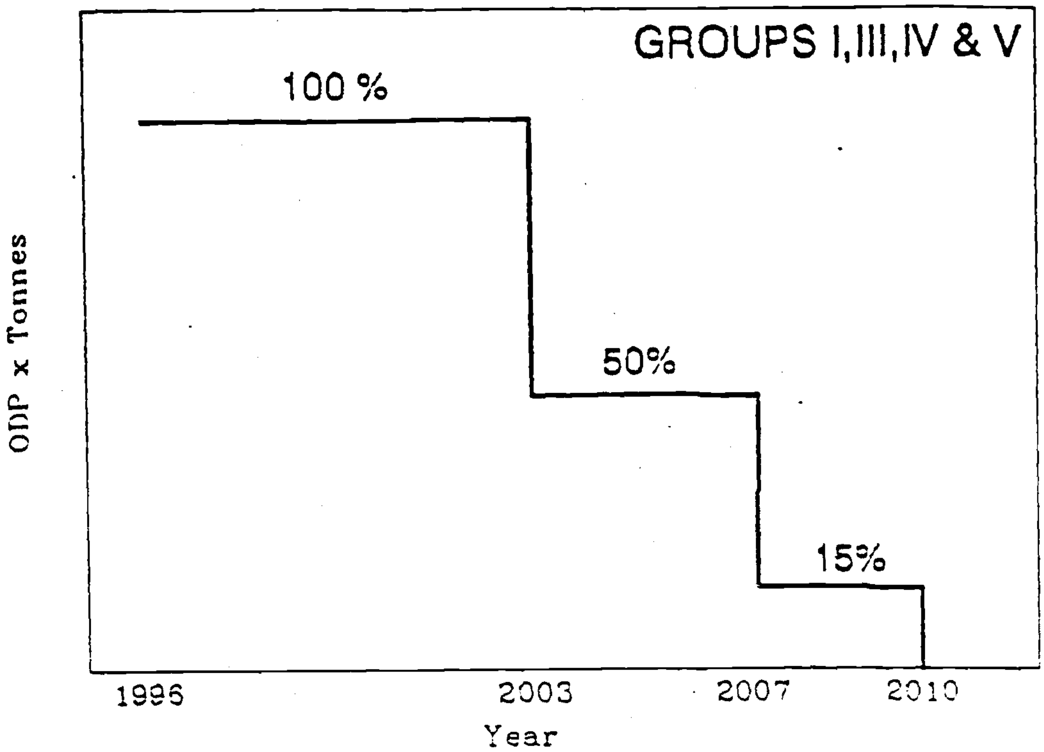
In the following the scenario for phaseout of ODSs in India is considered in an attempt to evaluate CFC emissions in the future.

THE MONTREAL PROTOCOL

The Montreal Protocol was signed in 1987, by 47 countries (mainly from the developed world), and discussions about amendments to this Protocol are now taking place. It is anticipated that these amendments will impose a more rapid phase out of ozone depleting substances and will extend the current list of controlled substances to include other ODSs. It is also expected to make provision for technology transfer and financial aid to developing countries to assist them to comply with the Protocol.

In general, the Protocol distinguishes between the developed countries and developing countries by allowing the latter a ten year respite in the implementation of the Protocol. The phase out profiles for developing countries of the existing Protocol and of the proposed June 1990 amendments are shown in Figure 1 and includes ranges for phase-out dates. The profiles presented here represent the likely profiles to be adopted in the view of the Government of India. These profiles form the basis of expected impacts presented in this paper.

In the existing Protocol, the level at which consumption is capped for developing countries is based on average consumption in the three calendar years 1995, 1996, 1997. Thereafter, the phase out for chlorofluorocarbons (CFCs) is specified as 80 per cent of the "base" level consumption in the year July 2008 to June 2009. Similarly the proposed amendments specify the base year as the average of consumption in the calendar years 1995, 1996, 1997, and phase out limits in terms of years running from July to June.



