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REPORT ON GLOBAL WARMING AND ASSOCIATED IMPACTS

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(PHASE IV)

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THE ECONOMICS OF CLIMATE CHANGE

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ABSTRACT

The paper discusses some aspects of the use of economics in policy analyses of Climate Change concerns, i.e., the difficulties and limitations of employing Cost-Benefit Analyses (CBA), the issue of uncertainty, the use of formal economic models, the inertia of social and economic systems, the question of choice of domestic and international regulatory instruments, and finally, one way of structuring the equity issue. Very broadly, one may conclude that while no major paradigm shift is necessary, the challenge of policy analysis in the Climate Change context will require a significant sharpening of existing analytical tools of economics, as well as the establishment of deeper interdisciplinary linkages.

1. Introduction:

The issue of Climate Change has emerged as potentially one of the most significant policy questions in the current international arena. This is because the risks of possible Climate Change may be high, and the costs of abatement or adaptation measures also large, and both are likely to fall variably, but uncertainly, on different regions and at different times.

Climate Change is also arguably, one of the most complex global policy issues to have arisen so far. The questions involved relate to numerous disciplines, in the pure and applied natural sciences, positive social science, and political economy, besides ethics and morality. Analysis of the divergent facets of the issue is likely to proceed at the cutting edges of current human knowledge and understanding, and indeed may involve several extensions to the frontiers.

Given the deep and pervasive complexities of the issue, it is a little disconcerting to find that some of the recent literature in the field has tended to focus largely on the technical aspects of Climate Change, in particular on some of the more alarming scenarios generated by Global Circulation Models (GCMs), and gloss over the key question of equity in abatement and adaptation measures. We emphasise at the outset, that in our view, both positive ("what is") and normative ("what ought") questions need to be kept in the spotlight at all times. We have attempted to follow this precept in the present paper.

It is, of course, gratifying that Climate Change has, in just a few years, acquired prominence in both the public mind, as well as that of policy makers throughout the globe. Further, that the world community has acted with commendable despatch in sitting down to substantive multilateral negotiations on regulatory approaches to the issue. However, one may as well recognize that the complexity, and the deep equity implications of approaches to the issue, rule out any quick fixes to the problem. Any multilateral approach which seeks to install a regulatory regime, without allowing for proper analysis and deliberation, or for periodic review of the substantive provisions of the regime, in the light of increasing understanding of the myriad dimensions of the problem, may soon prove to be unworkable, or inequitious, or ineffective.

This paper seeks to summarize some aspects of the current economic understanding of the regulation of Climate Change, in both positive and normative aspects. It is structured in the following manner: Section 2 discusses the application of Cost-benefit methodologies, which have emerged as a major analytical tool for public policy in several countries, to policy analysis for Climate Change. Much of our current knowledge of Climate Change has been revealed by the use of large-scale atmospheric and macroeconomic models, and Section 3 discusses the role, and limitations of employing economic models for predicting greenhouse gases (GHGs) emissions, and the impacts of regulatory and abatement strategies.

Section 4 is about the costs associated with economic and social transformation in different countries, if multilateral regulation for Climate Change is implemented. The choice of policy instruments is a crucial element in designing any regulatory scheme, multilateral or domestic, and Section 5 addresses this question in the Climate Change context, drawing upon both theoretical and experience based insights. Finally, Section 6 attempts to furnish a structure for analysing the key question of equity in Climate Change, drawing upon an existing theoretical framework, and attempts to derive some normative implications from insights gained from several ethical schools.

2. The Development of Cost-Benefit Analyses (CBA): Difficulties and Limitations:

The need for devising global policies for Climate Change arises from the fact that there is no reason to suppose that Providence would ensure that the costs of Climate Change manifestations would be visited exclusively on the polluters, and symmetrically, that benefits would flow exclusively to the environmentally abstinent. Variants of Cost-Benefit analysis have been developed for ranking alternative policy options in a number of situations, including several (local and regional) environmental contexts. However, CBA techniques need to be developed further in several aspects, before they can be applied meaningfully to the analysis of Climate Change options.

Very briefly, in CBA, different policy options are ranked with respect to the present value of the respective streams of benefits and costs over time, reckoned with respect to increase or decrease respectively in a chosen objective function, subject to the resource and technical constraints faced by society. There are two principal types of CBA. The first, i.e., Kaldor-Hicks CBA attempts to rank different policy options on the basis of their respective potentials for increase in national income (GDP) in society. An alternative procedure which is often employed in situations where there is great uncertainty regarding the future streams of benefits, is "cost-effectiveness analysis", in which the policy options are ranked in the order of lower (present value of) resource costs to achieve a given policy goal (for example, a specified level of environmental quality). The second, i.e., Social Cost-Benefit analysis, on the other hand, employs as a ranking criterion the potential increase in a Social Welfare Function (SWF), explicitly chosen by the analyst or the client policy makers, and which incorporates society's distributive concerns, along with efficiency considerations. An example of a SWF is a weighted sum of the aggregate income levels of different social groups, where the weights are the (relative) marginal utilities (cardinal, inter-personally comparable) of incomes of the respective groups ("Utilitarian SWF").

CBA methodologies have evolved for policy evaluations in limited temporal and spatial contexts, and further, for scales of costs and benefits which are not large in relation to the concerned national or regional economies.

Policy options for Climate Change present several challenges to the development of CBA methodologies. First, the "society" is no longer a national or regional entity, but global in a spatial sense. Second, the time-frames of policy options for Climate Change may extend over many human generations, while conventional public policy concerns do not generally spill-over more than a few decades. Third, the Climate Change issue is characterized by pervasive uncertainties in the timing and nature of environmental impacts, their regional distribution, besides the economic and social effects of the regulatory mechanisms themselves. Fourth, the likely scales of costs and benefits are no longer marginal, but large, so that major restructuring of economic patterns might be involved. Finally, one must confront a fundamental ethical question: Is it appropriate to address dee, environmental issues from an anthropocentric standpoint, i.e., basing policy choices on patterns of human preferences? We discuss below, in brief, each of these aspects:

2.1. Cost-Benefit Analyses for a Global Society:

CBA on the Kaldor-Hicks criterion, conducted for policy options for a national or regional economy, makes an important, if implicit, assumption. That is, either the distributive impacts of each of the policy options are negligible, or alternatively, that the economy has a suite of separate policy instruments which reliably, and costlessly, ensure that the society's preferred pattern of resource distribution is achieved at each level of aggregate societal income. If these assumptions are valid, in that case increases in economic efficiency (i.e., national income) are unambiguously desirable, and candidate policies may be ranked on that basis.

Policy analyses for Climate Change in a global perspective must, however, contend with the fact that neither assumption is tenable. Actual manifestations of Climate Change will almost certainly impose costs, and may confer benefits, unevenly across different regions. For some, the costs may be of catastrophic dimensions. Further, the control measures themselves, may impose highly skewed costs and benefits across different regions. In addition, no human agency yet exists which can be trusted to (costlessly) reassign these costs and benefits, (or indeed any kind of resources), according to any predetermined pattern.

Clearly an exclusive focus on efficiency in policy analyses of global Climate Change options is inappropriate. The analyst has to address the task of devising policies which incorporate mechanisms for redistributing costs and benefits across agents, besides efficiency concerns. In other words, a Social CBA approach is unavoidable in this instance. Conducting a Social CBA however requires the explicit adoption of a SWF at the global level. This is the central aspect of the equity dimension of the Climate Change issue, which is discussed in greater detail below. At this point one may note that the choice of a global SWF is not the task or province of the policy analyst, but is inherently a political act, in which policy makers from different countries, regions, and political and cultural orientations, are the players. At issue is the very nature and process of political authority in the global context.

2.2. CBA in an Inter-Generational Context:

Climate Change is characterized by benefits and costs flowing unevenly across several human generations. Policy analysis employing CBA have encountered few multiple generation situations so far, and accordingly the question of how different generations are to be treated by the present generation, which currently has the power to unilaterally decide on long-term policy options, is a fertile area for normative policy research.

One possible input to CBA methodologies from inter-generational considerations is the choice of (one or several) social discount rate(s), i.e., how benefits and costs, whether expressed in economic terms, or in relation to changes in a global SWF, are to be discounted over time.

Any strictly positive discount rate applied to economic costs and benefits implies a determination that allocation of resources to the current generation is more important than to future generations. One argument in justification of this position is that because of capital accumulation (and technological advances) by the current generation, future generations will be richer. A typical member of the future generation will therefore, value a unit of income (in utility terms) less than would a typical member of the current generation. Further, they will have greater resources for adapting to adverse impacts of actual Climate Change. On the other hand, arguments have been advanced for zero discount rates, i.e., which would not distinguish between individuals belonging to different generations.

A large volume of literature exists on the choice of a social discount rate in the CBA of conventional policies, i.e., with a time horizon of no more than a few decades. A major problem is revealed by the fact that the application of such conventional social discount rates, typically in the range of 8-12% per year, in an inter-generational context, i.e., with time horizons of, say, 100 years, yields extremely low present values of (postulated) very high future costs. This runs counter to intuitive notions of equity, because it implies that virtually all of the costs of adaptation or abatement measures should be passed on to future generations, even if they are believed to be very high.

Several attempts have been made to incorporate inter-generational concerns in the CBA framework, which are intuitively appealing. These approaches may be summarized as follows:

(a) Imposing sustainability constraints: This approach seeks to allow the maximization of net benefits to the current generation, subject to the requirement that (natural and man-made capital) resources available to future generations would allow them to attain at least the welfare level of the current generation. The major theoretical formulation of the sustainability principle was furnished by Solow (1974), who showed in a simple two-factor model (i.e., natural resources and capital), that a constant level of consumption can be maintained as long as any one of the following conditions are satisfied:

(1) The elasticity of substitution between the factors is greater than unity, or

(2) The substitution elasticity is unity, but the share of capital exceeds that of natural resources, or

(3) that there is sustained resource augmenting technical change.
Of course, important questions arise with respect to whether any of these conditions can

be maintained very far into the future. Little practical headway has yet been made in operationalization of this concept, except for tentative attempts at computing GDP, taking changes in levels of natural resources into account.

(b) Positive approaches: Some attempts have been made to show that even from the perspective of the current generation, social discount rates below private discount rates are appropriate in an inter-generational situation. An argument for considering only the preferences of the current generation, furnished by Arrow and Kurz (1970), is that because the revealed preferences of individuals are accepted in making other social choices, they should be accepted in the inter-generational context as well. The counter argument, of course, is that lack of representation to future generations is the real problem.

One example of a positive approach is that of Marglin (1963). The argument runs that consumption by future generations is a public good to members of the present generation. Accordingly, all members of the current generation are made better off by a social choice in favour of greater savings and investment than would have been the case with individuals acting independently. Such a decision would imply a social discount rate below the private rate. This argument, though intuitively appealing, does not hinge on notions of inter-generational equity, but rests on efficiency considerations.

(c) SWFs embodying inter-generational equity: In this approach, discounting is eschewed in favour of specifying welfare criteria based on the actual welfare levels of different generations. One example of this approach relies on welfare criteria based on the Rawlsian (Rawls, 1971) ethic. Very briefly, this principle ("maximin") states that the welfare of society is the welfare of the worst off member, given that basic freedoms are available equally to all.

A counterintuitive implication of this principle applied inter-generationally was noted by Solow (1974). He looked at the problem of determining the largest sustainable level of consumption for society, subject to constraints on capital accumulation and the stock of an exhaustible resource. The maximin principle would require a large initial capital endowment, and if it is small, then the level of consumption must be small forever, because capital must not be accumulated by sacrificing the consumption of the first generation which is poor.

A way out was suggested by Phelps and Riley (1978). If generations are allowed to overlap, the earlier generation which accumulates capital has a claim to more retirement consumption provided by the labour of the next generation, which has an obligation to work more in exchange for the gift of capital. Such a program can be supported by appropriate debt creation, and growth is further encouraged if the earlier generation derives utility from the consumption of the later generation.

(d) Modifications to the social discount rate: Several examples of this approach exist. One approach seeks to set discount rates to zero, on the ground that one should be impartial with respect to the time at which an individual lives. Such impartiality may be justified, for example in a Rawlsian framework, on the "veil of ignorance" argument. That is, individuals who are unaware of their future place in society and meeting to decide on a constitutional framework, would be risk averse, and accordingly choose not to place any group at an advantage or disadvantage relative to others. An argument against zero discount rates due to Olson and Bailey (1981) is that discounting proceeds from utility discounting ("time preference") and consumption discounting. They have shown that if time preference is zero, i.e., complete equality exists between generations, and interest rates are strictly positive, individuals should rationally reduce present consumption to zero, which is counterintuitive.

Formulations of consumer discount rates, as well as of producer rates, besides combinations of these also exist (see Pearce, 1991). These approaches are still not theoretically satisfying. Empirical results of the first and second of these approaches remain counterintuitive, and of the third, appear to rest on some strong assumptions.

The long time-horizon of Climate Change also leads to some problems in positive analysis of economic impacts. Long-term predictions are usually based on economic models, and several assumptions must be incorporated, which may drive the models' results. These assumptions may relate to technological change, economic structure, population trends, and other aspects. It is hazardous to assert that any one of the several alternative assumptions will ultimately prove to be valid.

2.3. Uncertainty:

The Climate Change issue is permeated with ubiquitous uncertainties in the types and regional distribution of environmental impacts, besides the economic and social impacts of control or adaptation policies. One way to think about uncertainty in Climate Change is to consider that at each period in the future, the world could experience different sets of such impacts or "outcomes". These possible outcomes may vary with the actual control (and/or adaptation) regime that is implemented, but while for each policy only one of the possible outcomes will be actually realized, there is no way of knowing in advance, which one it will be. Nonetheless, choices among competing policies must be made based on incomplete knowledge.

In an important sense, this notion of uncertainty in Climate Change differs from uncertainty as understood in conventional CBA. In the latter, it is assumed that outcomes of policies depend on "states of nature", i.e., unforeseeable events, but that for any realized state of nature, it is possible to determine unambiguously the outcome of a given policy. For example, whether or not an earthquake occurs is a state of nature, but given that one occurs, one may determine with certainty whether a particular hydroelectric dam, embodying a particular policy choice, will survive. On the other hand, uncertainty in Climate Change implies that the outcomes of policies cannot be determined definitively in any case, because they are insensitive to any intervening states of nature, all of which may be manifest in the long term over which Climate Change may occur. In other words, in Climate Change, "God does not play dice with the world," but that uncertainty arises from inadequate human knowledge and understanding, which could improve with time and effort. For example, uncertainty exists about the predictions of Global Circulation Models (GCMs) of the atmosphere, or of economic models of regulatory policies, on which policies must be based, because they are sensitive to modelling assumptions or parameter values, whose validity may be in doubt. However, further research may reduce these uncertainties.

In the context of Climate Change, further complexity is introduced by (a) long-time periods involved, on account of which uncertainties in the costs and benefits of policies, and their regional and inter-generational distribution increase; (b) the possibility of catastrophe, meaning that under some equity perspectives the costs of some impacts should be valued as infinite, even if they are remote in time or have a very small probability of occurrence; (c) that knowledge of the uncertainties may change over time, because of gains in scientific knowledge or better modelling (including economic modelling) techniques, meaning that in hindsight, policy choices may be seen to have been mistaken; and finally (d) that there is a hierarchy of policy choice situations, i.e., global, national, and perhaps, subnational, so that policy choices at one level of the chain may impact the outcomes of policies at other levels. This may be the case, for example, with trade and the international division of labour, which may depend on the interactions of global, national, and local regulatory regimes and economic policies. Further, in the multilateral context, the issue of the process of policy choice and of criterion of choosing among alternative policies is reasserted.

Ways of dealing with uncertainty in conventional CBA ultimately rest on subjective judgements. These judgements relate, first, to the choice of a decision criterion. For example, "maximization of expected value", in which the mathematical expectation of net benefits, using subjective probability estimates, is the decision variable). Alternatively, the so-called "maximin returns" rule, in which each candidate policy is evaluated at the minimal net benefit it assures, with the one with the highest such guarantee being chosen. Another option is the "minimax risk" principle, in which the alternative with the smallest "maximum risk", defined for each combination of an alternative and a state of nature, as the excess of the maximum net benefit available in the state of nature and that actually resulting from the given decision in that state of nature, is chosen. Second, judgements of the probabilities of the different outcomes are also inherently subjective, and cannot be formulated as a strictly technical exercise. Before or after an event, no particular probability estimate of the same can be unambiguously validated, even in principle.

In conventional CBA, with a clearly designated policy making authority, the subjective judgements of that authority must prevail. This remains true, even if the tasks of choice of decision rule, or estimating probabilities, are delegated to policy analysts or experts, because it is the decision maker who exercises this choice. In the context of multilateral decision making for global Climate Change policies, each party to the negotiations would make his own subjective choices. In this, there is scope for strategic behaviour by the negotiators. For example, a country may adopt a negotiating strategy of asserting a low probability to adverse impacts in its territory, or conversely, high probability to favourable impacts, in the expectation that this may reduce pressures on it to adopt stringent emissions limits. If enough countries behave in this way, the aggregate global levels of emissions may be negotiated at levels too high to appreciably impact the onset or severity of Climate Change.

2.4. Large Scale of Impacts:

Conventional CBA deals with policies whose economic impacts are at the margin, i.e., small in relation to the overall economy, and even perhaps to individual markets. Several assumptions may be justified in such cases. For example, most conventional CBA rests on partial equilibrium analysis, so that only the markets directly impacted need to be studied, maintaining the ceterus-paribus ("all else unchanged") assumption.

Climate Change impacts, or regulatory measures, may however, have to be studied in a more comprehensive manner. For example, since regulation of GHGs emissions will impact patterns of energy use, and energy is a significant input in all industries, regulatory policies may need to be evaluated in a general equilibrium framework, i.e., looking at the inter-dependence of and impacts on all markets, including the traded sectors. Additionally, policies for global GHGs regulation will impact national or regional economies differentially, altering their inter-relationships, for example patterns of comparative advantage and trade.

General equilibrium analyses typically rely on large-scale models of economies, in contrast to the small scale, project or program level focus of conventional CBA. A comparison of such micro level ("bottom up") and model based ("top down") estimates of abatement costs reveals systematic differences in the results. The top down studies, which typically rely on the neo-classical assumption of cost minimizing behaviour by firms, show national economies moving away from an initial equilibrium in which all firms employ resources optimally, so that abatement costs are positive. On the other hand, bottom up studies, employing the assumption of "unfettered penetration of technologies", frequently show negative abatement costs, because the benign technologies may also be more efficient, at least when no changes in relative prices are allowed for. While it is clear that because of the large scale of impacts, general equilibrium effects must be taken into account, one challenge of model development is to realistically incorporate rapid or discrete technological change.

2.5. Is an Anthropocentric Approach Ethical?

Climate Change may impact the major ecosystems of the globe, and thus, all life forms. It may promote speciation through modification of habitats, and for the same reason, may result in the extinction of some species. While several other policy questions have concerned significant local or regional ecological impacts, Climate Change is the one issue in which impacts may be planetary in scope and permanent in duration.

The validity of CBA, or indeed any methodological approach (for example, decision analysis), based on human preferences or valuations, presupposes that an anthropocentric world view is appropriate. The issue may be framed in terms of whether mankind has rights of domination over all Creation (and may therefore employ all of nature as he pleases), or is but one species among many (and accordingly, has no right to disturb the natural order), or has a special responsibility to preserve other living and non-living entities without regard to his own benefit, i.e., stands in relation to the rest of Creation as guardian or trustee. Clearly, no analytical answer to these issues is possible, and the matter is at the heart of ethical philosophy.

Several serious researchers (e.g., Tribe, 1987), have sought to define an environmental ethic not based on human domination over other "modes of being", including living and non-living entities. Thus, Tribe suggests that "at a minimum, we must begin to extricate our nature regarding impulses from the conceptually oppressive sphere of human want satisfaction, by encouraging the elaboration of perceived obligations to plant and animal life and to objects of beauty in terms that do not falsify such perceptions from the very beginning by "insistent 'reference to human interests'." Some specific proposals in this general direction include:

(a) Legal recognition of a principle that the concept of "rights" is not confined to humans (Stone, 1972). This should not be confused with the idea that their "wants" should be identified and included in a calculus of preferences. Recognizing these rights may be consistent with acknowledging that there maybe circumstances in which such rights may be overridden, as indeed is the case with several "human rights."

(b) The appointment of guardians or trustees for environmental entities, living and non-living, as an embodiment of the recognition of such rights.

(c) Making explicit obligations to nature in environmental surveys and statements, and allocating resources to improving the technical capacity to incorporate such obligations in policy analyses.

The use of CBA, or other analytical techniques based on human preferences, is ultimately based on the doctrine of human domination over nature. Since Climate Change has generated global discourse, it is indeed appropriate that the issue is looked at from alternative cognitive perspectives.

3. The Use of Formal Economic Models:

Policy analysis of Climate Change has relied extensively on formal modelling exercises. Two principal categories of such models are, first, global energy-carbon dioxide prediction models, and second, national or regional economic models focused on energy use and regulation. The next two subsections briefly recount these modelling efforts, and the last subsection considers the possible use of formal models in policy analysis of Climate Change.

3.1. Global Energy-Carbon Dioxide Models:

Numerous attempts have been made at making long-term (i.e., half a century or more) predictions of atmospheric carbon dioxide, employing formal, quantitative models. However, all such predictions are intrinsically uncertain, with the uncertainty increasing sharply with the time horizon. The uncertainty arises both from the tentative nature of economic forecasts of anthropogenic activities which generate GHGs, as well as from inadequate scientific understanding of the various natural processes of the carbon cycle. There are three basic types of such models:

The first type are simple extrapolations of historical trends of energy use, and may be regarded as summarizations of more detailed projections. They may be useful for sensitivity analyses of the carbon cycle and the climate system, but have little intuitive appeal as systems of comprehensive carbon dioxide accounting. Examples of this type of model include: Keeling and Bacastow (1977), and Siegenthaler and Oeschger (1978).

The second type of global carbon dioxide models are "uncontrolled" (i.e., no regulatory mechanism is embedded), global energy-climate systems models. They include relatively detailed descriptions of global energy supply and demand, and carbon dioxide emissions are an incidental output. Various models of this type vary greatly in design, in the extent to which formal modelling techniques are employed, and in the details of fuels, geography, and other factors. Examples of this approach include: Perry and Landsberg (1977), Edmonds and Reilly (1983), Rotty and Marland (1980), Nordhaus (1977 and 1979), and IIASA (1981).

The third type of models incorporate feedbacks from changes in atmospheric carbon dioxide to the global energy system. They require a basic analysis of a model of the second type as input, but additionally, take into acount changing levels of carbon dioxide, or costs of climate change. In other words, the level of atmospheric carbon dioxide is included as a possible external constraint on the energy system. Examples of models of this type include Nordhaus (1980), Perry et. al. (1982), and Edmonds and Reilly (1983).

The results of all models which are based on reasonably in-depth studies of carbon dioxide emissions project a growth in energy use over the next 40 to 50 years of 2 to 2.5 times the 1975 level (which was 8 Terrawatt-years/year). Whenever such scenarios do not project a large share of non-fossil fuels, they lead to serious concerns about climate change in the next 50 to 100 years.

3.2. National (Regional) Energy Focused Models:

Models of national economies focused on energy supply, demand, and the impacts of policy, have been taken seriously by policy makers from the time of the first oil price shock of 1973. An example is Hudson and Jorgenson (1978). Numerous models in this category have been developed, varying widely in level of modelling detail, assumptions, time-frame, and methodology.

The current generation of this category includes applied general equilibrium models designed to simulate the impacts of price shocks with a high level of causal detail (e.g., Despotakis and Fisher, 1989), or to simulate the impacts of multilateral and domestic GHGs regulatory instruments (e.g., Ghosh, 1990), or to evaluate the costs of environmental quality regulations (e.g., Hazilla and Kopp, 1990). It also includes disaggregated long-term models to evaluate the impacts of pollution regulation on growth (Jorgenson and Wilcoxen, 1989), and long-term macroeconomic models for estimating the economic costs of carbon dioxide emissions limits (e.g., Manne and Richels, 1989). Several of these models attempt to estimate the average or marginal costs of fossil fuel carbon dioxide reductions in the respective countries. The estimates vary widely, reflecting underlying differences in modelling assumptions, structure, and abatement scenarios. A representative sample of these estimates is furnished below:

Table 3.1: The Costs of Carbon Dioxide Reductions: Representative Estimates:

Author(s)	Region	Forecast Year	% CO2 Reductions	Reference Year	Costs 1989 US$/TC Average	Marginal
Gerbers et.al. (1990)	Nether.	2020	20	1990	31	31
		2020	70	1990	174	889
Yamaji et al. (1990)	Japan	2005	0	1988	n.a.	281
Manne & Richels (1990)	USA	2030+	20	1990	210	250
Jorgenson & Wilcoxen (1990)	USA	2100	20	1990	n.a.	46
CBO (1990)	USA	2100	20	1988	n.a.	110-440
Morris et.al. (1990)	USA	2010	20	1990	28	39

Source: Adapted from Edmonds and Wuebbles (1991).

3.3. The Use of Formal Models in Policy Analysis of Climate Change:

Typically, the development of formal predictive or policy analysis models requires significant resources of time and effort. Implicitly, the expectation of the modellers in engaging in such intensive research activity is that the simulation results of the models would be taken seriously by policy makers and activists, and actually employed as inputs to policy formulation. An important question that arises is: Why and to what extent should policy makers and other players in the policy game accept analyses which employ such models as credible inputs to the policy making process? The issue of validity of policy modelling is intimately linked to the perceptions of whether these approaches constitute "science". There is general agreement that the scientific method includes (a) the dominant role of empirical testing, (b) the reproducibility of results, (c) of being explicit about uncertainty, (d) of peer review, and (e) of open debate about alternative theories. We discuss below the applicability of each of these attributes of the scientific method to existing policy analysis practices:

(a) Empirical validation: Differences between validation in the natural sciences and policy analysis models are centered on the facts that empirical policy analysis models are contingent on place, time and circumstance, rather than universal, and that validation by the process of controlled experimentation is not possible when the subject of the experiments is society itself (a difficulty common to all social science).

Policy analysis models present some further difficulties which are not encountered in the "hard" sciences. First, policy analysis models often attempt to project the implications of policy decisions far into the future, and direct testing of predictive validity cannot be carried out until long after the analysis is required. Second, such models are frequently designed to simulate the impacts of alternative policies. In such cases, empirical validation of the models in respect of the policies which are not adopted is not possible, even in principle. Finally, when the models can be calibrated against historical data, there is no assurance that past parameter values, or even causal relationships will hold in the future.

It is clear that direct empirical validation is not possible for several types of policy modelling, including those related to long-term Climate Change. This unavoidable situation places a greater burden on policy modellers to observe the other canons of scientific procedure, if the results of the models are to be relied upon even to a limited extent. However, it seems that these conventions are not yet well established among policy analysts, as discussed below:

(b) Reproducibility: Policy analysts have largely neglected the issue of reproducibility, as may be seen, for instance in the frequent lack of adequate documentation that would enable other researchers to reproduce the results. This may be on account of the fact that standardization of methods and tools is not yet sufficiently advanced in policy analysis, so that it is difficult to convey the details of models adequately in typical journal length articles.

(c) Uncertainty: Despite, or perhaps because of, the vast uncertainties inherent in most policy analysis models, it is still not standard practice to treat uncertainties in an explicit, probabilistic fashion. This contrasts with the practice in the experimental sciences, in which it is usual to report estimates of random or systematic error in measurements or estimates. It is clearly prudent to conduct sensitivity analyses of policy analysis models with respect to parameter values or key assumptions, but this practice, while increasing, is not yet the norm.

(d) Peer review: In conventional science, peer review takes place largely through the refereeing and publication of research reports. For a large and complex policy model, an adequate review can be time consuming and problematic, even if adequate documentation exists. It has also been argued that owing to the time urgent nature of several types of policy analysis, peer reviews are inappropriate, even for models of modest scale. While this may be true in some cases, a general failure to focus on peer reviews has perhaps contributed to the slow development of standards of good analytical practice, as well as a failure to extract generalizable insights from specific analyses.

(e) Debate: Any model used in policy analysis will, at best, be an approximation to the real world. Further, policy analysis almost always deals with situations that are ill-structured. In traditional sciences there are norms about how to conduct experiments, what kinds of theories are interesting, and what questions are interesting: These constitute the prevailing "paradigm" of the discipline. In policy analysis, on the other hand, there seems to be no clearly prevailing paradigm, but rather a number of different contending criteria and methodologies. This lack of agreement on paradigm, and on the focus on ill-structured problems makes the criterion for deciding what is "best" especially difficult. It has been suggested (Mitroff and Mason, 1980) that policy analysis is a dialectical process in which a model is proposed, and counter-models are offered in response. Debate focuses on the relative failings of the competing models, and over time, an improved model may be synthesised from the initial ones. Claims to validity of any policy model, are thus always tentative.

It is likely that the findings of policy research influence policy making, not directly ("instrumental use"), but in a diffuse and indirect manner, without policy makers being able to cite specific research findings employed by them ("conceptual use"). Alternatively, such findings may be employed for reinforcing partisan viewpoints, or as an aid to legitimizing decisions that have already been taken ("symbolic use").

The fact of possible, even probable, symbolic and conceptual use of research findings, casts a special responsibility and need for restraint on the part of policy analysts. The findings of formal models which are not rigorously validated (including those which by their very nature or time frame do not lend themselves to empirical validation) and in which the extent of uncertainty in the results is not determined to specified confidence levels, should not be employed in proposing actual policy measures. This is not to suggest that the findings of such unvalidated models should not be disseminated to policy makers. Provided that the theoretical structure of the models is sound as determined by peer review, that the data employed is believed to be reliable, and that the models are robust as demonstrated through sensitivity analyses over key assumptions and parameter values, the focus of such revelations should be on the causal insights gained. In particular, these insights may relate to mechanisms which are not transparent to the intuition, and in identifying promising policies for further analysis.

4. The Inertia of Social and Economic Systems:

Simple economic models frequently furnish important insights that are difficult to gain from pure intuition. These models are "simple" in the sense that they involve several abstractions from reality, to reduce the number of interacting variables. The construction of such models involve making numerous assumptions, for which economists are notorious. Indeed it has been asserted that economic models are to be judged not by the plausibility of
their assumptions, but solely by their predictive power.

A "standard" assumption in economics is that factors of production are fungible between economic activities, and accordingly, changes in economic patterns are for the most part, costless. Firms may therefore respond smoothly to policy or price changes, although adjustments of different types of inputs may involve different time lags. Thus, in the "very short run", firms may alter materials (and energy) entering process streams, and in the "short run", labour. In the "long-run", capital employed may be changed, and firms may enter or exit a given industry. "Fixed costs" refer to capital (including human capital) stocks which are specific to a given plant (or activity, in the case of human capital), and which cannot be reassigned in any meaningful time frame. Such costs, once incurred, as treated as "sunk." A major theme of neoclassical economics is that only variable costs matter for making economic decisions, and that sunk costs are to be ignored in a rational calculus.

Strategies for reducing GHGs emissions, or in adapting to Climate Change may involve changes in technology, economic structure, and life-styles. The existing patterns are, in each country, the result of historical evolution. Unlike the neo-classical economic assumption, changes in technology and economic structure will not be costless, nor will changes in life-styles be without pain.

Considerable economic and social infrastructure is currently built around energy dependent systems. One example illustrates this assertion. Modes of transport, i.e., whether mass or personal transportation systems dominate, and the vehicular mix in each, determine capital stock and technologies in the sector, besides public infrastructure: railway lines, airports or highways, and patterns of fuel use. Second order linkages include composition of industrial output and trade, besides occupational patterns, human settlement modes, and lifestyles. Clearly, limitations on GHGs use in the transport sector would have pervasive effects throughout the economy. A similar order of economic and social linkages and effects of GHGs regulation may be traced for other energy intensive sectors, for example power generation, industry, agriculture, etc.

In reality, of course, physical capital stocks are not fungible across sectors, or across different technologies in a given sector. In other words, much investment in physical capital is to be regarded as a 'sunk cost', in any significant change in economic structure, including technical change. To an extent, this would also be true of human capital. While some types of workers may be retrained at relatively little cost and deployed in newer lines of economic activity, several skills may become manifestly obsolete and/or because of barriers to labour mobility, the workers may be unable to relocate. The human capital embodied in the skills of such workers must then also be reckoned as a 'sunk cost.'

Since regulation of Climate Change, as well as its possible impacts may involve major restructuring of the economy, the question of the magnitude of these 'sunk costs' becomes important. Analogously, lifestyle changes may also occur, bringing unhappiness or disutility (and it may be possible to assign monetary values to such disutility, for a given distribution of resources in society). These magnitudes are closely related to the time-frame in which regulatory measures are implemented (or adaptation is necessary). This is because of several reasons:

First, if the required changes are implemented gradually, it may be possible to run down existing (physical and human) capital stocks fully in a given sector, before fresh investments embodying new technology (and skills) are made. A similar situation may prevail for human capital i.e., workers of a given skill may superannuate by the time that new investments requiring new skills are made. Second, if existing capital is not in fact fully depreciated (i.e., in an intrinsic, not financial book value sense), but the period of (premature) replacement is spread out, given positive private discount rates, the present value of 'sunk costs' would be relatively low. Further, one may anticipate that significant technological improvements would occur over time, and this fact may also reduce anticipated adjustment costs if the period of restructuring is spread out. Finally, one may intuitively accept that rapid lifestyle changes may bring greater disutility than gradual changes, and further, if positive time preferences exist with respect to utility, the magnitude of total disutility (perhaps aggregated by monetary imputations) would be lower still.

Several differences exist between industrialized and developing countries with regard to the current age and composition profiles of (physical and human) capital stock. Generally speaking, in many OECD countries, traditional industrial sectors which are GHGs intensive have experienced slow or negative growth in the past several decades. On the other hand, several "sunrise" sectors, i.e., those which have shown relatively high growth rates in recent decades, for example, information intensive sectors such as services, pharmaceuticals, entertainment software, etc., are not GHGs intensive. This means that in industrialized countries, the age of capital stock in GHGs intensive sectors is on the average "high", and that of less GHGs intensive sectors, "low". This situation contrasts with that in many "Newly Industrializing Economies" (NIEs). In these countries industrial capital stock is largely concentrated in GHGs intensive sectors, for example, steel, fertilizer, electric power, and are "new", as compared to similar capital stocks in industrialized countries. A case is therefore apparent, even on cost minimization grounds, i.e., without involving equity considerations, for global GHGs regulatory policies to be focused on the earlier restructuring of OECD economies away from GHGs intensive activity. Equity considerations, taking into account the relative burden of restructuring costs across countries, would seem to only reinforce this conclusion, which dominates the alternatives of restructuring by all countries at the same rate, or a policy of earlier restructuring by developing countries.

5. The Issue of Instrument Choice:

The environmental economics literature distinguishes between two broad classes of environmental regulatory instruments, i.e., "command and control" or fiat type instruments, and market incentive based instruments. An example of the former is emissions standards (i.e., quantity restrictions on pollution emissions of a given type e.g., SOX, emitted) imposed by directive, and of the latter, pollution taxes i.e., a uniform tax on polluters per unit of pollutant of a given type emitted.

In the case of carbon dioxide whose emissions primarily result from fossil fuel use, the possibility also exists, at least in the context of a national economy, of the use of conventional fiscal and tariff instruments on energy sources and energy intensive sectors. The use of these instruments may, by altering the structure of relative prices perceived by economic agents, impact patterns of energy use by inter-fuel substitution (e.g., substitution of fossil fuels by hydropower for electricity generation), or of factors use (i.e., substitution of energy by capital and/or labor, e.g., by promoting energy conservation), or of industrial and trade structure (e.g., shifts in output and/or trade from energy intensive industrial sectors like steel to (skilled) labor intensive sectors such as services). These shifts in energy use patterns may impact the emissions of carbon dioxide, and perhaps of other GHGs as well.

Some results from the theory of environmental regulation relating to the choice of environmental regulatory policy instruments are summarized in the next subsection.

5.1. Standard Theoretical Results:

In the case of a pollution tax, a necessary condition of economic efficiency in a competitive economy is that the rate of tax is set equal to the marginal damage from pollution. However, and this would very likely be true of Climate Change, the information required to reach efficiency (i.e., the marginal damage at the efficient point to all agents exposed to the pollutant) is unlikely to be available. In that case, a pollution tax will still achieve a given level of environmental quality (e.g., aggregate GHGs emissions levels) at least resource cost, under the assumptions of cost minimization and price taking by firms, which fiat based instruments are unlikely to accomplish. Further, a rigid standard may involve unacceptable control costs if the regulator is misinformed about the magnitude of actual marginal control costs. Another advantage of a pollution tax over a standard under these assumptions is that a tax provides a continuing incentive to polluters to reduce emissions if cost effective means are available, no matter how low they are already. This may stimulate technical change in abatement methods.

On the other hand, while pollution taxes may involve substantial expenditures on monitoring and enforcement, these may be significantly lower for standards if they are imposed by the device of mandated technologies (e.g., a "best available abatement technology" policy). Another disadvantage of a pollution tax is that the level of environmental quality attained cannot be chosen in advance, as it results from the decentralized actions of numerous (and diverse) agents. To achieve a given level of aggregate emissions, tinkering with the pollution tax rate over time may be necessary. However, if an initial level of pollution tax leads to investments in abatement, the costs of adjustment in response to a change in tax rate may be high.

An alternative to pollution taxes that is sometimes suggested is a subsidy to reduce pollution. The argument goes that resource allocation, including the emissions of pollutants, does not depend on the assignment of environmental property rights (i.e., whether agents are taxed or rewarded for abatements does not affect the outcomes, except for the distribution of incomes). Typically such subsidies take the form of payment, at least in part, of the costs of pollution control. Three major problems arise in this approach. First, it is difficult to establish benchmarks for emissions levels (reduction below which will merit lump sum subsidy payments) for each agent without creating incentives for them to misrepresent their actual emissions levels. Second, a subsidy may bias the choice of abatement technology. For example, if capital costs are subsidized, but operating costs are not, capital intensive control methods may be adopted even if they are not efficient (economic). Third, because the subsidy payments can impact agents' profits, while each existing polluter may reduce emissions, an incentive is created to other agents to enter the polluting activity, and in the long-run, the aggregate level of pollution will tend to increase.

In addition, tradeable permits have been proposed by economists as a means of achieving aggregate pollution emissions levels at potentially lower costs than standards imposed on each polluter. Further, tradeable permits also eliminate uncertainty about aggregate emissions levels (or ambient quality, if so desired). However, the monitoring and enforcement costs of tradeable permits may be higher than for pollution tax, because of the need to keep track of trades in permits after the initial assignments. Additional administrative costs may be incurred in operating a scheme for the initial assignments. In the theoretical analysis of tradeable permits, it is assumed that once assigned, a competitive market operates among agents owning these permits.

Two principal ways of assigning these permits are as follows. First, the permits may be distributed among agents on the basis of a political determination of entitlements. In this case, unequal political power of agents may result in "inequitious" distributions of these rights among agents. Second, they may be auctioned by the regulator. In the latter case, if some agents are "large", they may form (buyers' and sellers') cartels and the outcome may differ from that which would be realized if the bidding were perfectly competitive.

A widely shared view among economists is that which of these instruments accomplishes a desired level of control at least cost, including monitoring and enforcement costs, is essentially an empirical one. The following subsection briefly surveys the experience so far with the actual operation of incentive based environmental regulatory instruments at the level of national (and subnational) economies:

5.2. Actual Experience with Environmental Regulatory Instruments:

Pollution taxes (emissions charges), and other similar fee based systems have been operated in Europe, Japan, and the U.S., for at least two decades. These include effluent charges on water pollutants (France, Italy, Germany, Netherlands and U.S.), air pollution charges (France and Japan), taxes on polluting vehicles (Sweden), and on hazardous solid waste (U.S.). Some insights which may bear generalization are as follows:

(1) Charges have been typically designed to raise revenue, rather than to achieve efficient levels of pollution control, or even minimize costs of achieving given environmental standards. The level of improvements appear to be positively related to the level of charges. However, the impacts are low when the revenues are returned to the polluters.

(2) Typically the revenues from charges are used for specific environmental purposes, rather than for reducing reliance on conventional taxes (which may involve greater distortions in resource allocation than pollution taxes).

(3) Where charges have been successful, they have been introduced gradually and increased over time (at rates exceeding the inflation rate).

Tradeable permits schemes have not yet been employed as widely as pollution taxes. Three examples are from the U.S., i.e., trading emissions rights under the Clean Air Act, trading of lead in gasoline, and control of water pollution in a river. A fourth example involves air pollution trading in Germany (for which only very limited information is available). Once again, some insights which might be relevant in other contexts, are as follows:

(1) The market structure and the behavioral norms of the regulated agents are important. In the case of the Wisconsin Fox River, the disappointing results of a scheme of trading discharge permits are traced to (at least) two reasons. First, several of the polluters (pulp and paper plants) are oligopolistic, and may not behave as competitive firms in the permits market. Second, another set of polluters are municipal waste plants subject to public utility regulation, and perhaps insensitive to market incentives.

(2) Where a trading scheme has resulted in large numbers of trades (e.g., as allowed under the "netting" component of the emissions trading program of the U.S. Clean Air Act), significant cost reductions in compliance have resulted (exceeding $ 10 billion in accumulated capital savings under all components of the program). Further, while environmental quality has certainly improved under the scheme, since the emissions trading program is additional to, and not in replacement of the traditional command and control regulatory approach, it is not possible to say how much of the improvement is attributable to the emissions trading scheme.

(3) Effective monitoring and widespread agreement on environmental objectives are important for the success of tradeable permits schemes. This appears to be the case with the lead trading program among refineries in the U.S., which also conforms closely to the notion of a competitive market in permits.

In the next subsection we identify some implications of the above discussion for the choice of multilateral and national level policy instruments for regulation of GHGs emissions.

5.3. Choice of Policy Instruments for GHGs Regulation:

Multilateral level policy instruments which have been suggested for regulation of GHGs

emissions by different countries or regions include variants of standards ("commitments on sources"), as well of pollution taxes ("carbon taxes"), and tradeable permits. While there has been some debate, both in
policy forums as well as in the academic literature, on instrument choice, the question of monitoring and enforcement (M&E) mechanisms has received comparatively little attention. This omission is surprising, both because regulatory schemes are critically dependent on effective M&E, and because the M&E costs of different regulatory strategies may vary widely, impacting the choice of policy instruments.

In the multilateral arena, several political considerations, for example, national sovereignty, may dominate strictly economic criteria (i.e., costs or efficiency), in the choice of regulatory schemes. In addition, the choice of policy instruments may have important distributive (or equity) implications both across and within the regulated agents (countries or regions). Thus, for example, considerations of national sovereignty may preclude the use of emissions standards based on technologies mandated by external authorities. Considerations of sovereignty would also dictate that the choice of domestic regulatory instruments, in fulfilment of multilateral obligations, must be left to national policy makers. However, the feasibility of effective national level regulation would constitute an input into the fixing of multilateral obligations. Equity issues within regulated entities (countries) may, for example, involve changes in relative factor rewards (i.e., interest rates, wage levels, and land rentals), impacting the incomes of different social classes.

If one assumes that any scheme of multilateral regulation of GHGs will be focused on sovereign States, the first question which arises in the context of instrument choice is whether the standard theoretical results would continue to hold in the multilateral context. In particular, we need to enquire whether the assumption of cost minimization by firms has a clearly identifiable counterpart in the case of States. Further, when considering international tradeable permits, whether there is good reason to believe that the resulting permits markets would be competitive.

In attempting to answer the first question we initially proceed in a normative, rather than a positive manner: The minimization of (domestic resource) costs of compliance with a multilateral regulatory regime would result in a gain in efficiency. Public authorities of States "should" however, seek to maximize societal welfare, which has components of both efficiency and distribution across societal classes. Characteristically, policy choices involve tradeoffs between efficiency and distribution. For this reason, gains in economic efficiency may not be unambiguously desirable. Because different (multilateral) regulatory approaches may have varying impacts on efficiency and distribution, it follows that quite rationally, policy makers may not display cost minimizing responses to multilateral regulation. Switching to a positive approach, we note that a sizable literature on the theory of public choice suggests that the maximization of a societal welfare function may conflict with the incentive structure of public officials, and for that reason, is unlikely to occur.