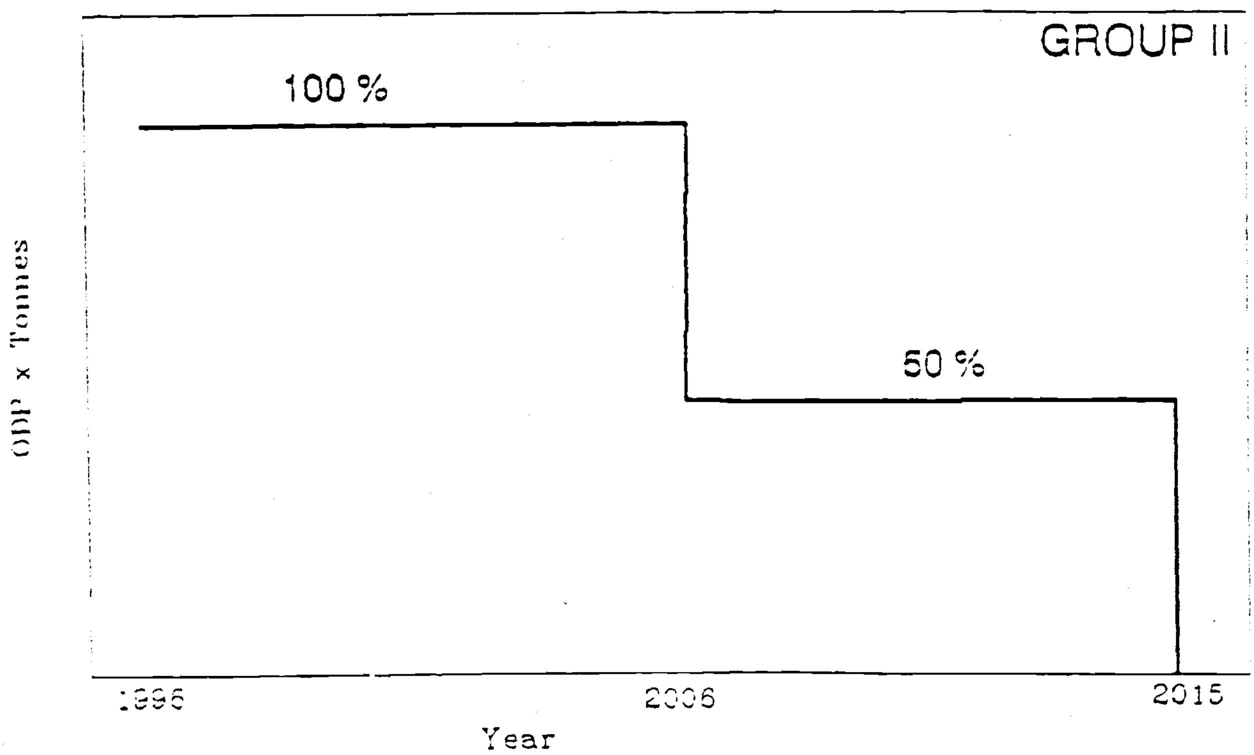


Fig. 1: Montreal Protocol: Developing Countries
(Proposed June 1990 Amendments)

There are suggestions in the proposed drafting of the amendments that this might change to calendar years.

It is important to note that the Protocol limits the "consumption" of ozone depleting substances (ODSs), rather than emissions to the atmosphere. Consumption is defined as production plus imports minus exports and minus any ODSs destroyed by approved technologies.

The Protocol also places restrictions on trade in ODSs with non-signatories, and seeks to restrict all trade in products containing ODSs after a period of time. Certain essential uses may however be allowed to continue.

The substances being considered for control by the amended Protocol are:

* CFCs (chlorofluorocarbons): one, two or three carbon compounds containing no hydrogen atoms and only fluorine or chlorine atoms;
* HCFCs (hydrochlorofluorocarbons): one, two or three carbon compounds containing hydrogen, fluorine and chlorine atoms;
* Halons: halogenated short chain hydrocarbons containing bromine;
* CTC: carbon tetrachloride;
* MC: methyl chloroform. (This chemical is more properly referred to as 1,1,1 trichloroethane).

The CFC, HCFC and Halon families include a large number of chemicals and isomers. Compounds are named according to a numbering system that relates to their chemical make-up (e.g. CFC 11, Halon 1211). (The CFCs and HCFCs are also alternatively referred to as R-products, for example, CFC 11 is also called R11, the R representing "refrigerant"). ODSs have different propensities to deplete the ozone layer. This propensity is referred to as the Ozone Depleting Potential (ODP) of the substance. ODP is measured taking CFC 11 as the reference point with an ODP of one.

The current Protocol defines controlled substances as follows:

* Group I: CFCs 11,12,113,114,115;
* Group II: Halons 1211,1301,2402.

The revision of the Protocol (due in June 1990) is widely expected to designate other chemicals as controlled substances, as follows:

* Group III: other fully halogenated CFCs;
* Group IV: Carbon tetrachloride;
* Group V: Methyl Chloroform;
* Group VI: HCFCs.

SUPPLY AND USES OF ODSs IN INDIA

Overview of supply & use of ODSs

Most of the developing countries import ODSs from developed countries. India, China and Brazil are the only manufacturers of ODSs in the developing world. Table I shows the ODSs manufactured in India, as well as those imported from other countries. The principal end-use sectors of each ODS are also listed in Table I.