The second question, i.e., whether we may expect an international tradeable permits market to be competitive, may be answered intuitively by looking at the existing distribution of resources across countries. The facts of vast disparities in the wealth of nations, concentration of wealth in a relatively small number of nations, and great heterogeneity and political differences among a much larger number of poor nations, would suggest that formation of emissions permits cartels by rich nations would be easy. No effective device can be visualized to counter this reality.

The limited experience with operating market based regulatory schemes (discussed above) suggest that deviations from the assumptions on which the theoretical results are based would tend to make these instruments ineffective. Two key theoretical assumptions indeed seem to be violated in the case of market based multilateral instruments. Further, as we have seen, in the case of emissions standards, the option of basing them on mandated technologies, which may reduce M&E costs in their case, may violate notions of national sovereignty. Having said this, one may recognize one advantage of international carbon taxes and (auctioned) tradeable permits over several alternative schemes. These instruments may yield significant net revenues to the multilateral regulatory agency, which may be important in devising practical schemes for financial transfers to developing countries, as may be mandated by a determination of the equity question.

Any multilateral GHGs regulatory regime focused on sovereign States has to be translated by national public authorities to a domestic regulatory framework for domestic emitters, designed to ensure national level compliance with the multilateral responsibilities. In the case of developing countries generally, an important consideration is that a major part of economic activity is in the "unorganized" sector, with little possibility of access by regulatory instruments, including market based instruments. This is because such activity is typically tiny in scale, widely dispersed, and may have little market nexus. It would be unrealistic, accordingly, to subject developing countries to stringent application of multilateral regulatory instruments, and at least in the near term, expect that they would be effective.

Energy is a ubiquitous input in all economic activity, and different energy sources are (partly) substitutable with each other, and in the aggregate are substitutes (or complements) for other inputs to production, i.e., capital, labor, land, and materials. Accordingly, the effects of any domestic policy instrument impacting GHGs emissions through inducing changes in energy use, applied to a single sector (e.g., electricity generation), or a category of economic agents (e.g., consumers) carry over, through changes in relative prices and factor rewards to all aspects of the economy. These include changes in patterns of production, trade, aggregate income and its distribution, consumer welfare, government revenues and expenditures, inflation, savings and investment, and the external balance of payments. Further, global regulation of GHGs may be expected to alter comparative advantage across nations, and relative prices of tradeables, besides financial and investment flows.

It is not likely that all these diverse impacts of GHGs regulation can be predicted intuitively. Some insights may be gained through formal economic modelling techniques. While several limited modelling efforts have indeed been made, we are still far away from an adequate understanding of the impacts of global and national level regulation of GHGs emissions. Clearly there is need for further research on the question of instrument choice in the multilateral and domestic GHGs regulatory context. Given the present state of knowledge, one would hesitate to unreservedly recommend any particular regulatory arrangement for adoption in the near term.

6. Structuring the Equity Issue:

The key to an eventual international instrument for regulation of Climate Change is the issue of equity or fairness. Equity is involved not only in the distribution of possible benefits of control, but also, importantly, in the costs of abatement responsibilities. A gestalt view of the latter aspect is that since a Protocol would have to limit global emissions, and also apportion entitlements to emissions (or the share of net revenues that might be yielded by the use of international regulatory instruments, such as carbon taxes or tradeable permits), real resource transfers are involved in such schemes. Further, since the sharing of burdens, entitlements, and benefits would occur not only among countries or regions, but also across human generations, equity in the context of Climate Change has both spatial and temporal dimensions. The issue is complex, and in this paper we do not attempt anything more than providing an outline of a framework for analysis of the problem.

Notions of fairness are deeply intertwined with the idea of "equality." The term 'equality' is used in different senses. It may refer to "equality before the law", i.e., equality of treatment by authorities. Alternatively, it may refer to "equality of opportunity", i.e., equality of chances in an economic system. A third meaning is "equality of result", i.e., equal distribution of goods or productive resources. Coleman (1987) seeks to distinguish between these different meanings in the following manner:

Suppose that a system consists of:

(a) a set of positions which have two properties:

(i) when occupied by persons, they generate activities producing valued goods and services;

(ii) the persons in these positions are rewarded for these activities, both materially and symbolically;

(b) a set of adults who occupy positions;

(c) children of these adults;

(d) a set of normative or legal constraints on certain actions.

Equality under law concerns (b), (c), and (d): i.e., the normative or legal constraints on actions depend only on the nature of the action, and not on the identity of the actor. That is, the law treats persons in similar positions similarly. Equality of opportunity concerns (a), (b), and (c), i.e., that the process through which persons come to occupy positions give an equal chance to all. Ordinarily this means that a child's opportunities to occupy one of the positions (a) does not depend on which particular adults from set (b) are her parents. Finally, equality of result has to do with (a ii), i.e., the rewards given to the position occupied by each person are the same, independent of the activity. These three concepts can also be seen as involving different relations of the "State" to inequalities that exist, or arise in society. Equality before the law means that laws do not recognize distinctions between persons that are irrelevant to the activities of the positions they occupy, but that otherwise policies do not attempt to eliminate inequalities as they arise. Equality of opportunity means that the State intervenes to ensure that inequalities do not cross generations. Equality of result implies that the State periodically or continuously intervenes to ensure that inequalities arising from activities are not accumulated.

In applying these concepts to Climate Change, the first key question is that of the "identification of agents". Ordinary notions of equity involve fairness among human individuals as agents, although often phrased in terms of equity between different groups, or classes. An intuitively appealing notion of "agent" in the Climate Change context would be human beings, irrespective of where or when they happen to live. Alternative notions of 'agent', for example, countries, regions, or defined communities are unappealing, if for no other reason than that they are susceptible to fundamental change in character and composition in the time frame of Climate Change. In that case, (i.e., with agents as individuals as defined above), sovereign States may assume the role of trustees with respect to their citizens in the matter of equity in Climate Change, and an attribute of sovereignty would be that such a claim of trusteeship is not open to challenge.

In the context of multilateral regulation of Climate Change, given that this definition of 'agents' is accepted, how may we identify the other elements of the system described above? 'Legal constraints on actions' may be interpreted as limitations on GHGs emissions. Further, the 'set of positions' would include various occupations (consumption) resulting in GHGs emissions and resulting in economic reward (utility), no matter where or when located. Finally, 'children', would, at any given generation, mean the members of the succeeding generations.

What would 'equality under the law' imply, given these definitions? Since under this principle, no note must be taken of distinctions which are irrelevant to the activities of the agents, a multilateral regulatory framework cannot distinguish between individuals on the basis of nationality, temporal generation, or other attributes, such as race, religion, or colour. Equality under law is generally considered the weakest equity principle, to which even an minimalist State may be expected to adhere, and almost coincident with the notion of "rule of law." It would be difficult to argue against following this principle, in any multilateral context, including of course, Climate Change.

What of 'equality of opportunity'? This principle requires that inequalities (in wealth, welfare) arising from differential levels of GHGs emissions by agents do not carry over across generations. Specifically, at a minimum this principle would seem to require that the access to GHGs emissions cannot be hereditary, (ruling out "Grandfathering" as a basis for emissions entitlements), and that the incremental wealth accruing to individuals from higher, unentitled GHGs emissions by them, cannot be bequeathed to their offspring. This principle furnishes the basis for the assertion that societies with higher historical per-capita emissions, should compensate societies with lower past per-capita emissions. Ensuring equality of opportunity is a central concern of the welfare State, and (to varying degrees) is sought to be realized in all but avowed legally minimalist States. Little support may be found in international public documents, or current instruments, for abrogating this principle.

Finally, 'equality of result'. Different ethical schools have evolved to address this question, albeit in the context of distribution of the national income between different social classes or groups. In the Climate Change context, this principle should be interpreted as equal per-capita rights to GHGs emissions (which may be voluntarily transferable) across all
agents.

Several philosophical positions take equality of result as 'natural', in the sense that while it needs no justification, deviations from the principle would require it. Rawls (1971), accordingly seeks to address the question: "When can inequalities of result be justified?" The answer, summarized in a sentence, is that "only those inequalities are just, which would make the least well off person in society better off than that person would be, (given ceterus-paribus and that basic human rights are equally assigned to all), in the absence of the inequalities." Rawls' theory of justice would thus cast a strong onus on advocates of differential per-capita GHGs emissions entitlements to demonstrate that any scheme of unequal entitlements would be of greater benefit to the poorest of mankind, than equal entitlements.

Traditional welfare economics based on Utilitarianism, would support the idea of equality of result in income, since declining marginal utility of income would mean that social welfare, an aggregation of individual utilities (cardinal, inter-personally comparable), is maximized when incomes are equal (Pigou, 1932). A progressive per-capita distribution of GHGs emission rights (i.e., emissions rights for the poor are higher than for the rich) might have the effect of equalizing incomes, and thereby, increasing global social welfare. Of course, the underlying assumptions for existence of such a social welfare function are strong. However, there is another objection to the Pigouvian result. That is, if individual welfare is inter-dependent, or in other words, if one person's activities benefit or harm others, even if such external effects are unintended, maximization of social welfare over time would require such external effects to be taken into account. This would mean an allocation of resources (emissions rights) to persons in line with the value of these external effects, justifying some inequalities. Of course, the application of this principle must be comprehensive, i.e., all external contributions of all persons over all time must be accounted for, and it is difficult to see that practical ways of implementing this principle can be devised.

Libertarianism (Nozick, 1973) points out that a preferred (say, equal) societal distribution of resources at one point in time will lead, by the very process by which persons pursue their own welfare, to less preferred (unequal) distributions at later times.

The three ways to prevent this, i.e., preventing economic exchange, or banning economic activities which lead to inequality, or progressive taxation, can each be shown, in the limit, to reduce societal welfare. In other words, continuous interventions by the State to restore the preferred resource distribution may lead to reduction in societal welfare. The Libertarian premise is thus, that interventions by public authorities to promote equality of result cannot increase societal welfare and is thus unjustified. Nozick further asserts that distribution of resources cannot be seen in isolation from the process by which wealth is created. "Whomever makes something, having bought or contracted for all other held resources used in the process (transferring some of his holdings for these cooperating factors), is entitled to it. The situation is not one of somethings getting made, and there being an open question of who is to get it. Things come into the world already attached to people having entitlements over them."

This "historical entitlement theory" would seem, as applied to goods which come into being with pre-existing claims to them, arising for example, from initial property rights over the factors of production, or from the application of one's skill, to deny that equal rights to these goods is natural. However, this would not be the case with resources which are virginal in nature, and Nozick has difficulty in specifying which of several possible methods, for example, through labour, first occupancy, possession, declaration, or some other historical means is appropriate. Steiner (1977) has pointed out that since the process of acquisition of natural resources (which would clearly include environmental resources) creates nothing new, but involves the extraction of pre-existent resources from nature, differential entitlements to virginal resources should be proscribed by the Libertarian. Moreover, the equal right to liberty to which Nozick (apparently) subscribes should imply an initial equal distribution of natural resources. It is thus possible, even from the premises of Libertarianism, to derive the principle of equal per-capita rights to GHGs emissions.

Developing countries assert that their levels of past, current, and (foreseeable) future per-capita GHGs emissions would not aggregatively induce Climate Change. On the other hand, just continuing with the past rates of emissions of industrialized States suffice to ensure increasing concentrations of GHGs in the atmosphere. Further, because of the apparent close linkages between economic growth and GHGs emissions, developing countries cannot accept any commitment with regard to their emissions levels in the foreseeable future. In addition, equity principles, as argued above, would justify compensatory transfers to them for the historically high levels of emissions by industrialized countries, besides equal per-capita emissions entitlements in the future.

The arguments of the developing countries cannot easily be dismissed, even if one urges that in their own self-interest, because of likely adverse environmental impacts, developing countries should eschew GHGs intensive growth paths. However, a determination of the equity issues in Climate Change before the current multilateral efforts to finalize a Framework Convention for regulating Climate Change are concluded, is unlikely. Two possible operative aspects of such a Framework Convention are commitments by industrialized countries to stabilize and then reduce GHGs emissions, within a specified time-frame, and second, financial flows to developing countries to adopt strategies to reduce future growth of GHGs emissions by them. The first aspect is unexceptionable from the point of view of developing countries, as long as similar commitments are not sought from developing countries before a determination of equity principles. Regarding the second, two considerations are important. One, that such flows must be additional to, and not competitive with, normal aid flows for growth. Second, that financial (and technology) flows, without an equity determination (when these might accrue as of right), must be considered as paternalistic, and no obligation can be cast on anyone to accept such transfers. Accordingly, it would be inappropriate to prescribe binding norms for such financial or technology transfers, and it should be open to individual developing countries to state the conditions under which they would accept such transfers.

Concluding comment:

The past two decades have witnessed a tremendous surge in public concern with the environment. Over time, attention has moved from local environmental quality issues impacting health, recreational amenities, and aesthetics, to global issues which involve the life-support systems of mankind and other living species.

The discipline of economics had, in the earlier phases of environmental awareness, an ambivalent relationship with the policy making process. One view which had some currency earlier, is that economics can contribute little to the resolution of natural resource depletion and environmental quality. This is because the origins of the problems are to be traced in the insensitivity of economic systems to these concerns. Economics was seen as guiding these systems, and the discipline was urged to undergo fundamental restructuring if environmental concerns were to be incorporated into economic policy.

While little paradigm shift occurred in economics in response to this criticism, economists did seek to develop a body of theorems, models and concepts for analysis of resource and environmental issues. Important insights were obtained regarding patterns of depletion or pollution emissions under different market and institutional arrangements. The role of identifying the incentives faced by agents, and their likely responses to these incentives, was identified as a crucial input in designing regulatory policy. Novel policy instruments were devised and to an increasing extent, employed in regulatory frameworks. Policy analysts gradually accepted that economics can indeed furnish useful insights in devising environmental policy.

One conclusion is however, inescapable from the present survey. That is, the challenges of global policy analysis for Climate Change will require a significant sharpening of existing analytical tools of economics. These challenges arise from the very long time frame, extending to the past as well as the future, besides the pervasive uncertainties, both scientific, as well as relating to economic and social impacts, involved in the Climate Change issue. While the basic approach of the discipline, i.e., a behavioral assumption that agents maximize some objective subject to their perceived constraints, remains valid, the global environmental arena calls into question many of the existing formulations of this theme. It is not easy to furnish a listing of the areas where advances of a rather fundamental nature will be required, suffice it to say that they will be over a very broad range, including both positive and normative aspects. It is also clear that the evolving discipline of environmental economics will have to establish deeper linkages with the theory of social choice, formal ethics, and positive political theory.

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GLOBAL WARMING:
IMPACTS AND IMPLICATIONS
FOR SOUTH ASIA

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Abstract

The paper reviews the political and economic situation in South Asia, with emphasis on likely economic changes in the 1990s. The range of climatic changes that are likely to take place on the South Asian sub-continent are discussed on the basis of projections made by the Intergovernmental Panel on Climate Change. The impact of these likely changes in climate are evaluated with respect to agriculture, forestry, biological diversity, water resources and human health and social impacts. The problem of sea level rise and its implications for South Asia are also discussed, since these are likely to have disastrous implications for countries of the region. The special implications of global warming in the Ganga River basin are explored, culminating with a discussion on the imperatives of international cooperation among countries of the region to successfully face the collective threat of global warming. The paper indicates that with the difficult economic situation facing this region, international assistance from outside the region and close cooperation between the countries within the region would be the only effective strategy for the future.

1. THE DEVELOPMENT SCENE

The South Asian sub-continent provides a unique range of political, social, economic, geographic and ecological conditions in the context of which the complex impacts and implications of global warming assume a significant dimension. For instance, if one considers diversity of climate, the countries of the region include areas which experience cold, sub-zero temperatures perennially, deserts which attain high temperatures matching the hottest regions of the world, and precipitation levels which are the highest anywhere on the globe. Further, apart from the highest mountain peaks on the globe this region also has some of the lowest islands inhabited by man, which rise barely a metre above the sea that surrounds them. In economic terms, South Asia is a poor region, but it does have centres of significant industrial activity, a science and technology infrastructure which compares, in some cases, with the best and yet a large population which ekes out a living at bare subsistence level from land which is degraded and which, in several areas, is slipping gradually from the marginal category into the uncultivable condition. In several respects, therefore, not only is South Asia a varied and rich microcosm of regions that would experience the full range of impacts that global warming would have on different parts of the globe, but it also provides a cross-section of capabilities and human capacities for coping with or adapting to these impacts.

There is, as yet, relatively meagre research in South Asia on the impacts and implications of global warming. Indeed, the first major event to focus attention on this subject in South Asia was the International Conference on Global Warming and Climate Change: Perspectives from Developing Countries, which was held in New Delhi in February 1989. This Conference, the proceedings (2) of which are an important contribution to the literature in this field, in general, was attended by outstanding scientists and researchers from all over the world, including those from the countries of South Asia, and led to several policy initiatives on the subject, at least, within the Government of India. Several research projects have also been launched subsequently to study both the likely impacts of global warming in the region as well as possible responses that, at least, some of the countries of South Asia can develop and implement. But knowledge in this field specific to the countries in the region remains scant and imperfect, and this publication, is, therefore, based on extensive analogies drawn from other parts of the world. To unfold a backdrop of likely demographic and economic developments against which the effects of global warming would have to be evaluated, we first review briefly the economic scenario pertaining to South Asia in the coming decades.

A major departure in the thinking of multilateral development organisations has been initiated recently in the UNDP publication on human development (8) and the most recent World Development Report of the World Bank (10). The UNDP report makes a pertinent point while stating "Life does not begin at $11,000, the average per capita income in the industrial world". The report establishes and reiterates the possibility and importance of human development independent (and in support) of efforts to improve material standards of living. The World Bank report of 1990, quoted above, also makes this point in a somewhat different way, emphasizing the importance of poverty removal, which requires provision of adequate social services such as for health, education and family planning. Human development and the elimination of poverty are critical not only for minimizing the impacts of global warming on human activities and actions but also for ensuring that abatement measures and adaptive responses can be launched to the full potential of the human capacity that should be developed in the region. To this end, the prognosis for South Asia as a whole does not appear heartening. This is conveyed by the projections made in Tables 1 and 2. While these projections portend a substantial decline in undesirable indicators such as illiteracy and child mortality as well as a major dent on the absolute poverty that exists in South Asia, this region would still remain weak and deficient in infrastructure to deal with crises and adverse impacts that may have to be faced as a result of global warming. The decade of the 1990s is, therefore, crucial for the people of South Asia, and much would depend on whether the tempo of economic growth of the 1980s can be maintained or improved on and whether the countries of the region would make a greater commitment to the provision and widespread supply of a package of social services, so that a safety net can be woven around the most populous and widespread communities, whose vulnerabilities to crises would be the highest. There is a danger, as the World Bank points out, that the number of the poor in Bangladesh would increase, which as we would discuss later, would be a particularly vulnerable part of the sub-continent.

Table 1

Social indicators, by developing region 1985 and 2000

	Net primary enrollment ratio		Under 5 mortality	
Region	1985	2000	1985	2000
Sub-Saharan Africa	56	86	185	136
East Asia	96	100	54	31
China	93	95	44	25
South Asia	74	88	150	98
India	81	96	148	94
Eastern Europe	90	92	25	16
Middle East and North Africa	75	94	119	71
Latin America and the Caribbean	92	100	75	52
Total	84	91	102	67

Source: World Development Report 1990

Table 2
Poverty in 2000, by developing region

Region	Incidence of poverty 1985	Incidence of poverty 2000	Number of poor (millions) 1985	Number of poor (millions) 2000
Sub-Saharan Africa	46.8	43.1	180	265
East Asia	20.4	4.0	280	70
China	20.0	2.9	210	35
South Asia	50.9	26.0	525	365
India	55.0	25.4	420	255
Eastern Europe	7.8	7.9	5	5
Middle East North Africa and other Europe	31.0	22.6	60	60
Latin America and the Caribbean	19.1	11.4	75	60
Total	32.7	18.0	1125	825

Source: World Development Report 1990

2. GLOBAL WARMING

The Intergovernmental Panel on Climate Change (IPCC) set up three working groups to go into the major subjects related to global warming and climate change. Working Group I dealt with the scientific assessment of climate change and estimated the extent of warming that is likely to take place upto the year 2100. Under the IPCC business as usual scenario (3) of greenhouse gas (GHG) emissions, the average global mean temperature increase during the next century is likely to be about 0.3°C per decade, with an uncertainty range of 0.2°C to 0.5°C. Consequently, the likely increase in global mean temperature would be 1°C above present levels by 2025, which would be about 2°C above temperatures during the pre-industrial period, and then rising to about 3°C above present levels before the end of the next century. The IPCC report gives values of global temperatures for high, low and best estimates. It needs to be explained that these estimates depict temperatures actually realised and do not include that component of temperature rise to which the earth may be committed, and which would be realised only after a time lag.

In respect of South Asia the IPCC business as usual scenario indicates warming of 1 to 2°C in 2030 over the pre-industrial period. Precipitation is predicted to increase 5 to 15% in the summer, but would change very little in the winter, throughout the region. The moisture in the soil during summer is projected to increase by 5 to 10%. There are, of course, various uncertainties associated with these projections and scientific doubts regarding their validity are widespread, but for the purpose of assessing likely impacts of global warming these magnitudes should be quite acceptable. The general circulation models (GCMs) on which predictions of climate change are based, unfortunately, have not attained a high degree of reliability with respect to regional climatic effects, but there is a general convergence in their results pointing to some conclusions which are of relevance to South Asia:

(1) In general, a warmer globe will also be wetter and more humid, particularly in tropical regions.

(2) Resulting from global changes in the climate, sea level is likely to increase, along with an increase in the temperatures of the oceans.

(3) Tropical regions are likely to suffer from increased risk of storm tides, because of the high frequency of tropical cyclones.

We would evaluate the implications of these possible changes later in these pages, but it would be useful first to assess the human dimensions of likely impacts that may occur in the region as a result of global warming and to quantify the number of human beings who would be affected by climate change. Population changes in the South Asian sub-continent are projected on the basis of World Bank estimates as shown in Table 3.

Table 3

Projections of population in countries of South Asia (thousands)

	1985 (Estimated)	1990	2000	2025
Bangladesh	101147	114783	146603	212672
Bhutan	1362	1516	1891	2831
India	769183	847925	1010954	1292640
Maldives	183	212	268	359
Nepal	16915	19037	23223	31126
Pakistan	103241	120701	153307	230257
Sri Lanka	16108	17162	19011	21859
	1008139			1791744
World Total	4853848			8466516
South Asia World Total (%)	22.77%			21.16%

Source: World Bank estimates

In essence, we would be dealing with over one fifth of humanity when we assess the impacts of global warming in South Asia. Some of the impacts which we would discuss may also have implications for movement of people across international boundaries in the region, and the dimensions of this problem can be assessed on the basis of the populations projected for the countries of the region. In particular, population increases in Bangladesh, Nepal and Pakistan are not only projected to be higher than the average for the region, but constraints in the availability of good land for cultivation and human habitats would make these societies particularly vulnerable to climate change and associated effects on agriculture and forestry.

3. EFFECTS OF GLOBAL WARMING

3.1 Agriculture

The countries of South Asia have a high dependence on agricultural activities. Table 4 shows the value added in agricultural production as well as GDP for the countries of South Asia in 1988.

Table 4

	Production (in Millions of dollars)		Share of agriculture in GDP (%)
	GDP	Value added in agriculture	
Bangladesh	19,320	8,882	46
Bhutan	300	130	44
Nepal	2,860	1,601	56
India	237,930	76,618	32
Maldives			
Pakistan	34,050	8,935	26
Sri Lanka	6,400	1,685	26

Source: World Development Report, 1990.

From these figures it is clear that the economic well-being of the countries of South Asia is highly vulnerable to changes in climate, the impacts of which on agriculture can be discussed in the following manner.

3.1.1 Effect of carbon dioxide - Several studies, as yet inconclusive, suggest that the responses of agricultural plants to higher levels of CO_2 concentration in the atmosphere vary in accordance with their being in the C_3 group, i.e. wheat, rice, legumes, oilseeds, cotton or the C_4 group consisting of sugarcane, sorghum or maize. The C_3 grouping shows higher CO_2 assimilation, growth and yield in response to higher CO_2 concentration than the C_4 crops. One preliminary survey indicates that CO_2 enrichment caused a 26% increase in economic yield of mature crops and 40% by dry weight of immature shoot. In general, C_3 crops showed a mean increase of 36%. At the same time, both C_3 and C_4 crops showed a decrease of 34% or more in transpiration with doubling of CO_2 concentration. This could lead to a net decrease in water requirements.

3.1.2 Effect of temperature - Some work on assessing the effect of temperature on rice yields indicates that increases in temperature result in a reduced growing season and a decline in productivity. There appears to be an increasing consensus among scientists that temperature increases would lead to lower yields in wheat and rice.

3.1.3 Effects of increased CO_2 and temperature and reduced water - Some simulations using computer models for crops have been undertaken recently to study the effects of changes in all these three sets of variables. The indications from these studies are that increased temperatures would have a much higher impact in the higher latitudes, particularly under conditions of dryland farming, but under irrigated conditions the variation would be minor. It also appears that increased CO_2 concentration would compensate for any yield decreases caused by higher temperature, particularly in the case of maize.

3.2 Forestry

While research on the impacts of global warming on agriculture in South Asia has been meagre, the assessment of the impacts on forestry has been more or less non-existent. Yet, perhaps forestry activity is far more critical to the eco-systems and human activities of South Asia than any other sector. Since region-specific analysis of this problem has not been carried out, all we can do is to fall back on research carried out elsewhere and then draw analogies between forests in other parts of the world and those in South Asia. The report of the US EPA to Congress (7) is perhaps the most comprehensive assessment of the impact of global warming on forests, and some of the assessments and conclusions contained in that report are of relevance to the situation in South Asia. Figure 1 provides an indication of the spread and distribution of different types of forests that exist in South Asia. In essence, the variability of climate in different parts of the subcontinent is such that we find in this region forests of every variety that occur in this figure, with a large predominance of deciduous forests. Hence, in assessing the

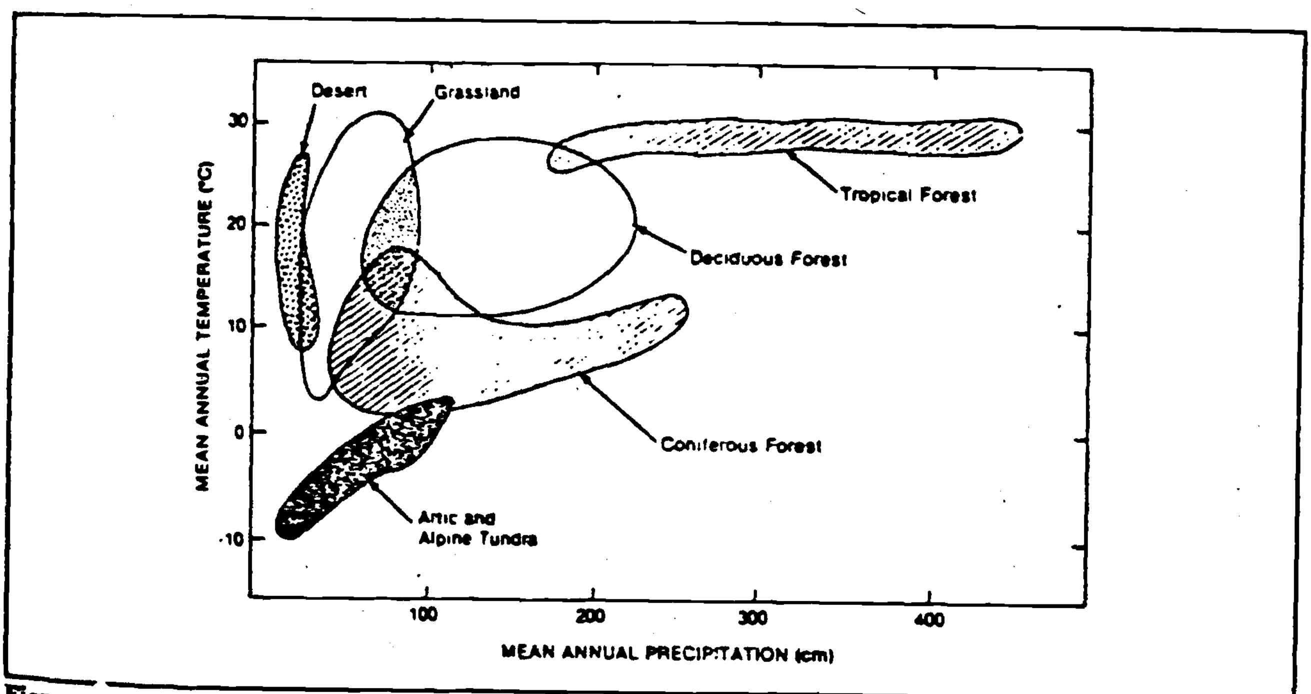

Figure - 1 Approximate distributions of the major groups of world biomass based upon mean annual temperatures and precipitation (Hammond, 1972).

impacts of global warming we would necessarily have to research into the specific impacts in each of the different agro-climatic regions in South Asia and derive implications for forestry activity accordingly.

Firstly, it must be understood that vegetation has been in a regular state of change and adjustment due to changes in climate over the past 10,000 years as well as over the past several hundred years. Added to this has been the effect of geological changes that have taken place over time. For instance, the Aravalli range of hills surrounding Delhi and spreading into the north-western part of India were at some stage a much higher mountain range, but through geological changes have diminished considerably in altitude. Consequently, much of the original vegetation has vanished, with just a few scattered trees of rare species surviving at the existing lower altitudes. The biological diversity of forestry stock in South Asia is generally on the decline as a result of various changes.

In general, forests in South Asia, as in other parts of the world, are sensitive to variations in temperature and precipitation. Within a certain temperature range, an increase would promote rapid growth of trees, but once the range of tolerence is exceeded, excessive warming can result in a reduction of growth and the destruction of plants. Similarly with rainfall; too much or too little precipitation can limit forest production and survival. An excess of rainfall can result in flooding or increase of the water table whereby roots can be drowned and oxygen intake denied for their survival. A reduction in rainfall can reduce growth and increase vulnerability to fire or pests that lead to their mortality. Higher CO_2 concentration levels could increase the growth rate of tree species with increased photosynthesis and higher efficiency of water use. This is particularly true of hardwood species. But most of the experimentation on this subject has been carried out in growth chambers, and, therefore, extrapolation to real world conditions is not always valid. A higher rate of CO_2 intake and forest growth could, to some extent, act as a balancing force, enhancing the ability of the forests to act as a carbon dioxide sink. Changes in the level of light, which could accompany climate change in the future would also have a direct effect on forests in South Asia. Greater cloud cover would reduce the flow of sunlight and could, therefore, reduce the growth of trees.

Some models have provided outputs indicating changes in forest cover resulting from climate change in North America. But these results are tentative not only in their applicability to North America but far more so in their relevance to other regions. In essence, of course, a change in climate would bring about migration of certain species from regions where they grow currently to other regions which may become climatically more favourable to their growth in the future. For instance, in the United States it has been suggested that in the eastern part of the country species such as spruce, nothern pine and northern hardwoods could move north by about 600 to 700 Kms. Consequently, coniferous forests in New England could be replaced by hardwood forests, particularly oaks. In the south-eastern part of the United States it was indicated that forest lands might get replaced by scrub, savanna or very sparse forest cover. In one of the scenarios that was developed, it was found that forest areas in South Carolina and lower in latitudes would become marginal, with biomass volumes roughly half of those existing currently. Given the fact that a large part of South Asia has very poor forest cover, it is not unlikely that extensive areas might get converted to grasslands and shrub covered marginal terrains. Also, several species of central India could migrate to the sub-Himalayan region and to the Ganga basin of North India. The exact process of migration is difficult to identify at this stage, but it could take place through a variety of possible movements, which could include changes in reproductive processes, such as flowering, pollination, seed setting and germination as well as through an increase in droughts and changes in distribution of rainfall.

The ecological implications of changes in forestry include impacts on animals, soils, water, etc. There would be considerable changes in biomass production, and it is not certain whether even with massive reforestation efforts species might be as productive as existing forests. At the same time, a change in the type and extent of forest cover would impact on the survival of certain types of animals. Animals themselves exert a considerable effect on forest structure as a result of selective browsing of seedlings, insect attack, seed dispersal and other factors. Hence, in effect the delicate balance that exists currently could get disturbed, whereby further changes in the type and pattern of forestry and forest resources could come about.

There would be significant changes in soils resulting from changes in forests. The existence of bacteria, fungi and animals has an important effect on the recomposition of litter and, therefore, the availability of nutrients essential for forest growth. The most important dimension of changes in forestry in South Asia is the effect that these would have on human lives and patterns of livelihood. For instance, large numbers of people in South Asia are dependent on fuelwood for meeting their cooking needs. An estimate of dependence on biomass forms of energy within four countries of South Asia is provided below:

Total Household Biofuels and Total Modern Fuels: Circa 1980

	(1) Population (millions)	(2) Household biofuels (Mtoe)	(3) (Mtwe)	(4) Modern fuels (Mtoe)	(5) Biofuels as % of biofuels + modern fuels (Col.2/(Col.2+Col.4))
Bangladesh	88.5	10.3	(27.3)	3.0	77
India	673.2	71.9	(191.4)	97.3	43
Pakistan	82.2	8.5	(22.6)	12.7	40
Sri Lanka	14.7	2.8	(7.4)	2.0	58

Mtoe: million tonnes oil equivalent (42.6 GJ per toe)
Mtwe: million tonnes wood equivalent (16 GJt^{-1})

Source: Leach (6)

It is evident from this that the already critical problem of fuelwood supply and constrained availability would only get accentuated by changes in forests and the stock of vegetation would reach crisis proportions due to the projected population increases discussed earlier. There are also several other wood products the use of which depends on continuous supplies from forest areas, and these too would suffer substantially as a consequence of global warming.

3.3 Biological Diversity

What is applicable in a limited sense to the balance between forests and the ecology of a region is relevant to a much greater degree in relation to biological diversity as a whole. It is, of course, difficult to arrive at specific predictions about how biological diversity would be affected by changes in climate, but some general directions of change and likely effects can be assessed to provide pointers to the future. Biological diversity would be influenced not only by direct impacts of climatic change but also as a result of indirect influences. For instance, changes in population which may bring about changes in habitat, food availability and predator/prey relationships, could prove far more important than direct effects of climate change. Barriers of various kinds including those made by man, such as roads, townships, mountains, bodies of water, land under agriculture and other elements of habitat could block migration of species due to climate change and thereby multiply the extent of losses. And, of course, rapid climate change would only accelerate the process of destruction of bio-diversity which is taking place as a result of manmade activities such as deforestation and fragmentation of habitats.

Fresh water fish in large bodies of water could increase in productivity as a result of warmer climates in some parts of South Asia, but it is equally likely that some species would actually die. The survival of migratory birds would also vary, with some birds actually benefitting from warming of climates, particularly those that migrate from arctic regions, but others could actually be threatened as a result of sea level rise inundating their wintering grounds or from increased temperature. There is already some indication that several types of butterflies in the Himalayas have become extinct due to warmer temperatures in the opinion of the famous collector F. Smetacck

The importance of maintaining biological diversity can hardly be overemphasized. Bio-diversity has evolved gradually through millions of years in response to climate changes that have taken place slowly over time, but what threatens future developments is the rapid rate of change that is likely to be experienced in South Asia as in some other parts of the world. The greatest concentration of biological diversity is seen in tropical forests, some of which exist in the hot and humid regions of South Asia. It is partly for this reason that the Silent Valley project that became the subject of great debate in India in the early eighties was rejected by the Government of India, since its implementation would have resulted in large scale inundation of rich tropical forests in the state of Kerala.

3.4 Water Resources

A warming climate would have serious implications for the availability of water resources and their use. The South Asian region already has serious problems of water management, with growing scarcities during certain periods of the year in some parts of the subcontinent. There are severe and recurring floods that have tragic effects on the lives of many millions of inhabitants in the region. A warmer and wetter climate could accentuate these effects.

In general, as the climate becomes warmer and drier the demand for water would increase, particularly for irrigation and the production of electric power. Reduced flows of river water, resulting from drier conditions could affect activities like production of hydro power, inland water transport, and aquatic eco-systems. With reduced water availability conflicts among users would only sharpen. These could include conflicts over the use of reservoirs for flood control storage, regulation of flows and water supply as well as control over water rights among agricultural, municipal and industrial users both within and between nations that get affected in South Asia.

Climate change is likely to affect both the supply and demand sides in the water cycle. Higher temperatures, in general, increase the demand for water, even for direct human consumption. With warming climates the extent of evaporation is likely to increase and, therefore, there would be greater precipitation. At the same time, the melting of snows in the northern region, along the Himalayan and Hind Kush mountains would increase. Ground water availability would also change as a result of recharge rates being altered. At the same time, transpiration may not increase correspondingly, because with higher levels of carbon dioxide the pores of plants may shrink. All in all, the most unpredictable effect of climate change is in respect of rainfall patterns and precipitation rates. And yet, this is one set of effects which would have perhaps the most important impact on the lives of the people of South Asia. In particular, the population in the eastern part of India and all of Bangladesh may be affected most seriously, since not only would this region become highly prone to increased flooding and drainage problems but also the timing and extent of monsoon rain would change substantially with serious consequences for agricultural practices and the living patterns of people in the area. Much greater modelling and development of predictive capabilities on precipitation would be necessary before reliable forecasts can be made about the impacts on water resources in the subcontinent.

3.5 Human Health and Social Impacts

The South Asian region has several areas which experience very high temperatures for prolonged periods during the summer. Often a heat wave brings about a sharp rise in mortality particularly among the aged and the very young. Table 5 shows some sample temperatures for the month of June 1989 as an indication of the severe summer heat that the large populations in the countries of South Asia are subjected to. The relationship between mortality and weather has been studied by several researchers, particularly Kutschenreuter (5) and Kalkstein (4). As would be expected they found mortality much higher during cold winters and hot summers and lower during warm winters and cool summers. Considering the fact that a small but significant number of people live at reasonably high altitudes in South Asia, this section of society is likely to benefit from global warming, with a possible reduction in mortality. However, the total number of people that live at altitudes of 4000 ft. above sea level is estimated to be no more than 50 million in all the countries of the region. At the same time, warmer temperatures in the year 2010 would adversely affect over a billion people living in the plains. The hottest conditions on the basis of meteorological data would appear to affect a total of about 250 million people who live in the highest temperature regions of the subcontinent, wherein maximum temperatures can go as high as 45°C.

Table 5

Mean Temperature in Degrees (Centigrade)
on Land Surface (June 1989)

Multan (Pakistan)	34.4
Jacobabad (Pakistan)	36.1
Bikaner (India)	34.8
New Delhi (India)	32.9
Trincomalee (Sri Lanka)	30.1
Kathmandu (Nepal)	23.8

Source: World Meteorological Organisation

An indirect health related impact of global warming could be changes in employment that people would have to adjust to. For instance, several industrial plants, such as steel mills, foundries and forging units generally experience much higher indoor temperatures than the ambient. With global warming, the extent of sickness and productivity decline in some of these industries would adversely affect their competitive positions in the international market. Consequently, it may very well happen that some of these units would actually become non-viable or future expansion as well as relocation may favour lower temperature regions in the subcontinent. Already there is a tendency to locate factories manufacturing electronic goods and watches etc. in mountainous regions, largely because the transportation requirements of some of these units are very small and relatively cold and dust free conditions are an advantage in their location in mountainous areas. The growth of industrial centres like Bangalore, Pune and Hyderabad in India is largely climate related.

Several diseases are directly related to higher temperatures, and it is likely that these would increase as temperatures in the region rise in the future. These include cardiovascular, cerebrovascular and respiratory diseases. The indication is that outside the range of $-5^{o}C$ to $+25^{o}C$ mortality would increase as temperature goes up at the upper end and down below the lower end of the range. Hence high summer temperatures are likely to increase mortality from cardiovascular, cerebrovascular and respiratory diseases in vast areas of the sub-continent far in excess of reductions in mortality in those regions which experience cold temperatures.

There are also several vector-borne diseases that could increase as a result of likely changes in humidity and temperature, which would have an impact on specific plants, animals, insects, bacteria and viruses. Similarly, in the case of mosquitoes, higher temperatures and humidity, and particularly with larger volumes of standing water from higher precipitation, mosquito-borne diseases are likely to increase. Perhaps the most dangerous of these is malaria, which, in any case, has increased in incidence in recent years. Unfortunately, mosquitoes have generally become resistant to several insecticides and sprays which have earlier been used in malaria eradication programmes. The most important social impact of higher temperatures and increased mortality and mobidity lies in the requirements of health care which would multiply particularly for infants and the elderly. Society would have to make provision in the future for a larger infrastructure and level of services to ensure the good health of the newborn and the aged.

3.6 Sea Level Rise

A major cause for concern in South Asia relates to the impacts of global warming on the level of the sea. The danger of sea level rise is dramatised by the threat of total submergence of the Maldive Islands, which has been put forward as a futuristic horror story in several conferences and deliberations. But there are several other parts of the subcontinent which also would face severe dangers in the event of appreciable rise in sea level. The primary effects of rising sea level will be increased coastal flooding, erosion, storm surges and wave activity. In order to assess the likely impacts of sea level rise it would be useful to classify coastal activities in terms of (i) coast dependent such as ports, oil terminals, fish processing, etc.;

(ii) coast preferring such as tourism, coastal residential development, etc.; (iii) coast independent, such as defence, industries not directly linked with the sea, etc. The extent of vulnerability of each of these has to be seen in relation to its linkages with coastal regions. The environmental effects of sea level rise is summarised in the matrix shown in Table 6.

Table 6

Relation Between Environmental Effects from SLR and Coastal Uses

Marine Environmental effects regulating from SLR	Uses Of Coastal Areas	Urban development	Tourism	Ports + Harbours	Power Stations	Comm. Fishing	Mariculture	Agri culture	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 Wetland			X			X	X	X			X	

X - Major impacts
(X) - Minor impacts

While the island nation of Maldives, and other island settlements such as in the Andamans, Lakshadweep and Nicobar islands are particularly vulnerable, the large coastline of the main land mass of South Asia makes coastal settlements and activities a far more serious problem in the event of sea level rise. For instance, India itself has a coastline of about 6000 kms. with about 55% of Indian shores being occupied by beaches. The eastern shore of India is rich in deltas which have been formed by the rivers Ganga, Godavari, Krishna, Mahanadi and Kaveri. These delta regions generally have large deposits of clay and mud and contain vast marshy areas. The eastern coast extending into Bangladesh is particularly vulnerable to tropical storms and coastal flooding. Sea level rise is likely to increase the vulnerability of this region to tropical storms, storm surges and greater inundation. Some of the mangrove forests of this region are likely to be completely decimated.

In terms of adaptative responses, the ability of the region is rather limited. Governments and societies essentially face four possible responses, which are:

(1) No protection
(2) Retreat from the affected areas and relocation of economic and human activity
(3) Construction of some form of structural protection; and
(4) Adaptation to the changed environment and climatic conditions.

Given the uncertainties attached to global warming and its impacts and the extreme poverty of the region, it is unlikely that Governments would make significant commitments of resources to take any action which could provide a suitable response to the anticipated problem of sea level rise. The problem is complex, because the cost, for instance, of holding back the sea would be so high as a share of total expenditure that it would be enormously more burdensome than for the developed countries. Additionally, to initiate action far ahead of adequate information being available would require tying up scarce resources in projects of less immediate and low relevance as compared to the immediate needs of the countries of this region, which are very basic. The countries of the region have dire need for food, clothing, shelter and basic infrastructure, and no government or society is likely to set aside resources for meeting the problem of global warming by ignoring these priorities. Consequently, sea level rise could cause the most serious human disasters in South Asia, unless it is financed and organised through some international action.