Table I. Ozone Depleting Substances Current Used in India

ODS	End-Use Sector	Consumption (T) (1980) Indigenous Production	Import	Substitutes
CFC 11	Foam & Aerosols			HCFC 22, HFC 134a, HCFC 123
CFC 12	Domestic Refrigeration & Air Conditioning	524	Negligible	
CFC 113	Phenolic Foams, Electronics Cleaning	-	84	
HCFC 22	Packaged Air Conditioning			
CTC	CFC Feedstock, Metal Cleaning, Process Solvent	7238	-	Water-based systems & other organic solvents
Methyl Chloroform	Metal & Electronics Cleaning	535	-	Water-based systems
Halon 1211	Portable fire Extinguishers	-	?	None known
Halon 1301	Fixed Flooding Units	-	?	None Known

Preliminary estimates for unconstrained growth of ODSs in India average at about 12% per year for the near future (upto, say 1996) and 7% per year in long-term (between 1996-2010).

Long range forecasting is difficult to carry out with any degree of confidence, as conventional time-trend analyses cease to be reliable more than a few years into the future. The demand forecasting methodology has to be based on a variety of appropriate techniques.

These techniques vary according to the nature of the market into which the end-user products are being sold and are divided into main categories:

* consumer oriented;
* industrially based.

The techniques used for consumer forecasting are as follows:

* measurement of likely macro-economic and social indicators;
* assessment of likely product penetration levels;
* the use of historical market development data of well documented developed countries, in order to provide models for developing countries.

In forecasting demand from industrial and service sector markets, sector growth rates can be used. Product penetration levels are virtually impossible to ascertain, and data on end-users is either unavailable, or else the products have multiple end-uses.

In all sectors, there are important factors which cannot be forecast, but are likely to have significant effects on demand. The principle factor is the likelihood of end-user manufacturers aggressively marketing and promoting new products. This is especially relevant in consumer driven areas, as these markets are often sensitive to advertising.

Consumer Driven Markets:

India has a growing affluent middle class, who account for the majority of the consumer related purchases of ODS containing products. This middle class is said to account for between 80 million and 150 million people (out of a total population of 800 million), and to be growing at a rate of six per cent p.a., compared to an overall population growth of two per cent. This high growth rate in both size and real spending ability has led to major growth in demand for consumer goods, especially white and brown goods, including television sets, fridges and washing machines.

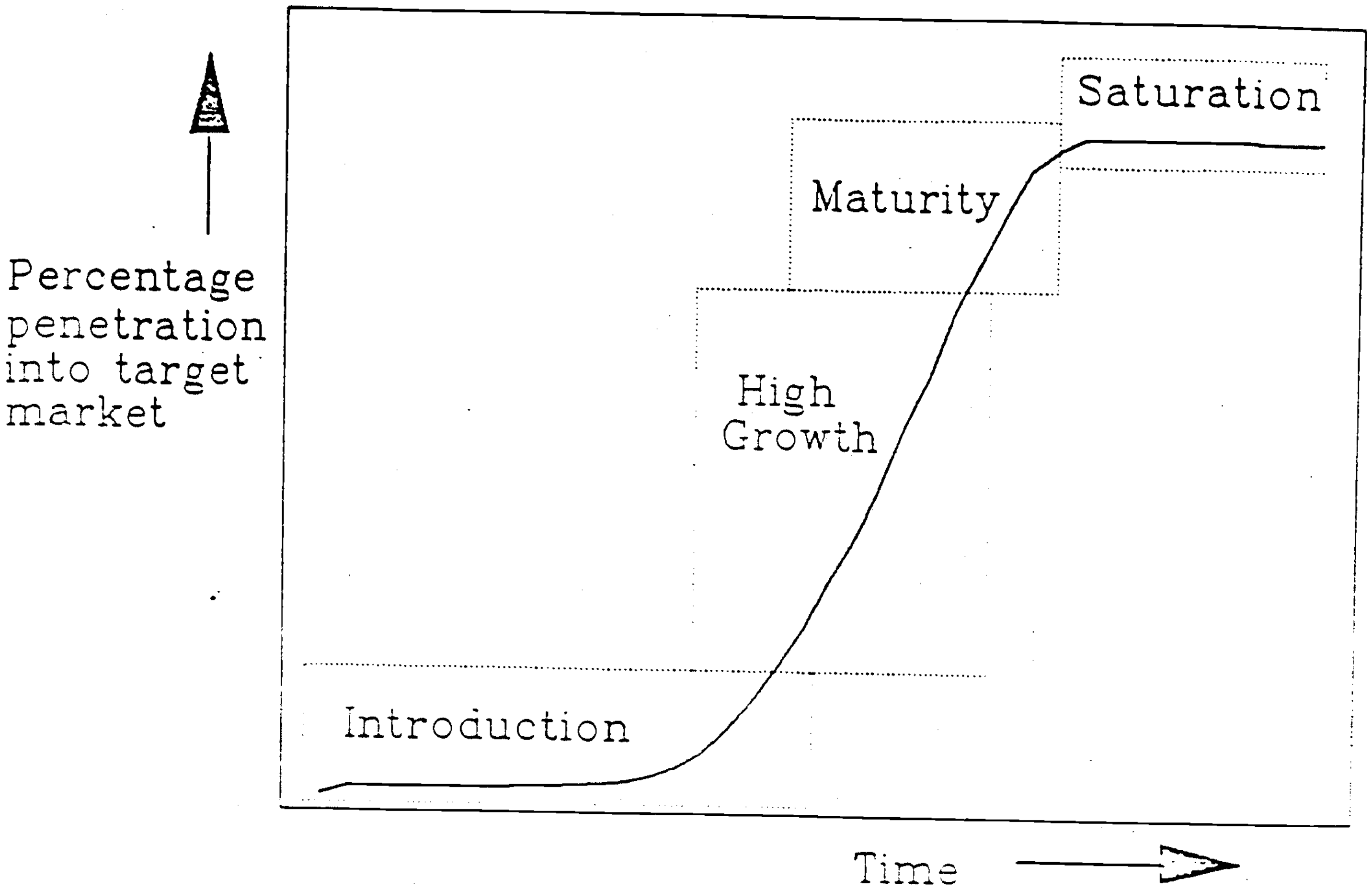
The branding of consumer goods is not well developed in India, although most industrial companies from the developed world have a presence, and national television advertising is possible. Many consumer goods are manufactured by indigenous companies, often under local brand names. The high presence of unorganized firms in some sectors (e.g. aerosol filling) also contributes to the low prevalence of branded products.

The retailing industry is also very disparate in developing countries. For example, there are few, if any, supermarkets and many purchases are made from small shopkeepers and bazaars. This makes studies of consumer behaviour and purchase patterns very difficult to analyze.

In forecasting consumer markets, the assumption is made that levels of penetration into the target end-user populations follow an S-curve (Figure 2). This assumption is borne out by experiences in the relevant market sectors in developed countries, and such a model is therefore considered relevant over the time span of the forecasts, and in the light of general macro-economic and social forecasts.

<u>End User Controlled Markets</u>:

End user markets are those where ODSs are used in production of goods and services, and these goods or services are consumed largely by other industrial users (e.g. building and insulation foam).



Examples of Localised Perturbations

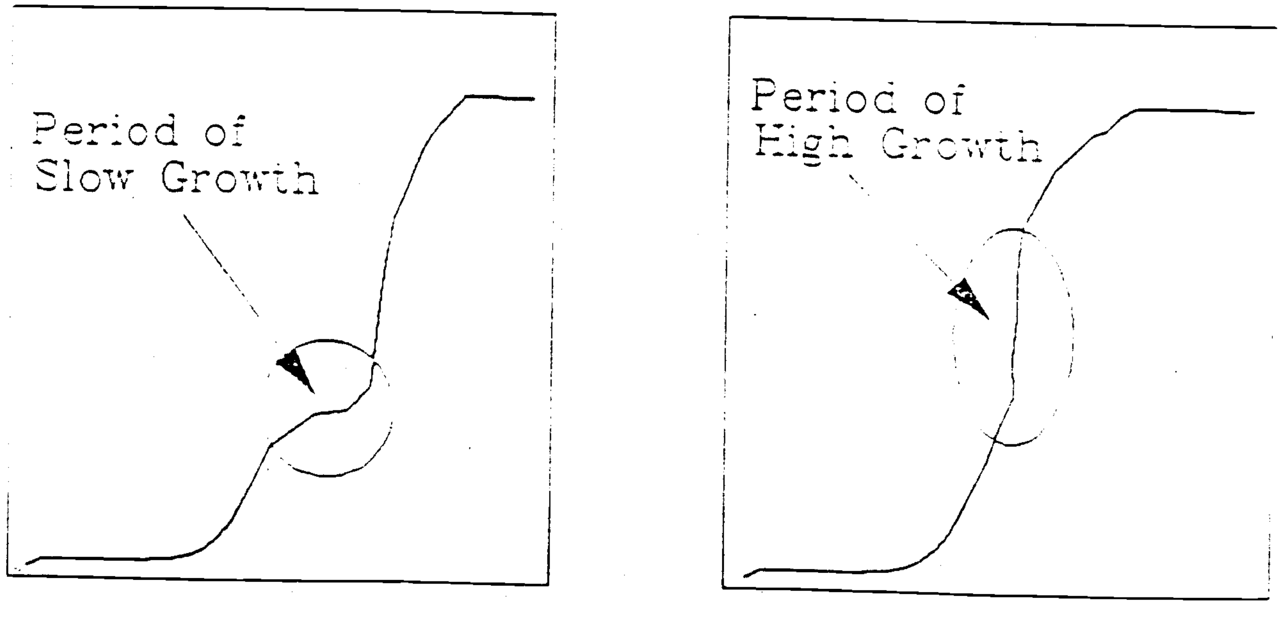


Fig. 2: S-shaped Product Demand Curves

In forecasting industrial markets, the general S-curves cannot be used with anything like the same degree of confidence, primarily because of the multiplicity of end-uses of products and therefore the differential rates of product penetration.