4. THE VULNERABILITY OF THE GANGA BASIN

The South Asian subcontinent is densely populated in general, but the most densely populated region is within the basin of the Ganga river. It is within this region that political, ecological and demographic changes would be influenced most seriously by global warming in the future. Based on censuses carried out during 1981, the population of India and the nations of Nepal and Bangladesh have been compiled in Table 7. Existing data indicate that population densities in the range of 301 to more than 600 persons per sq.km. extend throughout this region, and the bulk of the region shows population densities exceeding 401 persons per sq.km. A substantial area in the extreme south-east of the basin extending over West Bengal and parts of Bangladesh has population densities in excess of 600 persons per sq.km. The districts of Hoogly and Howrah which constitute a large part of the Calcutta metropolitan region had district densities of 1129 and 2022 persons per sq.km respectively in 1981. The total area of the Calcutta metropolitan region which is about 104 sq.kms has an average population density of about 32,000 persons per sq.km., which is perhaps one of the highest in the world. Based on current projections tabulated from the UN's population projections, the Ganga basin is expected to have a population of 485 million in the year 2000 and 570 million in the year 2010, which would represent more than a 80% increase over the census estimate of 319 million in 1981.

Table 7:
Population Density in the Ganges Basin, 1981, by countries and Indian States

Country	Total Pop. (,000)	Area (km^2)	Density (No/km^2)	Rural Pop. (,000)	Area (km^2)	Density (No/km^2)	Urban Pop. (,000)	Area (km^2)	Density (No/km^2)
India	283,283	851,390	333	225,867	835,686	270	57,416	15,704	3,656
Nepal	15,023	147,000	102	14,066	ND	-	957	ND	-
Bangladesh	20,945	39,000	537	18,495	ND	-	2,450	ND	-
China (Tibet)	ND	26,000	ND	ND	26,000	NEG	0	0	-
Total Basin	319,251	1,063,390	300	258,428	-	-	-	-	-

Source: Computed by author from UN and World Bank data

The land which is categorised as forest cover is approximately 16% (175,000 sq.kms.) of the total surface area, but a large part of this forest area is highly degraded and sparsely forested. Not only is the Ganga basin vulnerable in terms of its agricultural potential which is already overstretched in parts, but the growth of urban settlements and continuing degradation of land would only affect agricultural output adversely. Intensive forms of agriculture would, therefore, have to replace traditional systems accentuating the demand for water. To this must be added the growing demand for water for direct human consumption. If the demand for water per capita is to remain at 25 litres per day in rural areas and is to increase to 200 litres per capita per day by the year 2010, the total urban and rural demand for water in the year 2010 would translate to a mean annual flow of about 520 cu.m. per second for the basin as a whole. This quantum of water is about the same magnitude that would be required for diversion for a major surface water irrigation scheme. If there is a further increase in temperatures, with warmer and long summers, not only would the demand for water go up on account of increased evaporation, but human consumption itself would increase over the per capita requirements mentioned above, and so would the water requirements increase for the large and growing animal population in the region. Hence, water, which is already a scarce resource and the subject of territorial disputes, would become a bigger bone of contention in the region. Besides, if rainfall increases during the monsoon season there would be further requirements for major river projects for flood control and regulating the flow of water to provide benefits beyond the annual monsoon period. This would require greater understanding and improved institutional mechanisms for resolving riparian disputes and implementing mutually acceptable projects in one country with implications beyond that country. In the absence of a harmonious approach to solving each country's specific water problems, the 700 towns and cities that already exist in the Ganga basin would not even get proper supply of water for drinking purposes in the decades ahead. Even more intractable is the problem of migration from one country to another, which requires understanding and agreements to ensure that tensions are not created unduly by ecological refugees from those areas which are affected adversely by the impacts of global warming.

5. INTERNATIONAL CO-OPERATION WITHIN SOUTH ASIA

The problem of the Ganga basin and likely disputes on the control and use of water are only one area of concern which require cooperation on an unprecedented scale between the countries of the region. The growth in demand for electricity, which is currently at very low per capita levels throughout this region, would require greater trade of energy across international boundaries. For instance, Nepal possesses substantial hydro-electric resources (9) which, if tapped even to the extent of 25% of currently estimated potential, could provide at least 20,000 MW of power with a ready market in India. Unfortunately, several schemes which were identified for implementation through agreement between the two countries have not made much headway because of political suspicions and lack of understanding of pricing and transfer arrangements. Consequently, Nepal has foregone substantial revenues which could have helped alleviate poverty and promoted faster economic development and similarly India has had to forego development opportunities on account of shortages in power supply and losses of economic output as a consequence. The case of natural gas in Bangladesh is also identical. Suitable trade agreements between Bangladesh and India would prove mutually beneficial for both countries involving the sale of natural gas from Bangladesh to India. On the western side of the subcontinent there is an interesting possibility of supply of natural gas from the southern portion of Iran to Pakistan and India by construction of a natural gas pipeline. A preliminary estimate (1) indicates that such a pipeline would cost approximately 12 billion dollars for supply of 100 million cu.m. of gas per day. This supply would be consumed partly in the southern portion of Iran with the balance portion going to Pakistan and India.

While these possibilities would require political understanding and a framework for economic cooperation, which seems almost unthinkable at this stage, there is perhaps considerable scope even at present for cooperation in fields like the development of renewable energy technologies. There are substantial advantages in organisations and institutions in the countries of the region working together on joint R&D projects, whereby technologies for harnessing renewable forms of energy could be developed jointly. Even more relevant would be joint R&D in subjects such as forestry and, the applications of biotechnology to agriculture, so that species can be developed including agricultural crops and trees to withstand drought and saline conditions that are likely to worsen as a result of global warming.

South Asia, due to the vision of the leaders of the region, particularly the late Gen. Zia-ur-Rahman of Bangladesh, has established the South Asian Association for Regional Cooperation (SAARC) which has started functioning as the main instrument for promoting cooperation between the countries of the region. One of the subjects included under the present charter of SAARC is environment, and some minor exchanges have already taken place in sharing of experiences and knowledge on environmental protection between the countries of the region. It would be useful for SAARC to set up a small multi-nation group to go into the possibilities of cooperation in the context of possible global warming. Such a committee could mobilise experts within and outside the region to come up with a blueprint for cooperation, which the leaders of the region could debate and consider for implementation. Despite the political problems that hamper effective economic cooperation within the countries of South Asia, one should not under-estimate the power of analysis of the type proposed, which would only bring out clearly and unambiguously the benefits of cooperation within the region, which, while good in itself for a variety of reasons, acquires even greater value in view of the manmade natural calamities that we are propelling the world and South Asia towards. In essence, the poverty, the over-population, and stagnant economic growth of this region require greater cooperation not only for some of the specific reasons discussed above but also to ensure that the region emerges economically stronger in a short period of time. In the ultimate analysis, the ability of the countries and the people of this region to withstand the impacts of global warming would depend largely on their economic strength. If there is a peace dividend from removal of tensions and the threat of war in other parts of the world, such a dividend in South Asia is a pre-requisite for survival and stability.

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COST OF LIMITING CO_2 EMISSIONS:

WINDFARM AND SMALL HYDRO POWER GENERATION

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Abstract: The role of windfarm and small hydro power generation as a means of reducing CO_2 emissions in India have been discussed. The estimates of the costs and the benefits of these promising technologies have been refined from the earlier attempt (TERI 1990) through use of more accurate costs and estimates of energy output data for small hydro schemes from specific sites. For windfarms, better estimates are presented through the use of recent data on windspeeds for estimating costs and carbon savings. The cost curves for different levels of CO_2 reduction through the use of these technologies have been constructed. Of the two options, the use of wind electric generators in windfarms offers the highest potential for energy paths to lower CO_2 emissions but the estimated costs (of the order of Rs 1500-6000 /t of carbon equivalent) are significantly higher than the costs of small hydel (in the range of Rs 200-1600 /t of carbon equivalent).

Background

Greater use of renewable sources of energy, efficient use of energy and increasing the forest cover in India have reasons more compelling than the threat of climate change induce by greenhouse gasses (GHGs). Sustainable energy systems demand the ultimate reliance on renewable forms of energy.[1] Different technologies based on renewable sources of energy, often less harsh on the environment, have been developed and/or deployed in developing countries in attempting to build sustainable energy systems which reduce environmental concerns such as that of climate change. Much more, however, remains to be done. As pointed out by Grubb (1990), the speed and the impact of the transition to energy systems relying more on renewable sources will depend largely upon the political and financial commitment made and the policies adopted over the next decade or so for this transition. In India, some efforts and progress has been made in the past decade and is summarised in Table 1.

Table 1: Summary of deployment of renewable technologies in India

	unit	Installation in India	date up to dd.mm.yy
Biogas programme (NPBD)	no.	1400000	31.3.91
Cookstove programme (NPIC)	no.	10300000	31.3.91
Solar hot water systems			
domestic	no.	6692	31.7.91
total collector area	m2	174000	31.3.91
Solar cookers	no.	180000	31.3.91
Solar photovoltaics			
total systems	no.	34000	31.3.91
total systems	kWp	4000	31.3.91
power plants	kWp	594	31.9.91
Windmills (irrigation)	no.	2710	31.3.91
Windfarms (power generation)	MW	37	31.3.91
Waste recycling plants	no.	697	31.3.91
Mini/micro hydel			
commissioned	kW	550	31.3.91
under installation	kW	15000	

source: DNES 1991

In the context of climate change induced by increased CO_2 emissions, renewable energy sources are likely to receive increased attention. In an earlier paper (TERI 1990), rough estimates and costs (in 1988 prices) of reducing CO_2 emissions were presented. Summary of the estimates are presented in Table 2. The specific costs indicated in Table 2, however, are average figures. More realistic estimates require the consideration of the site specific nature of both, the costs and the likely performance of the technologies.[2] This paper is a preliminary attempt in this direction. Based on the level of development of different technologies (discussed in a subsequent section of this paper), the exercise of constructing cost curves of CO_2 reduction focuses on windfarm power generation and small hydro on existing irrigation dams and canal drops in India. It may be worthwhile to point out that the specific costs of biomass based power generation (Table 2) appear particularly attractive and has the highest potential among the listed options. Two reasons preclude its inclusion in the analysis here. Firstly, realisation of the potential is subject to the creation of energy plantations for this purpose. Such afforestation will take time and require policy changes for shifts in land-use. Issues related to land-use shifts are complex due to the pressure on land and this is likely to further reduce the chances of success of this option. Clearly, the success of energy plantations on a substantial scale must be established prior to examining the technical feasibility of biomass based power generation at any reasonable scale. Secondly, we believe the costs, performance and the potential projected is overly optimistic in the context of the experience with the technology in India.

Table 2: Carbon saving potential with renewables in the power sector

	Total potential (MW)	Total investment (crore Rs)	Carbon saving potential m T of C eq.	Specific cost Rs/t of C eq.
Power from biomass	6000	8000	128.90	621
Power from wind	5000	7500	42.97	1745
Power from small hydro	2000	4000	51.56	776
Power from solar systems	2000	6000	8.59	6982
Energy from MSW	160	533	3.44	1552
Energy from distillery	140	49	4.01	122
Sewage sludge	50	125	1.07	1164
Windpumps	50	91	0.26	3530
Photvoltaic pumps	15	156	0.86	1818
Small battery chargers/ and stand-alone systems	10	100	0.06	17455
TOTAL	15425	26754	253.16	1057 (average)

This paper begins with a summary of the financial allocation for the renewable energy sector in India. Inadequate financial resources has been, and is likely to be, the major constraint for these technologies and will determine the level of the deployment programme. The costs of renewable energy technologies and the experience in the last decade is then discussed. Based on the experience, costs, and the potential, the latter part of the paper focuses on windfarms and small hydro for power generation.

<u>Financial constraints and deployment</u>

Financial commitment poses, perhaps, the most serious hurdle in the context of developing countries opting for technologies relying on renewable forms of energy. As Grubb (1990) points out,

> it is implausible under almost any technical outlook that the costs of collecting and converting diffuse renewables can compete with the costs of drilling a hole in the ground and letting oil or gas well up.

While this may no longer be the primary issue in the context of developed countries with environmental concerns such as climate change and long term sustainability becoming paramount, investment requirements cannot be ignored considering the more immediate concerns of developing countries in the context severe financial resource constraints. Opportunity costs of higher investments for a sustainable energy system are likely to be much higher, both qualitatively and in terms of quantity.

In this context, the relative reluctance of a majority of developing countries to commit substantial funds for developing and deploying technologies based on renewable sources becomes understandable -- it has probably less to do with lack of foresight or concern for sustainability than with finding means of dealing with more pressing concerns.

The renewable energy programme of India must also be viewed in this context. The programme started on a significant scale with the establishment of the Department of Non-conventional Energy Sources (DNES) in 1982. Started as a modest programme with an annual outlay of about Rs 4.3 crores in 1980/81, by the end of the 6th Plan period (1985) the annual allocation of the DNES increased to over Rs 33.7 crores. The 7th Plan (1985-90) continued with the increase in funding for these technologies. The first year allocation of the 7th Plan (of Rs 88.7 crores) itself touched the total outlay of the five years of the 6th plan (1980-85) and the allocation in the renewable energy sector stabilized to about Rs 130 crore annually. In spite of the sharp increase in funding for the renewable technologies, the fund allocation remained small in comparison to the total outlay for the energy sector as a whole. Between 1980 and 1990, the total cumulative Government expenditure in the renewable sector totaled to nearly

Rs 985 crores. In comparison, the Government invested nearly Rs 69,270 crores in the power sector, over Rs 28,200 in the petroleum sector and about Rs 13,780 in the coal sector (Table 3).[3] In the context of limited financial resource availability, prioritization of renewable energy technologies based on cost effectiveness appears important for this sector to make any significant impact.

Table 3: Summary of expenditure in the energy sector

in crore Rs

	Total expenditure 1980-85	Sixth plan Official Outlay 1980-85	Total expenditure 1985-90	Seventh Plan Outlay 1985-90	Surplus(+) deficit(-) 1985-90	Cumulative Expenditure 1980-1990
Power	18298.6	19265.4	38489.4	34273.5	4215.9	69267.3
New and Renewable Sources of energy	163.1	100.0	667.8	519.5	148.3	984.6
Petroleum	8482.1	4300.0	15940.6	12627.7	3312.9	28214.1
Coal	3807.5	2870.0	7528.0	7400.6	127.4	13782.0
	30751.3	26535.4	62625.8	51767.1	10858.7	112248.0

Source: Economic Survey-1990-91, MOF, 1991, p.S-41-42

Cost of renewable technologies in India

There appears to be some dispute on the overall economics of renewable energy technologies in India. Part of this arises from the traditional supply orientation in energy planning in the past, which has shown emphasis on development of the power, coal and hydrocarbons supply industries without adequate regard to specific enduses which determine the total demand for these and other forms of energy. Proponents of renewable energy technologies have often assumed ideal conditions in the operation, maintenance and performance of renewable energy devices, while on the other hand, those without faith in these technologies tend to underestimate the total social cost of supply of conventional fuels. The costs associated with some of the more promising technologies based on renewable sources are summarised in Table 4. Estimates of the true (but quantifiable) costs of conventional energy conversion routes are also summarised in this table. For a rational comparison, the costs are presented in two categories -- centralised power generation and decentralised routes for meeting similar energy end-uses.

The technologies and the conversion routes listed are selective and the intention here is to present indicative comparison rather than a comprehensive one and the purpose is to present a broad picture within which the two of the more promising technologies (wind electric generation and small hydro power) will be discussed in some detail.

Table 4: Summary of the cost of energy from various technologies

Technology	unit	Capital cost Rs/unit	Useful life y	Annual capital cost CRF (@)	Annual capital cost Rs/unit/y	Recurring costs O&M (#) Rs/unit/y	Recurring costs Fuel Rs/y	Total annual cost Rs/y	Annual generation (*) kWh/unit	Cost of energy Rs/kWh
Centralised power generation										

RENEWABLE TECHNOLOGIES										
Wind farm	kW	30000	20	0.134	4016	1500	-	5516	1752	3.15
Solar thermal	kW						-		1100	
-central receiver system		125000	20	0.134	16735	2500		19235		17.49
-line focussing system		80000	20	0.134	10710	2400		13110		11.92
Small hydel	kW	30000	30	0.124	3724	600	-	4324	2628	1.65
COAL THERMAL	kW	15000	25	0.127	1912	375			4818	
		cost of coal with coal transport cost (@Rs 0.26/t-km) and marginal pit-head cost of Rs 235/t [a]								
	300	313					1953	4241		0.88
	500	365					2133	4421		0.92
	800	443					2404	4691		0.97
	1000	495					2584	4872		1.01
Decentralised power generation										

Stand-alone wind turbines	kW	60000	20	0.134	8033	8190	-	16223	2190	7.41
Photovoltaics	kWp	110000	25	0.127	14025	4220	-	18245	1560	11.70
Gasifier [b] - agro-waste based	kW	9500	15	0.147	1395	950	4415	6760	5256	1.29
- wood based	kW	7500	15	0.147	1101	750	5992	7843	5256	1.49
Biogas dual fuel	kW	9500	20	0.134	1272	950		2222	5256	0.42
Solar dish stirling	kW	90000	20	0.134	12049	1800		13849	1752	7.90
Contribution of distribution	km									
line for different distances	1	43000	25	0.127	5482	2150	-	7632	30660	0.25
from the 33 kV grid [c]	5	215000	25	0.127	27412	10750	-	38162	30660	1.24
	10	430000	25	0.127	54825	21500	-	76325	30660	2.49
	15	645000	25	0.127	82237	32250	-	114487	30660	3.73
Irrigation/ shaft power										

Windmill [d]										
-shallow well unit		25000	20	0.134	3347		-	3347	1000	3.35
-deep well unit		45000	20	0.134	6025		-	6025	1200	5.02
Gasifier [b] - agro-waste based		14085	15	0.147	2068	1408	2208	5684	2628	2.16
- wood based		12085	15	0.147	1774	1208	2996	5978	2628	2.27
Photovoltaic [e]	kWp	230000	25	0.127	29325	3450	-	32775		
-irrigation		(demand restricted to 120 days/y)							624	52.52
-water supply		(constant demand throughout the year)							1560	21.01

[a] see TERI 1991a; [b] see Kishore and Sinha 1991; [c] see Sinha and Kandpal 1991a;
[d] see Sinha and Kandpal 1991b; [e] Includes lead-acid battery storage costs of Rs 2/kWh for wind and solar stand-alone systems. Assumed annual mean daily solar insolation: 5.2 kWh/m2. See Sinha and Kishore 1991. Discount rate of 12% used

Experience with RETs: 1982-90

A dispassionate look at the renewable energy programme in India to date would indicate that there are some technologies (namely, grid connected wind turbines, solar cookers) which have achieved a level of reliability and user acceptance. Government support in terms of subsidy may be required only to correct the distortions in the pricing of conventional energy sources.[4] There are others (such as gasifiers, windmills, solar hot water systems) which are nearing the commercialisation stage and government support is required for demonstration and further work on enhancing reliability. Then, there are a group of technologies somewhere in between the two. These technologies have achieved a fair degree of maturity but their diffusion suffers due to the manner in which they are promoted. Biogas, small hydel, improved cookstoves are some technologies that fall in this category. Finally, there are several technologies which still seem to require an extensive R&D effort and/or substantial cost reduction.

In past decade in India (and in many other developing countries), many of the new technologies have been forcefully promoted as solutions to the energy problems before the technology reached the level of maturity warranting such an effort. Aggressive promotion led to unreasonably high expectations from RETs and the promotional effort, either explicitly or implicitly, gave the impression that these technologies were the answer to all the energy problems of the country. Ironically, today those efforts have resulted in the greatest barriers to the introduction of these technologies -- there is widespread feeling among those associated with the energy planning process that RETs and their possible role is grossly overrated.[5] Therefore, now when some of the renewable technologies have actually achieved some level of maturity, proponents of these technologies find few planners with faith in their viability. Clearly, unambiguous statements of the constraints and the strengths associated with different renewable technologies is called for in order to regain credibility for these technologies. Substantial efforts need to be devoted to a serious assessment of what current technology is able to achieve and to arrive at a realistic estimate of the potential for these technologies within the context of the overall energy system. Unfortunately, there seems to an inadequate appreciation of the reasons for the indifferent performance of some renewable technologies by those managing these projects. The gasifier programme in India is a good example. As indicated earlier, there is a proposal to expand this programme to such levels that it would become the largest in the renewable sector. To date, there is hardly any experience in gasifiers of capacity above 10 kW. Furthermore, the limited experience has been largely restricted to wood gasification and this indicates that obtaining steady supply of feedstock because of scarcity of wood is a major constraint. Attempt, therefore is being made to develop gasifier designs for utilising a wider variety biomass feedstocks (such as agro-residues). Developing this technology to achieve commercialization, however, may require anywhere between 3-10 years (depending on the R&D funding levels). Attempt to seek massive funding for a technology at this level of development, as is being tried at present, invariably leads to a significant loss of credibility for other technologies in the renewable sector.

Clearly, for the renewable programme to make a significant contribution to the energy scene in India, firm priorities must be set. Technologies which are mature and reliable must be promoted with vigour. For some, the implementation aspects must first be reevaluated. Others require specific R&D efforts related to particular feature of a system. As implemented today, the programme is extremely diffuse and seems to be moving in too many direction. With this in view, this paper deals with windfarm and small hydro power generation as these two technologies (for power generation using renewables) have reached a level of maturity which merits such a discussion. It must, however, be emphasised that the purpose of restricting the discussion is not to give the impression that other renewable technologies have not reached the level of maturity deserving such attention. The focus of the present discussion is on technologies for the power sector as a result of which numerous other deserving technologies are not discussed.

Windfarm power generation

Amongst renewable technologies, windfarms appear the most feasible and cost effective for supplementing the conventional means of power generation on a large scale. As of late 1991, 37.5 MW of grid connected windfarms were operational in India and the performance of these windfarms has established the technoeconomic viability of this option. The operation of windfarms over the last 5 years shows an average availability of about 98% and the Capacity Utilisation Factor (CUF)[6] has been found to be as high as 30% at some locations. The wind mapping program of the DNES has identified several potentially windy regions indicating a fairly large potential for wind energy utilisation. The exact potential[7] for windfarms in India, however, is yet to be properly assessed. Estimates of the DNES place the ultimate wind-energy potential at 20,000 MW. Another study (Hossain 1991) estimated the potential on the basis of land availability only along the coastal regions having adequate wind resource to be of the order of 50,000 MW. If offshore and inland installations are also considered, the figure should be much higher.

The DNES has initiated a wind monitoring programme with 10 m and 20 m masts in the states of Tamil Nadu, Orissa, Maharashtra and Gujarat (Mani 1990). Mani and Mooley (1983) had earlier compiled and published windspeed data from 343 meteorological stations in the country. The data generated by the wind monitoring programme and the meteorological data both are used here.[8]

Wind energy power generation in the regions with windspeeds of 5 m/s or greater at the hub height of the turbines (25 m) is considered to be economically viable. Table 5 lists sites with mean annual windspeeds (extrapolated to the hub height of 25 m) exceeding 4 m/s. The sites have been categorized according to the windspeed range viz., 4-5 m/s, 5-6 m/s and those with windspeeds exceeding 6 m/s.

Table 5: Mean Annual Wind speeds at potential sites in India

I (4 m/s-5 m/s)				II (5 m/s-6 m/s)				III > 6 m/s			
Station	a	b	c	Station	a	b	c	Station	a	b	c
Bangalore	3.89	14.6	4.20	Indore	5.33	10.9	5.90	Tuticorin	5.63	9.9	6.30
Bhopal	3.63	11.7	4.09					Kandla	5.75	14.3	6.11
Meenakshipuram			4.49	Veraval	5.22	14.9	5.55	Mandvi	6.33	18.7	6.51
Jamnagar	4.11	13	4.51	Coimbatore	5.02	16.1	5.30	Okha	5.72	7.1	6.71
Madras	4.47	30	4.37	Devgarh	4.61	7.5	5.48	Muppandal			7.06
				Andipatti			5.29				
				Kayattar			5.73				
Tiruchirapalli	4.30	23	4.35	Dwarka	4.80	8.7	5.55				
				Kanyakumari	4.91	7.5	5.81				
Alibag	4.08	12.6	4.13	Keshode	4.86	10.2	5.47				
Aminidivi*	3.91	12.1	4.36	Porbandar	4.30	6.2	5.33				
Bhuj	3.69	10.2	4.25	Puri	4.52	9.9	5.15				
Bidar	3.69	10.4	4.20	Rajkot	5.16	13.4	5.57				
Dahanu	4.13	10.9	4.67	SagarIsland*	5.44	16.1	5.72				
Dohad	4.05	12.7	4.47	Sandheads*	4.55	12.2	5.01				
				Poolavadi			5.81				
Goa				Puliyakulam			5.40				
Marmagao	3.94	10.6	4.48	Tondi	4.27	5.0	5.52				
Gopalpur	4.02	7.9	4.87	Sembagaramanpudur			5.95				
Harnai	4.27	9.6	4.97	Sultanpet			5.03				
Jaisalmer	3.61	4.7	4.83	Harshad			5.97				
Jalgaon	3.75	11.0	4.25	Paradweep			5.19				
Kodaikanal	3.66	13.1	4.04	Vijaydurg			5.54				
Chandipur			4.89								
Mahabaleshwar	3.63	8.5	4.33	Bhavnagar			5.35				
Chatrapur			4.31								
Nagapatinam	3.86	11.7	4.32								
Kaipador			4.22								
Naliya	3.75	11.7	4.15								
Pamban	4.02	8.0	4.80								
Tambaram	4.36	10.0	4.97								

(a) Mean Annual windspeed (in m/s) as observed at the meteorological station.
(b) Anemometer height (in m) at which wind speed is recorded.
(c) Wind speeds in (in m/s) extrapolated to hub height of 25 m.
* These are small islands and, therefore, not considered for potential assessment.

The stations listed in Table 5 are located in the states of Karnataka, Madhya Pradesh, Gujarat, Tamil Nadu, Orissa, Maharashtra, Rajasthan, Goa and West Bengal.

With the available wasteland as the only constraint, the level of potential at some of the best sites exceeds 172,441 MW (Table 6). This may be deemed as the "ultimate" potential of windfarms and, as the costs (below Rs 3/kWh) in the table indicate, are fairly cost effective. Of all the districts listed, Kachch, in the western state of Gujarat, accounts for nearly half of the potential and this is more because of large amount of wastelands than high wind energy resource.

Table 6: Ultimate potential of windfarms in selected districts with highest wind resource

District	Waste-land sqkm	Windfarm potential MW	Wind-speed at 25m m/s	Specific output kWh/kW/yr	Cost of electricity Rs/kWh	Tot. Gen. in life of WEG GWH	Carbon equivalent mt of C eq.	Specific cost Rs/t of C eq.
Kachch	38640	82998	5.25	1607	2.87	2668123	872	2854
Jamnagar	7280	15637	5.68	1945	2.37	608281	199	2358
Rajkot	3300	7088	5.57	1858	2.48	263340	86	2469
Junagad	3080	6615	5.58	1866	2.47	246814	81	2459
Bhavnagar	4400	9451	5.35	1685	2.74	318466	104	2723
Ratnagiri	5980	12845	5.22	1584	2.91	406994	133	2895
Puri	2700	5799	5.15	1531	3.01	177528	58	2997
Baleshwar	1440	3098	5.04	1447	3.19	89682	29	3169
Ramanathapuram	5850	12565	5.16	1538	3.00	386575	126	2982
Coimbatore	2220	4768	5.38	1708	2.70	162895	53	2685
Tirunelvelli	4950	10632	5.84	2073	2.23	440770	144	2213
Kanyakumari	440	945	6.43	2546	1.81	48126	16	1801
Total		172441						

There is, however, significant difference between the "ultimate" and the realisable potential of wind energy and this is largely due to the highly intermittent nature of wind as an energy source. The fluctuating nature can have serious implications for the stability of the grid depending on level of contribution that this source makes to the total capacity (henceforth referred to the "penetration" level) on the T&D network. In general, the penetration level (indicative of the realisable potential that windfarms can make to the regional grid) depends on the operating constraints/ characteristics of the power system in question. Studies indicate that the optimal penetration levels may vary 5% to 50% (Table 7) depending on the generation mix on the grid. In a simulation study for Tamil Nadu, the optimal penetration level was found to be of the order of 25% (Hossain et al. 1991) and this is used for estimating the realisable potential of windfarm power generation in the present paper.

Table 7: Penetration levels suggested by different studies

Windfarm Penetration (%)	Study	Country
5%	Musgrove 1977	U.K.
20%	Golanis 1977	Greece
20%	Larsson 1978	Sweden
10% - 20%	Davition 1978	-
23% - 26%	Bossanyi 1983	U.K.
5% - 40%	Grub 1988	-
15% - 20%	Jaras 1981	FRG
25%	Hossain et al. 1991	Tamil Nadu

The growth in the capacity of the various regional grids (Table 8), i.e., eastern, northern, southern, western, etc.[9] are based on the current estimates of the financial allocation to the power sector and the stage of implementation of the different projects (see TERI 1991b for more details). Using the penetration level of 25% (with the capacity at the end of the 9th plan), the realisable potential of windfarms total 29,267 MW by the end of the 9th plan (1997) and 38,794 MW by 2002 AD.

Table 8: Grid capacity and potential for windfarms on the basis of 25% penetration level (in MW)

	INSTALLED CAPACITY END OF...		MAXIMUM WINDFARM POTENTIAL END OF...	
	9th plan	10th plan	9th plan	10th plan
EAST	19381	25933	4845	6483
NORTH	38397	49645	9599	12411
SOUTH	25780	38928	6445	9732
WEST	33510	40670	8378	10168
TOTAL			29267	38794

assumed penetration: 25%

The windspeeds at the best sites in India along with the estimates of the performance of windfarms at these sites is presented in Table 9. Among the sites, Mupandal in Tamil Nadu is the most attractive with the specific costs at Rs 1508/t of carbon equivalent. The potential capacity of the specific location is based on the specific output at a site and the level of windfarm realisable on the basis of the penetration level. The cost curve are is depicted in Figure 1.

Table 9: Cost, performance and equivalent carbon of some best wind sites in India

Location	Regional grid code	Wind-farm capacity (MW)	Wind-speed at 25m m/s	Specific output kWh/kW/yr	Cost of energy Rs/kWh	Tot. Gen. in life of WEG GWH	Carbon equivalent mt of C eq.	Specific cost Rs/t of C eq.	Cumulative saving m t of carbon equivalent
Muppandal	S	577	7.05	3042	1.55	35109	11.48	1508	11.5
Okha	W	650	6.71	2765	1.67	36000	11.77	1657	23.3
Mandvi	W	613	6.51	2610	1.77	31994	10.46	1757	33.7
Tuticorin	S	457	6.30	2442	1.89	22636	7.40	1878	41.1
Kandla	W	535	6.11	2290	2.02	24619	8.05	2003	49.2
Harshad	W	511	5.97	2177	2.12	22259	7.28	2107	56.4
Sembaganaramanputhur	S	410	5.95	2161	2.14	17724	5.80	2122	62.2
Indore	W	495	5.90	2121	2.18	21124	6.91	2163	69.1
Poolavadi	S	389	5.81	2049	2.25	15930	5.21	2235	74.4
Kanyakumari	S	389	5.81	2049	2.25	15930	5.21	2239	79.6
Kayathar	S	377	5.73	1985	2.32	14951	4.89	2311	84.5
Rajkot	W	436	5.57	1858	2.48	16205	5.30	2469	89.8
Veraval	W	433	5.55	1842	2.51	15930	5.21	2491	95.0
Dwarka	W	432	5.55	1842	2.51	15930	5.21	2491	100.2
Vijaydurg	S	348	5.54	1834	2.52	12764	4.17	2501	104.3
Tondi	S	345	5.52	1818	2.54	12545	4.10	2527	108.4
Devgarh	W	419	5.49	1787	2.59	14989	4.90	2569	113.4
Kasmode	W	418	5.47	1779	2.59	14857	4.86	2575	118.2
Puliyankulam	S	327	5.40	1724	2.68	11277	3.69	2661	121.9
Bhavnagar	W	396	5.35	1685	2.74	13330	4.36	2723	126.3
Porbandar	W	390	5.33	1669	2.76	13085	4.28	2745	130.5
Coimbatore	S	312	5.30	1646	2.80	10281	3.36	2787	133.9
Andipatti	S	311	5.29	1638	2.82	10185	3.33	2800	137.2
Paradweep	E	1714	5.19	1561	2.96	53522	17.50	2938	154.7
Puri	E	1651	5.15	1531	3.01	51447	16.82	2997	171.6
Sultanpet	S	277	5.03	1443	3.20	7865	2.57	3186	174.1
Tambaram	S	265	4.97	1395	3.31	7386	2.42	3288	176.5
Harnai	W	329	4.97	1395	3.31	9135	2.99	3288	179.5
Gopalpur	E	1451	4.87	1321	3.49	38332	12.53	3472	192.1
Jaisalmer	W	300	4.83	1252	3.57	7840	2.56	3550	194.6
Pamban	S	241	4.80	1271	3.63	6124	2.00	3611	196.6
Dahanu	W	276	4.67	1177	3.92	6511	2.13	3896	198.8
Jamnagar	W	250	4.51	1066	4.33	5340	1.75	4302	200.5
Meenakshipuram	S	200	4.49	1053	4.38	4206	1.38	4357	201.9
Goa (Marmagoa)	W	246	4.48	1046	4.41	5139	1.68	4385	203.6
Dohad	W	244	4.47	1039	4.44	5072	1.66	4414	205.2
Madras	S	185	4.37	977	4.74	3590	1.17	4717	206.4
Tiruchirapalli	S	180	4.35	959	4.81	3497	1.14	4781	207.5
Mahabaleshwar	S	180	4.33	946	4.88	3399	1.11	4847	208.6
Nagapattinam	S	179	4.32	940	4.91	3352	1.10	4881	209.7
Bhuj	W	210	4.25	895	5.16	3760	1.23	5127	211.0
Jaigad	W	210	4.25	895	5.16	3760	1.23	5127	212.2
Kaipadar	S	166	4.22	876	5.27	2910	0.95	5238	213.2
Bidar	S	164	4.20	863	5.35	2827	0.92	5315	214.1
Bangalore	S	164	4.20	863	5.35	2627	0.92	5315	215.0
Naliya	W	195	4.15	832	5.55	3250	1.06	5514	216.1
Alibag	W	192	4.13	820	5.63	3155	1.03	5597	217.1
Bhopal	W	187	4.09	795	5.80	2969	0.97	5769	218.1
Kodaikanal	S	145	4.04	765	6.03	2221	0.73	5996	218.8
		19813							

Small Hydel power generation

Small/micro/mini hydel is another technology with enormous potential. Till the beginning of 1990, installed small hydro capacity had exceeded 25 MW and work on an additional 82 MW was under progress. Additional sites have been identified (see tables below). It is difficult to estimate the likely penetration of this technology beyond 2000 AD. Obviously, a lot depends on the experience with the programme in the next decade. To date however, this experience has not been very encouraging. It is common to encounter doubts among those involved with the power sector regarding the viability of the small hydel projects. These doubts persist because the experience with pilot irrigation based small hydel schemes. During the Seventh (1985-90) Plan, SEBs in the South initiated work on 16 projects. Till late 1990, only six of these had been completed. Three main reasons have been forwarded for the poor performance of these projects (ESMAP 1991). Firstly, the initial batch of schemes were conceived, designed and executed as scaled down versions of large conventional hydro installations. Consequently, there are numerous redundancies in the design for key features such as the layout for the civil works, the facilities incorporated into the powerhouse structures, the selection for turbine-generator equipment, and the specification of the electrical switching and protection systems. Second, due to the use of relatively complex layout for the schemes, the gestation time to construct and commission the schemes the schemes had been high. For example, majority of the pilot schemes in the southern region has taken over four years to commission. As a result of the slow pace of implementing the construction work, there has been a significant escalation of the costs.[10] Thirdly, the viability of the pilot schemes were undermined by the use of unnecessarily large number of technical staff to operate and maintain the pilot schemes. It is expected that with the experience of the pilot schemes would result in qualitative improvement of the programme. In fact, detailed reexamination of the project reports in the five states of Andhra Pradesh, Karnataka, Kerala, Punjab, and Tamil Nadu (totaling to over 130 MW of proposed capacity) has been completed. The summary of the potential based on other identified sites are given below (Table 10).

Table 10: Summary of the potential of small hydel at identified sites

	Capacity MW	Total cost crore Rs	Installed cost Rs/kW
Mini hydel schemes	980.46	2117.20	21594
Canal drop schemes	148.71	332.93	22388
Total	1129.17	2450.13	21699

The state-wise summaries are presented in Tables 11 and 12. It must be emphasised that the presented estimates are only for identified sites and reflect possible installations in the next 5-10 years depending on the priority attached to developing the potential in this sector.

Table 11: Proposed and ongoing Mini hydel schemes

	DPR NOT ready		DPR ready		Targeted		Operational	
	Capacity MW	Cost crore Rs	Capacity MW	Cost crore Rs	Capacity MW	Cost crore Rs	Capacity MW	Cost crore Rs
Bihar	25.10	64.70	1.00	2.50				
Orissa	14.60	29.90	0.01	0.30			0.04	0.80
West Bengal	38.20	70.50						
sub-total	77.90	165.10	1.01	2.80	0.00	0.00	0.04	0.80
Haryana			24.10	52.30	0.40	1.30		
Himachal Pradesh	8.30	12.40	0.50	1.30				
Jammu & Kashmir	63.00	103.90	23.70	62.30	7.60	28.80		
Punjab	41.90	124.20	29.30	60.90				
Uttar Pradesh	99.00	208.60	4.40	11.60	16.70	35.70	8.60	20.90
sub-total	212.20	449.10	57.90	136.10	24.30	64.50	8.60	20.90
Assam	9.60	15.60	6.00	7.80				
Manipur	7.00	13.00						
Meghalaya	5.20	13.80						
Nagaland	0.50	1.00	7.80	18.00	0.80	2.30	2.50	5.80
Sikkim	9.10	17.00						
Tripura	4.40	10.10						
Arunachal Pradesh	40.30	76.00			6.80	14.40	14.10	27.80
Mizoram	1.50	11.10						
sub-total	77.60	157.60	13.80	25.80	7.60	16.70	16.60	33.60
Andhra Pradesh	30.30	71.80	12.60	28.30				
Karnataka	6.90	17.60	17.00	32.00	24.10	64.10		
Kerala	112.00	247.50	9.70	25.20	10.00	12.90		
Tamil Nadu	77.40	125.50	7.90	10.30	4.80	9.90		
A. & N. Islands	3.00	4.50						
sub-total	229.60	466.90	47.20	95.80	38.90	86.90	0.00	0.00
Gujarat	8.30	25.30	18.51	46.00	2.00	6.60		
Madhya Pradesh	27.50	60.30	9.70	21.80	3.80	9.60		
Maharashtra	61.00	142.10						
Rajasthan	0.80	2.00	8.60	21.70	1.00	3.30		
Goa, Daman and Diu	1.50	2.30						
sub-total	99.10	232.00	36.81	89.50	6.80	19.50	0.00	0.00
TOTALS	696.40	1470.70	180.82	402.30	78.00	188.90	25.24	55.30

DPR: detailed project report

Source: DNES, 1989, Mini Hydro Power: proposed Eighth Plan implementation programme, Vol 1, p23-24

Table 12: Proposed small hydel schemes on canal falls

	Capacity MW	Cost crore Rs	Number of sites
Bihar	1.00	2.50	1
Orissa	0.01	0.03	1
sub-total	1.01	2.53	2
Haryana	24.00	52.30	20
Punjab	29.30	60.90	21
sub-total	53.30	113.20	41
Andhra Pradesh	40.60	96.30	8
Karnataka	17.00	32.00	8
Kerala	9.70	25.20	6
Tamil Nadu	2.40	3.40	2
sub-total	69.70	156.90	24
Gujarat	15.00	38.50	13
Madhya Pradesh	9.70	21.80	12
sub-total	24.70	60.30	25
TOTALS	148.71	332.93	92

Source: DNES, 1989, Mini Hydro Power: proposed Eighth Plan implementation programme, Vol 1, pp.25-26

As discussed, the estimates of the cost are based on the limited experience in India in the design and commissioning of small hydro installations. It is therefore important to examine the costs of projects where considerable effort have been made to optimise the design (to increase the energy output) and, simultaneously, reduce design complexities to lower the costs. Table 13 summarises the cost and performance data for 145 such small hydel units in five states totaling about 130 MW a the approximate capital requirement of Rs 260 crores (late 1991 costs, incorporating the devaluation of the Rupee). The costs and estimated energy output for all such projects is listed in Table 14. As indicated in table, the range of cost varies between Rs 180-1600 per tonne of carbon equivalent. The CO_2 limiting potential of the listed sites is over 5.8 m t of carbon equivalent.[11] The data presented in Table 14 is also used to construct cost curves for small hydro technology on all of the identified sites.[12]

The cost curve for a mitigation strategy involving small hydel generation in depicted in Figure 2.