Experience of the use of industrial products in developed countries is, however in this case, a much more useful indicator, as replacement of substitute technology can have a major effect on product sales. Examples of this include the use of CFCs for insulation in fridges (replacing natural minerals) and the projected decline in rigid polyurethane foam demand due to enhanced fire regulations.

USER SECTORS AND SUBSTITUTION POSSIBILITIES OF ODSS

Refrigeration

The key areas of ODS use in refrigeration are:

* domestic refrigerators;
* ice candy machines;
* cold stores.

Domestic refrigerators are an entirely consumer-market product, whilst the latter two are mainly used in the industrial and service sectors.

Fridges in India are still very much of a luxury item, and currently only a small number of households own one. These households are mainly those of affluent urban class, and there is reportedly little use in the rural population. However, as the middle-class market reaches maturity and rural affluence increases, there will be a significant population of second-hand fridges too.

This growth in the replacement market is likely to be characterized by shorter working lives for the majority of fridges. This is borne out by developed country experience in that consumers often trade-up models before the original model is worn-out.

The use of foams as insulation in domestic refrigerators is increasing rapidly. In India, all refrigerator manufacturers have either switched to foam insulation, or are in the process of doing so.

Substitutes:

It is expected that HFC 134a will be the most important substitute for CFC 12 in the domestic refrigerator sector. Comprehensive technical support to the indigenous manufacturers from their collaborators in the developed world has to be forthcoming for a gradual change-over to HFC 134a will occur. This change-over will require some redesign of the refrigeration units, in particular the compressor, vapourizer and condendser.

For domestic refrigerators, the best substitute refrigerants for CFC 12, from a technical point of view, are ammonia and propane. These, however, are unlikely to be acceptable due to safety considerations. It is conceivable, however, that with the use of hermetically sealed units, these objections could be overcome at a later date.

At present, manufacture of much of the insulating material used in domestic refrigerators in India does not depend on CFCs. However, market forces appear to be forcing a move towards CFC 11 blown polyurethane insulation. HCFC

123 or 141b could be used to replace CFC 11 in this application; we have assumed that this will occur. In addition, the use of 'water' blowing technology may greatly reduce the quantity of blowing agent required.

A promising long-term solution, still at an early stage of development, is the use of vacuum panels. Problems of low structural strength and loss of insulating properties remain to be solved.

Other Refrigeration:

In terms of ODS consumption, the other categories of refrigeration are less important than domestic refrigerators. The second most important sector, ice candy machines, are used primarily in rural areas. In India, present indications are that the use of such machines is already at a high level and that significant further market penetration is not expected.

Commercial refrigeration in India is mainly carried out using ammonia/propane equipment and this is not expected to change in the foreseeable future. However, a rise in the number of CFC driven cold storage units is projected, based on industrial sector growth rates.

In general, industrial refrigerators have a high demand for recharging, this being due to heavy use and generally poor maintenance. Accordingly, it appears that demand for CFCs for recharging will rapidly outstrip demand from manufacturers for new production of industrial refrigerators as the stock of these refrigerators grows.

Ammonia and propane are currently widely used as industrial refrigerants and we have assumed this will continue.

Lorry refrigeration systems will probably be redesigned to use HFC 134a in place of CFC 12.

Air Conditioning

There are two distinct major sectors in air conditioning:

* room air conditioners;
* office/building air conditioners.

Both these sectors are further sub-divided into two types of equipment: room air conditioners into those built in the organized sector and those made in the unorganized sector, and office/building air conditioners into reciprocating units an centrifugal units.

Other air conditioning:

There are a number of other air conditioning sectors, with in-car air conditioning being the most significant. Such portable units tend to be unreliable and require extensive recharging in use.

Substitutes:

At present, HCFC 22 is widely used as a refrigerant in room and package air conditioners. This substance, although include in the Montreal Protocol (Group VI), is not expected to be subject to early phase-out limits so there is no immediate pressure for change. No obvious substitute is known.

In the case of central air conditioning for buildings, it should be possible to redesign reciprocating systems to use HCFC 22 in place of existing CFC 12. In centrifugal systems, HCFC 123 could replace CFC 11. In neither case are these drop-in substitutes which would allow continuing use of existing designs. Recovery and recycling of the refrigerant in existing central air conditioning systems may become very important. In many cases, these systems have a lifetime which will extend past the time when the original refrigerant ceases to be available.