Table 13: State-wise summary of small hydel projects with reexamined DPR

	No. of units	Total Capacity MW	Total cost crore Rs	Energy output GWh/y
Andhra Pradesh	36	58.1	78.07	287.40
Karnataka	38	33.0	64.15	147.31
Kerala	24	16.9	40.18	62.51
Punjab	20	8.2	35.77	27.38
Tamil Nadu	27	13.15	40.22	48.62
TOTAL	145	129.4	258.39	573.22

Table 14: Site-wise details of cost, performance and carbon equivalents of small hydel sites

	Unit Size kW	No. of units	Total Capacity MW	Total cost crore Rs	Energy output GWh/y	Tonnes of C eq. over life	Rs per tonne of C eq.	
Peechi	1500	1	1.50	1.96	11.11	108989	180	108989
Peechi	2500	2	5.00	6.85	32.70	320787	214	429776
Thablan	1000	6	6.00	10.59	44.40	435564	243	865340
Sathanur	2500	2	5.00	5.45	21.82	214054	255	1079394
Chanarthal	1000	4	4.00	6.87	26.80	262908	261	1342302
Maniyar	2500	6	15.00	15.13	57.10	560151	270	1902453
Sidhana	350	1	0.35	1.15	4.00	39240	293	1941693
Lower Bhavani Dam	3500	2	7.00	7.57	24.25	237893	318	2179586
Aliyar	1250	2	2.50	2.98	9.32	91429	326	2271015
Dalla	1000	2	2.00	3.03	9.00	88290	343	2359305
Harangi	1500	3	4.50	4.98	14.52	142441	350	2501746
Lower Maneru	2 1500	2	3.00	5.83	16.48	161669	361	2663415
Chupki	650	2	1.30	2.82	7.90	77499	364	2740914
Deverebelekere	1000	1	1.00	2.86	8.00	78480	364	2819394
Mudhol	1000	1	1.00	1.78	4.86	47677	373	2867071
Dolowal	650	2	1.30	2.79	7.60	74556	374	2941627
Amravathy	2000	2	4.00	3.93	10.58	103790	379	3045416
Ongol BC	2 350	2	0.70	1.92	4.72	46303	415	3091720
Guntur BC	1 1250	3	3.75	6.92	17.00	166770	415	3258490
Chak Bai	650	2	1.30	2.74	6.70	65727	417	3324217
Guntur BC	2 1250	3	3.75	8.13	19.80	194238	419	3518455
Babanpur	650	2	1.30	2.79	6.50	63765	438	3582220
Kila	650	2	1.30	2.72	6.30	61803	440	3644023
Narangawal	650	3	1.95	3.81	8.60	84366	452	3728389
Lock-in-sula	1500	2	3.00	6.46	14.50	142245	454	3870634
Malapraba	1000	2	2.00	3.62	8.08	79265	457	3949898
Thirumurthy	650	3	1.95	3.54	7.73	75831	467	4025730
Maddur	1000	2	2.00	3.85	8.30	81423	473	4107153
Tugal	350	3	1.05	2.98	6.00	58860	506	4166013
Peechiparai	650	2	1.30	3.08	5.95	58370	528	4224382
Nugu	1000	2	2.00	3.34	6.15	60332	554	4284714
Attehala	350	1	0.35	1.53	2.80	27468	557	4312182
Anveri	650	2	1.30	2.94	5.26	51601	570	4363782
Wanchiam	1500	2	3.00	5.40	9.50	93195	579	4456977
Ongol BC	3 350	2	0.70	2.96	5.00	49050	603	4506027
Kakatiya d-83	4 350	2	0.70	2.69	4.40	43164	623	4549191
Kuttiyadi	1 1500	2	3.00	4.57	7.03	68964	663	4618156
Kabini	650	3	1.95	4.09	6.25	61313	667	4679468
Perunchani	650	2	1.30	3.38	5.10	50031	676	4729499
Rajankollur	650	3	1.95	4.22	6.33	62097	680	4791596
Chembukadavu	650	3	1.95	5.39	8.00	78480	687	4870076
Shahpur BC	1 350	3	1.05	3.49	5.10	50031	698	4920107
Kilara	650	2	1.30	3.99	5.80	56898	701	4977005
Guntur BC	3 650	2	1.30	4.50	6.40	62784	717	5039789

		Unit Size kW	No. of units	Total Capacity MW	Total cost crore Rs	Energy output GWh/y	Tonnes of C eq. over life	Rs per tonne of C eq.	
Shahpur BC	5	350	3	1.05	3.54	4.88	47873	739	5087662
Kakatiya d-83	1	350	3	1.05	4.04	5.36	52582	768	5140244
Addaki BC	2	1250	2	2.50	5.20	6.80	66708	780	5206952
Mangalam		350	1	0.35	1.02	1.30	12753	800	5219705
Ongol BC	1	350	2	0.70	2.86	3.64	35708	801	5255413
Salar		350	2	0.70	2.06	2.60	25506	808	5280919
Guntur BC	4	1000	2	2.00	5.11	6.40	62784	814	5343703
Kakatiya d-83	3	350	2	0.70	2.69	3.20	31392	857	5375095
Shahpur BC	4	350	3	1.05	3.67	4.15	40712	901	5415807
Shahpur BC	6	350	1	0.35	1.83	2.00	19620	933	5435427
Ongol BC	4	350	2	0.70	2.96	3.01	29528	1002	5464955
Kuttiyadi	2	650	2	1.30	2.56	2.60	25506	1004	5490461
Kakatiya d-83	2	350	2	0.70	2.68	2.68	26291	1019	5516752
Kuttiyadi	3	650	2	1.30	2.61	2.60	25506	1023	5542258
Shahpur BC	2	350	3	1.05	4.34	3.90	38259	1134	5580517
Ongol BC	5	350	1	0.35	1.83	1.56	15304	1196	5595820
Grand Anicut		350	2	0.70	2.96	2.50	24525	1207	5620345
Shahpur BC	3	350	3	1.05	4.38	3.65	35807	1223	5656152
Passukkadavu		650	2	1.30	4.84	3.75	36788	1316	5692939
Villampati		350	1	0.35	1.83	1.30	12753	1435	5705692
Tughlapati		350	1	0.35	1.83	1.30	12753	1435	5718445
Mettur West Bank		350	1	0.35	1.83	1.30	12753	1435	5731198
Addaki BC	1	650	2	1.30	5.18	3.64	35708	1451	5766907
Kakatiya d-83	5	350	2	0.70	2.69	1.88	18443	1459	5785349
Krishnagiri		350	1	0.35	2.03	1.30	12753	1592	5798102
Krishnagiri		350	1	0.35	2.03	1.30	12753	1592	5810855
				8.2	35.77	27.38	5810855		

ESMAP 1991:22 for capacity and energy production; ESMAP 1991:36 for costs

Conclusions

Some of the major conclusions of the analysis presented here are as follows:

1. Of the renewable energy technologies, the use of wind electric generators in windfarms offers the highest potential for energy paths to lower CO_2 emissions in India. The potential at the most cost effective sites, for the projected expansion of the regional grids, is of the order of 20,000 MW in the medium time frame (5-10 years).
2. The cost of such a path would be in the range of order of Rs 1500-6000 per tonne of carbon equivalent.
3. Though the potential of small hydro power is considerably smaller than that for windfarms, these offer the lower cost option for energy paths to lower CO_2 emissions in India. The costs are in the range of Rs 200-1600 per tonne of carbon equivalent.
4. The realisable potential for small hydro is conservatively estimated at 5000 MW (about 52 m t of carbon equivalent) in India. Of this, schemes totaling about 22 m t of carbon equivalent can be implemented in the short to medium term.

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Endnotes

(1) See Jackson (1991) for a review of the role and the relevance of renewables for a sustainable energy system and Sorenson (1991) for a brief history of technologies based on renewable energy sources.

(2) The cost estimates also need to be updated due to the devaluation of the Rupee in the second half of 1991. The devaluation severely effects the costs associated with the wind electric generators, the indigenisation of which leaves a lot to be desired. As of late 1991, the exemption of customs duty on the import of turbine and other components was also withdrawn and a 40% duty was imposed, supposedly to encourage indigenisation. As a result of these two factors, the cost of wind electric turbines has jumped from Rs 18,000/kW to about Rs 30,000/kW in between 1988 and 1991 end. The effect of the devaluation on small hydro has been less severe since significant indigenisation has been achieved in the last decade.

(3) Despite the relatively small investment in the renewable sector in the first decade of its existence, the trends in the investment appear encouraging. Using the investments of 1980/81 as the base, the investment in 1988/89 are higher by a factor of over 30 while those in the other energy component sectors range between 3 to 4 times that of the levels of 1980/81.

(4) In the case of grid connected wind turbines, substantial commitment may be desirable from the Government for (a) changes in policy and existing law relating to the generation and the sale of power, and (b) initiating and encouraging the indigenisation of the technology in view of the

large projected potential (of the order of 20,000-45,000 MW for this technology in India and the existence of the industrial infrastructure to achieve self-reliance (see Hossain 1991 for details.

(5) This situation is not unique to India and an excellent summary of the perceptions regarding the role and the relevance of renewables can be found in Grubb (1990).

(6) The capacity utilisation factor (CUF) is defined as

CUF = [Annual Energy Generated]/[Rated Power X 8760])

(7) The term "potential" can be used in several contexts. It can refer to the capacity that can be ultimately installed at a certain point of time in future without any consideration of other factors. For wind energy utilisation the potential, <u>in this sense</u>, would be very large with the land availability determining the upper bound. The <u>realisable</u> potential of windfarms is, however, limited by the nature and capacity of the existing generating system in addition to the physical land availability. In the present paper, "potential" refers to the **realisable potential** for windfarms, keeping in view the land availability, wind resource and the expected generating capacity in future.

(8) Though there is some skepticism regarding the usefulness of the meteorological data for wind energy calculations as these observations were made for meteorological purposes at varying heights and the anemometers were not sited from the point of view of wind resource assessment. A combination of the data generated by wind monitoring programme and the meteorological data, however, does give a fair idea of the wind regimes in the country.

(9) Of the states with significant potential for windfarm generation, the states Madhya Pradesh, Maharashtra, Goa, and Gujarat fall in the western region; states Tamil Nadu and Karnataka in southern region, Orissa in the eastern region and Rajasthan in the northern region.

(10) In Tamil Nadu such delays resulted in cost escalations in all the three projects. The cost of the Lower Bhavani Scheme, in the 5 years of construction work, rose from Rs 20.7 to 24.1 crores. For the Vaigai the escalations were from Rs 14 to 16.2 crores.

(11) The total small hydel potential of 5000 MW corresponds to a limiting potential of nearly 52 m t of carbon equivalent.

(12) As indicated in Table 5, the identified sites amount to about 1130 MW. Estimates place the potential of small hydro at 5000 MW in the country based on the survey of REC in the mid-eighties.

CO2 reduction cost curve: Windfarms
ALL PROJECTS

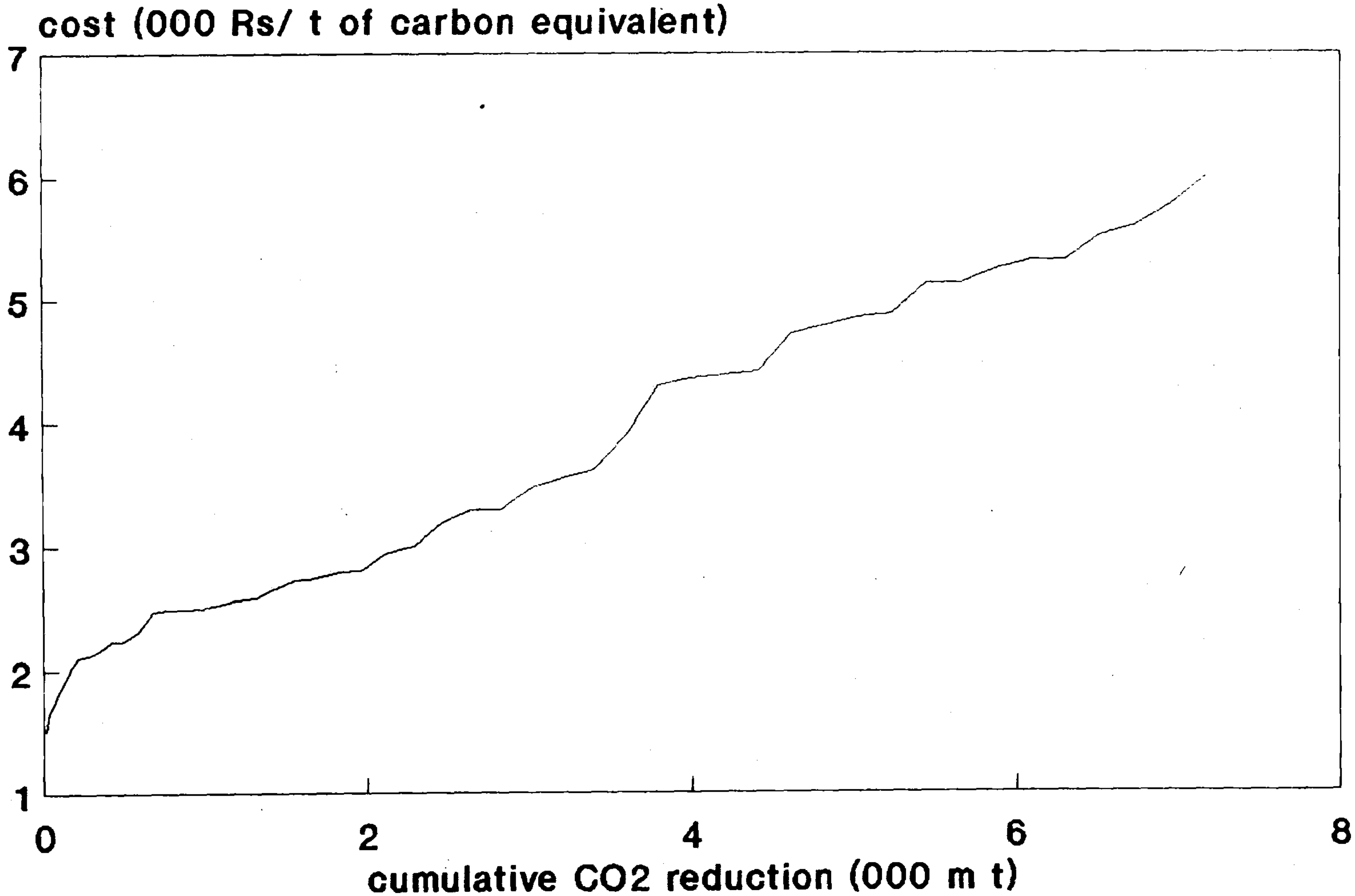

fig 1.

CO2 reduction cost curve: Small-hydro
ALL PROJECTS

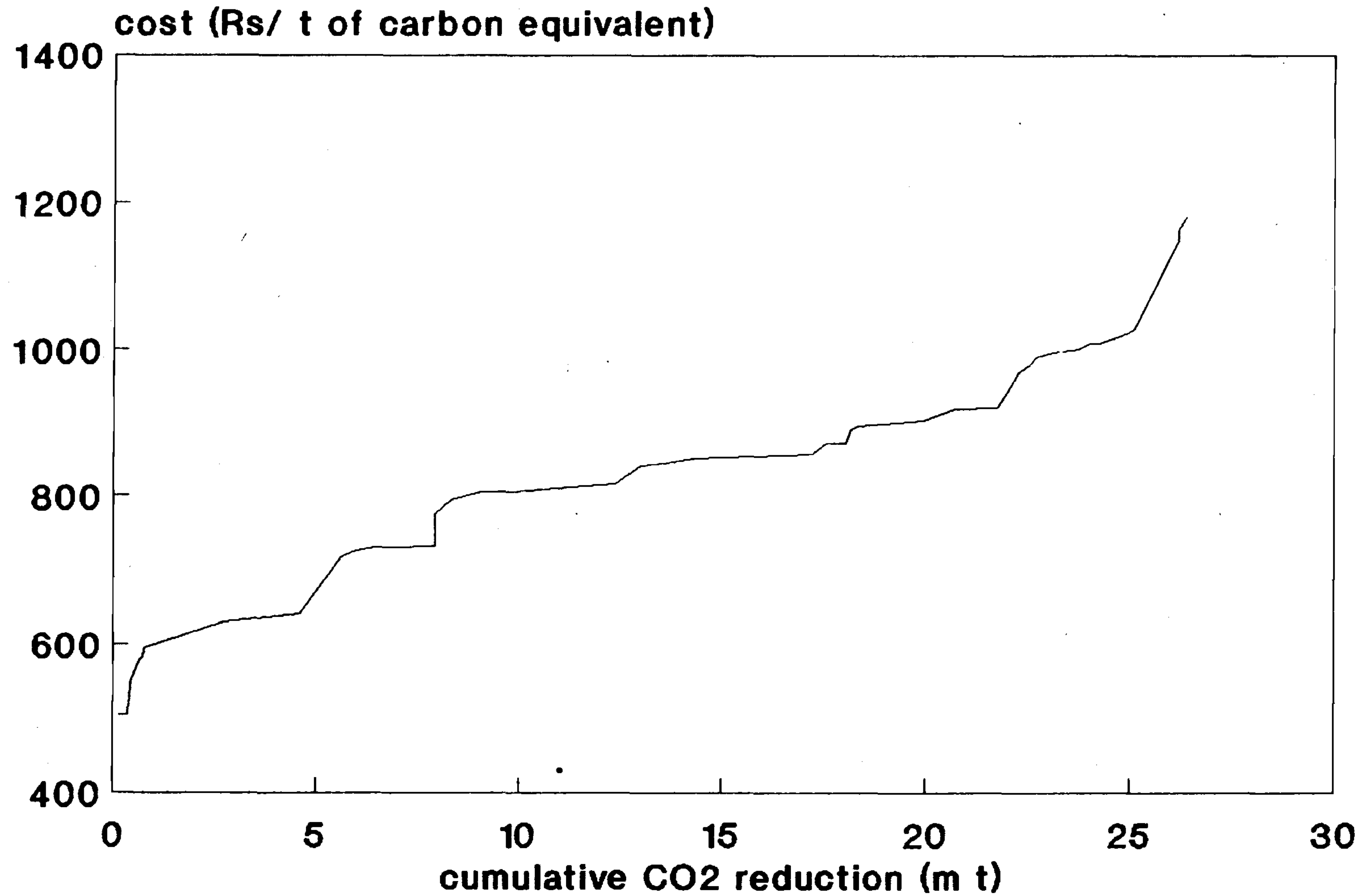

fig. 2.

ESTIMATE OF N_2O EMISSIONS FROM USE OF NITROGENOUS FERTILIZER IN INDIA, AND POTENTIAL FOR REDUCTION THROUGH MANAGEMENT PRACTICES

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ABSTRACT

This paper makes a preliminary estimate of N_2O emissions, due to the use of inorganic nitrogenous fertilizer in India. It also examines the potential for limiting agriculture related N_2O emissions through the use of various management practices. The conclusion of the paper is that although annual N_2O emissions for 1990-91, are as low as 1.35 Tg; there is merit in Indian farmers adopting N fertilizer use efficiency measures on their own merit.

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INTRODUCTION

Nitrous oxide (N_2O), is not only a greenhouse gas absorbing in two bands where the atmosphere and the earth emit, but also has a concentration of slightly over 300ppbv contributing approximately 1K to the greenhouse warmed mean surface temperature. (Kuhn, 1985) Due to its long tropospheric lifetime (150 years) it can diffuse into the stratosphere where through reaction with excited oxygen atoms, it produces nitric oxide(NO). The reaction with nitric oxide so produced is the major removal process for stratospheric ozone. (WMO, 1985)

Known sources of nitrous oxide include anthropogenic sources such as burning of fossil fuels, biomass burning, land clearing and nitrogenous fertilizer use; and natural sources within soils, oceans and freshwater ecosystems.

According to the IPCC in 1985, nitrogenous fertilizer use constituted approximately 18% of the total anthropogenic nitrous oxide emissions including those from energy use. **(1)** In 1984-85 India consumed 5.5 MMT (approx. 8%) of a total world consumption of 70.5 MMT N fertilizer **(2)** and in 1990-91 the consumption of nitrogenous fertilizer (based on despatch figures) has been estimated at 8.02 MMT. **(3)**

This preliminary study is to (i) focus on nitrogenous fertilizer use as a source of nitrous oxide, (ii) estimate nitrous oxide emissions from nitrogenous fertilizer use in India, for the year 1990-91, (iii) examine the potential for reduction in such emissions through the use of management practices. The study has tended to concentrate on rice cultivation given the low nitrogen use efficiency of the rice crop.

Nitrous oxide

Although present only in small amounts in the atmosphere N20 plays a significant role both in the radiation balance as well as in the atmospheric chemistry.Inspite of its concentration being far below (0.31 u mol mol-1) that of CO2, its radiative forcing is far greater; (approximately 230 times greater per molecule added). It also contributes to stratospheric ozone depletion by producing NOx as it breaks up in the atmosphere. The annual growth rate of N2O is about 0.2 to 0.3% per year (Rasmussen and Khalil, 1986) **(4)**

Nitrous oxide emissions result from varying sources including burning of fossil fuels, biomass burning, land clearing, nitrogenous fertilizer use and natural processes within soils, oceans and freshwater systems. Table 1 gives an overview of the major sources (natural and anthropogenic) and sinks of nitrous oxide.

Table 1. Estimates of sources and sinks of nitrous oxide (N_2O)

Sources	Range (TgN per year) unless otherwise stated (I)	(II)
Natural Sources		
Oceans	1.4 - 2.6	2.0 ± 1.0 *
Natural Soils (Tropical forests)	2.2 - 3.7	6.5 ± 3.5x1012 g N/yr
(Temperate forests)	0.7 - 1.5	
Wildfires	≃ 0	
Lightning	≃ 0	
Volcanoes	≃ 0	
Atmospheric chemistry	≃ 0	
Manmade/Anthropogenic sources		
Fossil fuel combustion	0.1 - 0.3	4.0 ± 1.0 Tg N/yr
Biomass burning	0.02 - 0.2	0.7 ± 0.2 Tg N/yr
Fertilizer	0.01 - 2.2 @	0.8 ± 0.2 Tg N/yr $
Sinks		
Removal by soils	?	--
Photolysis in the stratosphere	7 - 13	- 10.5 ± 3.0 #
Atmospheric increase	3 - 4.5	3.5 + 0.5

I Source : Bolin, B., Doos, B., Jaeger, J. and Warrick, R.A. (eds) The Greenhouse Effect. Climatic Change and Ecosystems. (SCOPE 29) John Wiley. New York 1986. p.397 (5)

II Wuebbles,D.J.,Edmonds,J. A Primer on Greenhouse Gases Prepared for USDOE March 1988. (6)

@ This includes ground water
# This is inclusive of reaction with O.
$ This estimate refers to fertilized soils.
* This estimate includes both oceans and estuaries

Estimates of N_2O emissions from fertilizer use

Varying estimates of the share of agriculture and in particular inorganic nitrogenous fertilizer use have been made. Given below are some of the better known estimates.

Table 2. Estimate of Share of agriculture in anthropogenic and total emission of NO_x - N and N_2O - N

Source	NO_x - N ($NO + NO_2$)			N_2O-N		
	10^6 t/a	% of Man's share	Total	10^6 t/a	% of Man's share	Total
Natural	17 (5 - 27)		49	10		77
Anthropogenic	18.2	100	51	3.1	100	24
Non agricultural sector	18 (11-24)	99	50.4	3	96	23
Agriculture (inorganic N fertilizer)	0.2	1	0.6	0.12	4	1

Source :Prasad,Rajendra.,Katyal,J.C.,Fertilizer Use related Environmental Pollution.Unpublished.1991.(6a)

Of an estimated global annual N_2O source of 8 to 22 Tg per year nitrogenous fertilizer contributes about 0.14 to 2.4 Tg per year (Lashof and Tirpak, 1990). There are several estimates which have been made of the annual global emission resulting from Nitrogenous fertilizer use, emissions based on estimates of the amount and type of fertilizer consumed and emissions per unit of fertilizer applied. Some of these estimates are 9.4-31.4 Tg N_2O (6-20 Tg N_2O-N, Hahn and Junge, 1977); <4.7 Tg N_2O (<3 Tg N_2O-N Crutzen et al., 1983). 0.9-3.6 Tg N_2O (0.6-2.3 Tg N_2O-N Bolle et al., 1986); and 0.3-3.8 Tg N_2O (0.2-2.4 Tg N_2O-N U.S.EPA., 1990). (7)*

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* [N_2O is expressed in the literature in mass units of nitrogen (N) as N_2O-N. However later in the paper N_2O-N is converted to molecular N_2O by a conversion factor (44/28), representing the molecular weight of N_2O].

Nitrous oxide is produced naturally in soils by bacterial denitrification and nitrification. The addition of inorganic N fertilizer is an additional N source leading to an increase in N_2O emissions from the soil.

Fertilizer use is likely to become an important source of N_2O given the rate of its consumption which is 1.3% per year in industrialized countries and 4.1% in developing countries (World Bank 1988) **(8)**

A large number of factors influence the biological processes of the soil organisms that determine N_2O emissions. They could be categorized into two general categories; management practices and natural processes . Management practices include fertilizer type, amount of fertilizer applied, method of application, timing of application, tillage practices, use of chemicals,irrigation practices among other factors. Temperature, rainfall, organic matter content and pH constitute the natural factors which affect N_2O emissions to varying degrees. (Sahrawat and Keeney 1986) **(9)**, Fung 1988 **(10)**. In this study emphasis has been laid on the management practices both in use as well as those having the potential for increasing nitrogen use efficiency and therefore reducing nitrogen losses.