It is expected that HFC 134a will replace CFC 12 where it is used in mobile air conditioning systems.

Foams

Of the foams in use in India, by far the most important in terms of CFC consumption are rigid polyurethanes. The main sector for use is in domestic fridges as insulation, but they are also extensively used for building insulation.

There is a widely reported trend towards the phasing out of such products for building insulation in the developed countries, but there is a general consensus that in India such as phase out may not occur for some years. Replacement products include natural materials and granular foams, which are more convenient in use than slabstocks.

Flexible polyurethane foams (open cell) are primarily used for furniture, mattresses and car seats. In India, however, most of these items are currently of traditional design (e.g. coil springs, natural materials) and although an increasing trend is forecast for CFC blown foams, this is unlikely to be more than a linear expansion, at about the industrial sector growth rate.

Substitutes:

The expected high prices of HCFCs 123 and 141b compared with CFC 11 are likely to be prohibitive as far as their use in flexible foam blowing is concerned. 'Water' - blowing will be widely used in conjunction, if necessary, with an alternative blowing agent such as methylene chloride. For the costing exercise, we have nevertheless assumed that HCF 123 will be the substitute.

There are some doubts over the suitability of rigid blown polyurethane foam (made with CFC 11) for continued use as building insulation. Other insulating materials such as polystyrene beads or glass fibre may replace foams in this application. If polyurethane foam continues to be used, HCFC 123 or 141b may be suitable blowing agents.

Good substitutes for CFC 11 and 113 as blowing agent for phenolic foams are not easy to find; one of the new generation HCFCs may prove suitable, but they could be replaced by carbon dioxide. Similarly, nitrogen or butane may replace CFC 12 for blowing polyolefinic foams.

Pentane is already widely used in India as a polystyrene blowing agent and could be used to replace any remaining CFC 12 use.

Aerosols

Aerosols are by far the most important CFC usage sector in most developed countries, sometimes accounting for up to 80% of all CFC demand.

In India, however, the aerosol is currently little used. The reason for this are:

* social habits: Indians generally prefer to to use traditional cosmetics and remedies. These are normally simply packed and delivered. There appears to be a significant resistance to change in most cases;
* price: aerosols made in the organized sector currently attract 100% luxury tax. In consequence a product such as deodorant could cost 60-80 rupees, significantly more than in developed countries. In the unorganized sector products are cheaper, but they lack a recognized brand name, which trends to offset the price advantage;
* branding: as outlined in the previous section, the lack of branding and more specifically of consumer advertising is a major factor in the low usage of aerosols.

In considering how demand may change in the future, however, there are significant imponderables to consider. Amongst these are whether or not larger manufacturers will choose to promote aerosols as value-added products and use national TV advertising to promote them. In addition, the predicted availability of locally produced valves and suitable cans in place of imports may also be seen by manufacturers a an opportunity.

<u>Substitutes</u>:

Aerosols in India use CFC 11 and 12 mixtures as propellants. Though in many ways mechanical sprays are the best available alternative from an environmental point of view, experience in Europe and the USA indicates customer resistance to their introduction. In the light of experience in developed countries, hydrocarbons (propane and butane) could be the adopted replacement option. It would be noted, however, that some manufacturers of aerosols in developed countries regard hydrocarbons as only a short-term solution due to their 'greenhouse' properties. Some of these manufacturers are concentrating their research efforts on compressed gas systems.

There may be a few products, such as inhaled pharmaceuticals, for which none of the available options for eliminating CFCs is appropriate for safety reasons. In these cases, the most substitute may be HFC 134a. However, should this prove to be unsuitable, it may be felt that this is one sector in which the continued use of CFCs is permissible.

Cleaning

Unlike most developed countries, ODS substances are not used for dry cleaning in India and most other developing countries. There is, however, extensive use of methyl chloroform and carbon tetrachloride in the metal cleaning industries. Due to the diverse nature of the end users and their small size, there is no reliable way to forecast these areas. Projections have to be based on projected industrial sector growth rates.

<u>Substitutes</u>:

Water-based cleaning agents could be used in much of the electronics industry instead of CFC 113 and methyl chloroform and we have assumed that they will be adopted.

However, these are operationally inconvenient and require major investment in different types of equipment from that currently used. High energy consumption and high liquid effluent flow-rates may be particularly significant in an Indian context. These problems may make the use of the new HCFCs attractive to some users.

In the case of metal cleaning, which currently uses carbon tetrachloride and methyl chloroform, it is likely that the expected high cost of the new HCFCs will prove a significant disadvantage. The most promising option is a switch to water-based cleaning agents and we have assumed that this will occur. However, we note that the acceptability of water-based systems in India depends on the price and availability of the energy required for heating the baths and the ability to handle the liquid effluents generated.

Vapour degreasing systems can incorporate solvent recycling, which should reduce the cost disadvantage of using new generation HCFCs or other organic solvents. New Equipment is required if water-based agents are to be used as they cannot be used for vapour degreasing.

Fire Extinguishers

The introduction of halon based fire extinguishers into India has been relatively slow, and has been led by defense based standards and requirements.

Thus whilst halon extinguishing systems are widely distributed in India, they are mixed with more traditional (and sometimes less suitable) extinguishants. The exception to this is the military and those locations where the fire protection systems are highly specified or controlled (e.g. oil installations, nuclear power plants, etc.).

In addition to conventional extinguishants (dry powder, CO_2, foam, etc.), there is still considerable usage of CTC (and possibly ethyl dibromide), both substances which are banned in India as extinguishants, but are still allegedly supplied via less reputable sources.

As stated, the main users of halons are the defence industries (e.g. for planes, missiles, tanks, ships, etc.), but there are other large users, and these include power generators, petrochemical companies and the airports authorities. Some portable halon extinguishers are also used in public buildings, hospitals, trains, and buses.

There is currently no domestic production of any halons, although production is planned. All the halons used in India are imported mainly in cylinders, although some are imported as contents in package fire fighting units, for example where foreign contractors are undertaking turnkey operations.

The price of halons is relatively high in India and this has effectively stunted demand for all but essential uses. For example, there is little penetration of small portable units as carried in cars in the developed world. Equally, Indian insurers have been slow to recognize the efficacy of halon systems and to encourage their use with lower premiums. Moves to set this in train have only just commenced.

There is, however, a steady growth in halon usage, and they are increasingly taking market share from other extinguishants. In part this is due to recently enhanced Factory and Industrial Premises Acts in India and a tightening of workplace health and safety, although this is still not widespread.

The majority of halon usage is in small, portable units (comprising about 70% by quantity of halon used), with the rest in fixed fire flooding systems.

There is said to be a substantial trade in halons that is unrecognized by official channels, and industry estimates indicate that official figures may be understated by 20% or so. In addition, there is considerable and illegal use of CTC and CFC 22 via less reputable suppliers, although the scale of this is not known.

Substitutes:

In a large proportion of its uses in portable and mobile equipment, Halon 1211 could be replaced with other extinguishing agents. In cases where a non-conductive extinguishant is required and it is important that no residue be left, carbon dioxide may be used. However, carbon dioxide is of little use in fighting large fires. New, non-corrosive, dry powder formulations are being developed which may be an alternative, particularly in outdoor applications.

In total flooding systems where evacuation of personnel is not possible, no alternative to Halon 1301 exists and it is unlikely that one will be found in the near future although where human exposure is not a problem, carbon dioxide can be used. It may be felt that this is an application in which continued use of an ozone depleting substance is permissible. Emissions of halons could be greatly reduced if new testing standards and procedures were adopted in which their discharge was not required. We have not, at this stage costed any replacements for halons.

The use of carbon tetrachloride in fire extinguishers is assumed to decrease as existing equipment becomes obsolete and refill material becomes unobtainable.

STRATEGIES FOR IMPLEMENTATION OF THE PROTOCOL

The Protocol defines the phase-out profiles for Group I, III, IV, and V as shown in Figure 1. This profile is indexed to ODS usage in 1996. These indices are set at a level calculated by multiplying the tonnage of each individual product in the group consumed in 1996 by the ozone depleting potential (ODP) of that product.

The ODP is a measure of the damage to the tropospheric ozone level caused by an ODS. ODP values are assigned relative to that of CFC 11 which is assumed to have an ODP of unity. A table of ODP values is given in Appendix I.

Strategies for phase-out of ODSs are necessarily complex as any action can lead to major effects in other areas. As a general rule, it seems best to analyze first the phase-out of ODSs the user sector which account for large ODS usage, and use the smaller sectors for balancing purposes. In any event, this is only important for Group I ODSs as these are used in many sectors. For other groups, there are generally only single measures available to comply with the Protocol.

TRANSITION STRATEGIES

Transitions will be costly: in general, the incremental costs to producers are an order of magnitude less than those to users, and in turn, user incremental costs are an order of magnitude less than those of consumer. Also, incremental costs are an inverse function of transition time - so the shorter the time, the larger the costs. These cost sensitivities lend themselves to the evolution of a framework for the transition strategy: phase-out of ODSs in consumer-oriented products and services to be spread out over a long time-period, while switchover in the production of ODS substitutes can be achieved in a comparatively short time-period. Phase-out of ODSs and switchover to substitutes in the user sector can occur in a medium-time interval.

Translating this framework into a strategy would imply the following chronological order of decisions:

* Banning of the production of ODSs in a phased manner. This would be carried out so that ODS used in consumer-oriented products with large markets (e.g. fridges) are slowly phased out, while those utilized by user industries for which substitutes are easily available (e.g. ODSs used for cleaning) are banned first.
* products that do not have very large consumer markets and for which substitutes for ODSs are available (e.g. aerosols) are mandated to use substitutes.
* manufacture of new products using ODSs is banned.
* recharge of ODSs in old equipment is banned.

IMPACT OF STRATEGIES ON INDIA

The ODS use pattern in India indicates that domestic fridges are the major product whose switchover will have to be planned.

In India, fridges easily have a life of 20 years, with one or two recharges. It is also common for fridges to be sold by the first owner in 8 to 12 years. In order to decrease costs to the economy by avoiding scrapping of fridges using ODSs, it is necessary that CFC 12 be available for recharging till about 2020. However, the Montreal Protocol requires a complete ban on ODSs by 2010. It seems that incremental costs can be greatly reduced if a low level of CFC production (for recharging only) is allowed till 2020.

For the producer and user sectors, some scrapping of existing capacity seems inevitable. However, the incremental cost due to this scrapping will be far less than the costs to the consumers due to the higher prices of non-ODS products.

For the producers and the users (and ultimately the consumers), the largest uncertainty relates to the costs of technology transfer of ODS-substitute technologies. These royalty payments can place a great burden on the national exchequers. The other major problem to the national economies will be the foreign exchange requirement for importing new plants and equipment for the production of ODS substitutes and products using ODS substitutes. The debt crunch will only be enhanced unless foreign exchange is freely made available.

EXPECTED ODS EMISSIONS IN INDIA

Table I listed the total consumption of ODSs in India in 1980 by product-category. The expected consumption by user-categories in 1990 and 1996 are listed in Table II.

Table II. Expected growth in ODS consumption in India

User Sector	Consumption (Tonnes) 1990	1996
Refrigerators	500	1,500
Air Conditioners	1,500	2,500
Foam	750	2,000
Aerosol	500	2,000
Cleaning	4,000	7,000
Fire Fighting	250	1,500
Miscellaneous	1,500	1,500

The consumption levels in Table II are based on the expected unconstrained growth of the respective user sectors. The user sectors of interest to global warming are those which utilize CFCs: refrigeration, air conditioning, foam and aerosols. The total consumption of CFCs in 1990 will therefore be about 2,750 tonnes, and will increase to about 8,000 tonnes by 1996. The strategy adopted by India with respect to the Montreal Protocol would imply completely banning use in aerosols after 1996: these would give headroom for growth in ODS use in other sector of about 2000 tonnes - equivalent of CFC-11 till 2003. It is expected that the majority of the growth would occur in the refrigerator and foam sectors. CFC use in air conditioning and foam-blowing (accounting to about 5,000 tonnes) could be banned in 2003 which would decrease Group I production by 50% of the 1996 production. Beyond 2003, till 2007, only refrigerators would be charged with CFCs. The growth in the refrigerator industry would prbably lead to a consumption level of 4,000 tonnes by 2007. In 2007, all new refrigerators could be required to switchover to substitutes, and further production of CFCs (of 1200 tonnes per year till 2010) would only be for recharge. Table III illustrates this CFC consumption profile.

Table III. CFC consumption profile in India beyond 1996

User Sector	CFC Consumption (Tonnes)			
	1996	2003	2007	2010
Refrigeration	1,500	2,650	4,000	1,200
Air Conditioning	2,500	2,900	0	0
Foam	2,000	2,450	0	0
Aerosols	2,000	0	0	0
Total	8,000	8,000	4,000	1,200

Considering the consumption levels in Table III, the emissions of CFCs can be evaluated. CFC emission is immediate on use in foam-blowing and aerosol use. However, there are considerable delays in the emissions of the CFC charges in refrigeration and air conditioning. Here, the delays are assumed to be 10 years and 5 years, respectively. Consequently, the probable emissions will follow the profile described in Table IV below.

Table IV. CFC emissions in India

User Sector	CFC Emissions (Tonnes)			
	1995/96	2000/01	2006/07	2009/10
Refrigeration	475	500	1,500	2,200
Air conditioning	1,475	2,500	2,800	0
Foam	1,975	2,200	0	0
Aerosol	475	0	0	0
Total	4,600	5,200	4,300	2,200

Beyond 2009/10, the emissions will correspond to the consumption in the refrigeration sector ten years earlier. Thus, emissions will rise to 2,650 tonnes in 2013 and peak at 4,000 tonnes in 2017. Beyond 2017, the emissions will correspond to the emissions of remaining stock of refrigerators which will be negligible.