Table 3. Factors affecting fertilizer-derived N_2O emissions

Management practices	Environmental factors
Fertilizer type	Temperature
Application rate	Precipitation
Application technique	Soil moisture content
Timing of application	Organic C content
Tillage practices	Oxygen availability
Use of other chemicals	Porosity
Crop type	pH
Irrigation	Freeze and thaw cycle
Residual N and C from crops and fertilizer	Microorganisms

Source: Eichner,M.1990.Nitrous oxide emissions from fertilized soils. Summary of available data. J.Environ.Qual. 19:272-280 **(11)**

The flux of $N2O$ into the atmosphere is primarily due to microbial processes in the soil and water. Denitrification and nitrification are the primary processes that lead to the evolution of $N2O$ from soils fertilized with nitrogenous fertilizers. In well aerated soils, nitrification is the primary process producing $N2O$ (Breitenbeck et al., 1980) whereas denitrification is prevalent in poorly drained wet soils. Although till recently denitrification (reduction of $NO3$ to $N2$) was considered the major mechanism of $N2O$ production, more recently nitrification has been attributed a significant, if not dominant role. In this study, rice cultivation and the associated management practices have been dealt with in greater detail due to the fact that rice cultivation is the largest agricultural contributor to denitrification losses (Hauck, 1988) (12)

On the basis of global production rates of nitrogen fertilizers, loss of $N2O$ has been estimated at 0.5-20%. The same amount may be emitted from nitrification/denitrification of mineral fertilizers leaching from fields into groundwater/freshwater ecosystems. (Conrad et al., 1983; Kaplan et al., 1978 ---- Source Bolin). There is no inclusion of estimates of nitrogen losses occurring from leaching from fields into groundwater or freshwater ecosystems in this study.

Application of mineral nitrogen fertilizers leads to an increase in $N2O$ flux, since part of the fixed nitrogen applied is released as $N2O$ into the atmosphere. Data showing the highest loss rates have been associated with use of anhydrous ammonia and ammonium fertilizers further reconfirming the fact that nitrification is the dominant N_2O production process. Anhydrous ammonia is only used extensively in the U.S. (38% of N fertilizer consumption). Urea is used extensively in Asia and South America where it accounts for 69% and 5% respectively of N fertilizer consumption.

In an experiment to assess the biological production of NOx (NO and N_2O) from fertilized agricultural soil, in Ontario, Canada using enclosure techniques Shepherd et al (1991) **(13)** found that for the most highly fertilized soil NOx fluxes range from 3.1 to 583 ug (NO)m^{-2} h^{-1} and the N_2O fluxes range from 0 to 446 ug (N_2O)m^{-2} h^{-1}, as compared to NOx fluxes from unfertilized soils ranging from 1.5 to 41.6 ug (NO) m^{-2} h^{-1} and N_2O fluxes of 0-61.8 ug (N_2O)$m^{-2}h^{-1}$. The fluxes increase linearly with fertilizer application, with 11% of the nitrogen in the ammonium nitrate converted to NOx and 5% to N_2O. **(13)**.

The data in the tables below (4 & 5) is an index of the large variability in emission estimates among the experimental sites.

Table 4. NOx emission fluxes from fertilized agricultural soils

Ground character	NOx Flux ug(NO)$m^{-2}h^{-1}$	Reference
Corn field	20-860	Williams et al. (1988)
Wheat field	1.3-6.2	Williams et al. (1988)
Corn field	21-241	Anderson and Levine (1987)
Soy field	2.5-33.8	Anderson and Levine (1987)
Arable field	0.4-223	Johansson and Granat (1984)
Experimental field	1.5-583	This study

Table 5. N_2O emission fluxes from fertilized agricultural soils

Ground character	N_2O Flux $ug(N_2O)m^{-2}h^{-1}$	Reference
Arable field	228-1712	Blackmer et al.(1982)
Arable field	34-367	Bremner et al. (1980)
Arable field	35-482	Anderson and Levine (1987)
Corn field	411-594	Cates and Keeney (1987)
Cropped field	868 (average)	Mosier & Hutchinson (1982)
Experimental field	0-446	This study

Source: Shepherd, M.F., Barzetti, S., Hastie, D.R., The production of atmospheric NO_x and N_2O from a fertilized agricultural soil.Environment Vol. 25A, No. 9, pp 1961-1969, 1991.(13)

Eichner (1990) who has examined N_2O emission data from 104 field experiments between 1979 and 1987 has found a relationship between emissions and type and quantity of fertilizer applied; although the available data does not allow for determining a trend between emissions and a particular soil type or agriculture system.(11) Table 6 shows that fertilizer type is an important factor influencing emissions.

Table 6. Fertilizer-derived N_2O emissions for five fertilizer types during the sampling period only. @

Fertilizer type	No. sites	Percent of N fertilizer evolved as N_2O #			Daily average emissions $			Daily average emissions per kg N applied per hectare		
		Range	Median	Avg.	Range	Median	Avg.	Range	Median	Avg.
		%			g N_2O-N ha^{-1} d^{-1}			mg N_2O-N ha^{-1} d^{-1} kg N^{-1}		
AA	9	0.86-6.84	1.63	2.70	10.5-123.0	23.4	44.0	61.1-492.1	140.0	200.9
AN	8	0.04-1.71	0.12/0.40	0.44	0.3-17.4	2.5/3.2	4.5	4.3-174.5	25.6/26.7	40.1
A	17	0.02-0.90	0.12	0.25	0.4-14.3	2.4	4.6	2.8-142.8	18.9	44.4
N	6	0.07-0.18	0.11/0.11	0.11	0.9-3.0	1.4/1.8	1.6	4.8-19.6	7.5/12.0	10.6
U	13	0.001-0.50	0.03	0.07	0.03-10.2	0.4	1.5	0.3-102.0	2.9	15.2

@ Controlled experiments only. Excluding experiments with fertilizer applications > 250 kg n ha^{-1}. Regardless of soil system, location and other variables
$ Regardless of the quantity of fertilizer applied
# Regardless of the length of the sampling period.
A - Ammonium type, ammonium chloride, ammonium sulphate;
AA - Anhydrous ammonium;
AN - Ammonium nitrate
N - Calcium nitrate, Potassium nitrate, Sodium nitrate
U - Urea
[Experiments using mixed fertilizers, manure, green manure and sludge are not included]
Source : Eichner, M.J., 1988. Current knowledge of fertilizer derived nitrous oxide emissions. Paper prepared for the USEPA, Washington D.C.

Eichner's study also examined data from diverse soil systems (as seen in table 7 below). No clear trend could be seen between emissions and type of soil system. Some of the reasons to which this was attributed are a. residual plant materials from previous harvests, b.extent of disturbance between sample sites varied c.foliage and roots removed prior to sampling in some experiments.

Findings from Eichner's review of direct N2O measurements from fields are :i.Most of the fertilizer derived N2O from agriculture is released during the growing season, ii.Sampling procedures are expensive and time consuming and hence often limited, and therefore inadequate for estimating annual emission trends,iii.Measurements of N2O may be concluded once they reach background levels at the contol site,iv. The emission coefficients do not include N2O from fertilizer lost in drainage water nor the fertilizer derived N2O emitted in addition to that measured during the sampling period.One of the assumptions made while using these emission coefficients for calculation of an annual emission is that the level of fertilizer derived emissions remains the same beyond the sampling period,which need not be so.

Table 7. Fertilizer-derived N_2O emissions for soil systems and fertilizer types during the sampling period only. @

System	Fert.	No.	Percent of N fertilizer evolved as N_2O #			Daily average emissions $			Daily average emissions per kg N applied per hectare		
			Range	Median	Avg.	Range	Median	Avg.	Range	Median	Avg.
			%			g N_2O - N ha^{-1} d^{-1}			mg N_2O - N ha^{-1} d^{-1} kg N^{-1}		
Grass	A	10	0.03-0.70	0.15/0.22	0.27	0.4-14.3	2.5/7.0	5.7	4.1-142.9	25.1/69.7	57.1
	AN	2	0.04-1.71		0.87	0.3-17.4		8.9	4.3-174.5		89.4
	N	7	0.001-0.50	0.07	0.11	0.03-10.2	1.2	2.4	0.3-102.0	12.0	24.5
	U	1	0.18			2.0			19.6		
	Total	20	0.001-1.71	0.08/0.10	0.27	0.03-17.4	2.1/2.3	4.7	0.3-174.5	21.0/22.9	47.0
Soil	AA	9	0.86-6.84	1.63	2.70	10.5-123.0	23.4	43.7	61.1-492.1	140.2	200.9
	A	5	0.04-0.18	0.11	0.10	0.5-2.9	1.5	1.6	2.8-18.9	8.3	9.2
	N	4	0.01-0.04	0.02/0.03	0.03	0.3-0.5	0.3/0.4	0.4	1.2-4.3	2.4/2.9	2.7
	U	5	0.07-0.14	0.11	0.10	0.9-3.0	1.4	1.6	4.8-14.4	7.5	8.8
	Total	23	0.01-6.84	0.12	1.10	0.3-123.0	2.4	17.9	1.2-492.1	12.0	83.0
Plant	A	2	0.09-0.90		0.49	1.3-12.5		6.9	12.6-125.0		68.8
	AN	1	0.05			0.6			6.3		
	N	2	0.007-0.10		0.05	0.1-1.4		0.7	1.0-13.9		7.4
	Total	5	0.01-0.90	0.09	0.23	0.1-12.5	1.3	3.2	1.0-125.0	12.6	31.7
Grains	AN	5	0.04-0.70	0.40	0.34	1.6-5.7	3.2	3.6	9.4-44.9	26.7	27.1
Corn *	AA	4	0.0-1.80	1.57/1.78	1.29	0.0-25.9	8.9/13.3	12.0	0.0-184.9	48.8/49.3	70.7

@ Controlled experiments only. Excluding experiments with fertilizer applications > 250 kg n ha^{-1} .Regardless of soil system, location and other variables

\# Regardless of the length of the sampling period

$ Regardless of the quantity of fertilizer applied

* includes mixed N amendments and fertilizer application >250 kg N ha^{-1}

Source : Eichner, M.J., 1988. Current knowledge of fertilizer derived nitrous oxide emissions. Paper prepared for the USEPA, Washington D.C.

Strategies to reduce nitrous oxide emissions

This can fall into three categories :

i. Identification of the mode and magnitude of nitrogen losses under various agroclimatic conditions.

ii. Development of products and/or management practices that will reduce these losses.

iii. Determination of the applicability of these products and /or practices to the important agroecological zones.

I. Mode and magnitude of nitrogen losses

Nitrogen is considered to be a mobile nutrient which is lost from both soils which are cropped as well as uncropped. The magnitude of loss by a particular mode would depend on soil conditions, agricultural practices, agroclimatic conditions ,type of fertilizers and method of application. Nitrogen can be lost from the soil through ammonia volatilization, nitrification-denitrification, leaching, run off,biological immobilization by soil organic matter and NH4 fixation by clay minerals.

Ammonia volatilization:

A study of losses through ammonia volatilization indicate that as much as 60 per cent of the fertilizer nitrogen can be volatilized, especially when algal growth flourishes and marked rises in pH of the floodwater occur. Vlek and Stumpe, 1978 **(15)** have established that urea has a greater potential than ammonium sulphate for ammonia loss because hydrolysis to ammonium carbonate increases floodwater alkalinity. Other factors which influence the intensity of loss are the concentration of ammonia in the floodwater, water temperature, nitrogen source, amount of water turbulence and air exchange. Losses through this mode were negligible when urea was deep placed or sulphur coated urea was surface applied.

Denitrification

For a considerable amount of time it has been believed that nitrification-denitrification are the main processes by which N loss occurs from a soil plant system. The problem with denitrification is that the evolving nitrogen is indirectly measured. Measurements of denitrification losses from intermittently/continuously flooded soils indicate that they are far less than previously believed. Findings indicate that N losses due to denitrification seldom exceed 10% of N applied to soils of continuous/intermittent flooding provided a plant is actively growing and taking up nitrogen. Higher denitrification losses have been observed for soils where urea is applied and the land kept fallow.

Rice cultivation provides an ideal environment for the release of nitrogen viz supply of decomposable organic material to provide the energy for nitrate reduction, any oxidized form of Nitrogen - nitrate, nitrite or nitrous oxide and anaerobic conditions. Deficits in N balance experiments conducted using labeled nitrogen (Shinde and Chakravorty 1975, Patrick and Reddy 1976) **(16)** indicate the major role of denitrification in rice soils. Within a rice field, the aerobic and anaerobic zones are in close proximity and this also influences denitrification losses.

In aerated soils, the zone of maximum denitrification is near the soil surface. In flooded rice fields, in the flood water, and in the aerobic zone at the soil water interface oxygen is freely available to aid in nitrification. Once nitrification occurs the nitrate or nitrite produced then moves into the reduced zone where denitrification would occur (denitrification is favoured by reducing conditions).

Ammonium also diffuses from the anaerobic zone to the aerobic zone. Ammonium is converted to nitrate in the aerobic and the anaerobic zone. Reddy et al (1976) have estimated that diffusion of ammonium from the anaerobic to the aerobic soil layer accounts for more than 50% of the total N loss from columns of flooded soils.(17)

When land is not under continuous submerged conditions (intermittent flooding), conditions favour nitrification and denitrification.

The method of placing fertilizer in the reduced zone of the soil, is intended to prevent immediate nitrification although diffusion to the aerobic zone cannot be prevented. Since ammonium nitrogen is stable in the reduced zone of the soil basal applications of fertilizer are made. The presence of an active root system at the time of fertilizer application would also aid in reducing losses via denitrification, due to a rapid assimilation of ammonium. Correct placement and timing of application would limit losses of nitrogen from the applied nitrogenous fertilizer.

Leaching

Nitrogen losses due to leaching are influenced by soil texture, land preparation, depth of placement and water percolation rate. If the fertilizer is either deep placed or concentrated in coarse textured soils with a low cation exchange capacity there are extensive losses. Puddling on fine textured soils reduces losses due to leaching.

II. Development of products and/or management practices that will reduce these losses.

The products and or management practices listed below have been taken up for consideration. They are (A) Type of Fertilizer (B) Fertilizer application rate (C) Crop type (D) Timing of Fertilizer application. (E) Placement of Fertilizer (F) Water Management (G) Tillage practices and herbicide use (H) Legumes as a N Source.

A. Type of fertilizer

For Rice, ammonium sulphate has been considered superior to urea under normal soil conditions due to the latter's high leaching tendency. Kumar and Singh observed that use of ammonium sulphate leads to significantly higher grain yields. **(18)** Calcium Ammonium Nitrate was considered inferior to other nitrogen sources. The nitrogen recovery being (less than 38%) lower than even urea (less than 53%) recovery in the case of Ammonium Sulphate was much higher. The liquid fertilizer ankur, gave a higher grain yield as well as a higher percentage recovery. The higher leaching tendency of urea and Calcium Ammonium Nitrate, where urea leached as such with the water and

Calcium Ammonium Nitrate did so in the form of nitrate. Ammonium Sulphate and the liquid fertilizer ankur did not suffer from these type of losses. Thus, in all coarse textured and more permeable soils fertilizers susceptible to leaching before their transformation or having a higher nitrate N should not be used. For those areas having fine textured soils almost equal grain yields were obtained for these three (Urea, Calcium Ammonium Nitrate, Ankur) fertilizers for Haryana.

Prilled Urea

The application of prilled urea to transplanted rice would lead to the loss of upto 60% from the soil plant system due to ammonia volatilization, nitrification- denitrification process, leaching and surface runoff. Sudhakara and Prasad (1986) reported that when prilled urea was surface applied and incorporated between the rice rows twenty days after sowing, the loss due to ammonia volatilization in a week was 8.37% of that applied (120 kg/ha) at panicle initiation stage.**(18a)**; the loss was reduced to 1.61% when prilled urea was applied at panicle initiation stage. Buresh et al (1984) at IRRI reported a loss of 16-25 % from the surface application of prilled urea. This is of immediate concern since a major part of fertilizer in India is surface applied.

Urea Super Granule

The deep placement of USG when followed by immediate sealing of holes helps to retain almost all the urea N at the point of placement, particularly in soils with a low percolation rate. This retention of urea-N markedly decreases urea N and/ or ammonium N amounts in the floodwater and therefore minimizes N losses due to ammonia volatilization from the floodwater, nitrification - denitrification process in the surface soil layers and surface run off. In a greenhouse 15N experiment, Crasswell and Vlek (1979) **(19)** reported a total loss of less than 4% from USG placed at 8 cm soil depth.

In the non traditional rice growing areas USG has not been recommended due to the soils being either coarse textured or sandy loam soils, and therefore percolation losses being more likely. In the traditional rice growing areas USG has been recommended. Data reported by Katyal et al (1988) **(20)** show that plant N uptake from deep placed USG in coarse textured permeable soils (CEC 7.2 meq/100g) can be increased by decreasing granule size to less than 0.7g and proportionately increasing deep placement sites to achieve tha same N rate.

Deep placement of USG is not recommended in soils, where percolation rates may exceed 5mm/day particularly if the cation exchange capacity of the soil is low. Moderate to high percolation in silt loam will lead to significant fertilizer losses via leaching of unhydrolyzed urea-N and reduce fertilizer uptake by plants. In India, IFFCO has commenced commercial production of USG and its use is likely to rise significantly in the future.

B. Fertilizer application rate

1. Split application

The efficiency of N use tends to range between 25-35 % and seldom exceeds 50 % in India and abroad. In countries like USA it has ranged from 33-61 %. In India, George and Prasad (1989)

(21) using 15N showed that the recovery of applied N was 31.0, 26.7 and 25.9% at 50, 100 and 150 kg N/ha respectively. Subbiah et al (1985) **(22)** using 15N reported that when 120 kg N/ha was applied to maize in a single dressing, only 20.8% could be recovered and recovery could be raised to 38.3% by application in 3 split doses.For rice, Tandon (1989) **(23)** has recommended both the dosage and the splits of the fertilizer to be applied.

Table 8. Strategies for Split application of N in rice, Kerala

Variety and situation	kg N/ha	Application
Short duration varieties	70	in 2 splits (2/3 + 1/3)
Medium duration varieties	90	in 2 splits (1/2 + 1/2)
Medium duration varieties coarse soil	90	in 3 splits (1/2 + 1/4 + 1/4)
Long duration variety hilly area	90	in 2 splits (1/2 + 1/2)
Long duration variety coarse soil	90	in 5 splits at planting and 15, 38, 52, 70 days later

Source: Tandon,H.L.S.1989.Fert.News.34 :63-77 **(23)**

<u>Fertilizer</u> <u>Use</u> <u>Efficiency</u>

The low efficiency of N utilization by cereals especially rice, is of serious concern especially due to the crop's share of total fertilizer consumption in India, being nearly 40%. It is well known that both the efficiency of N fertilizers as well as the N recovery in plants is by and large low. Using 15N Shinde (1979) **(24)** found that recovery was as low as 24%.

C. Crop type

Upland crops

The direct loss of N in upland crops has been estimated to be 5 to 45% whereas in lowland rice it ranged from 5 to 51%. The extent of loss would also depend on the fertilizer material used. Losses under upland conditions would also be influenced by the wetting-drying cycle (intermittent flooding) which leads to increased N2O release.

Studies of N losses from fertilizer usé have concentrated for most part on the rice crops since the growing conditions favour such losses.

Seasons

The extent of N recovery by the barley/wheat crop in rabi may range from 50 to as much as 70% (under good management) whereas in kharif it may range from 50-60% (under good management). This could be attributed to a greater likelihood of leaching and runoff during the rainy season. The results of international yield trials on nitrogen fertilizer efficiency for rice, conducted in collaboration with IRRI and national programs during 1981-84 indicate that an additional yield of 1 ton/ha can be produced with 33% (dry season) and 56% (wet season) less USG N for irrigated transplanted rice and 65-67% USG-N for rainfed transplanted rice.

(D) Timing of Nitrogenous fertilizer application

Nitrogen must be applied in 2/3 split doses to coincide with critical crop growth stages (in terms of yield) when N requirement is high. There exists variation in number of splits, crop growth stage and quantity to be applied in each split. For rice, Prasad and De have found the best response was obtained when N was applied in three splits, half at the time of transplanting, and one fourth at panicle initiation and one fourth at the booting stage.**(25)**

For transplanted rice, Katyal and Pillai have recommended three splits and for direct seeded rice, two splits; half at tillering and half at panicle initiation.**(26)** However more split applications are needed for long duration varieties and for lighter soils.

E. Placement of fertilizer

Mobility of the nutrient

In the case of phosphatic fertilizers they are placed close to the root zone. Urea could either be broadcast or could be basally applied. Once so placed there would be losses due to urea hydrolysis but ammonia volatilization losses would be less than in the broadcast method.

15N labelled fertilizers on a montmorillonitic clay showed that nitrogen utilization and grain yield were highest when the fertilizer was placed at a 10 cm depth. (De Datta et al., 1968) Prasad et al 1970, showed that deep placement of nitrogen and use of pellets was superior to broadcast application and both gave a higher nitrogen efficiency.**(27)**

Placement of USG is recommended in the reduced zone (lower oxygen conditions, less aerobic nitrifying bacteria and therefore less release of N2O emissions).In this reduced zone the ammonium ions would be stationary and stable due to absorption by the negatively charged clay particles of the soil.The placement of USG at a 8-10 cm depth leads to a higher nitrogen concentration gradient which in turn lowers the rates of hydrolysis and nitrification, minimizes ammonia volatilization and denitrification losses and therefore increases the plant's response to N application. The oxidized zone is the zone closest to the surface where ammonia would be converted to NO3. At present, according to Dr Naresh Prasad there are no applicators for placement of USG in the reduced zone, although USG and Briquette applicators have been developed.

Deep placement

In this method, fertilizer is placed in the reduced soil layer so that the concentration of urea and ammonia in the water remains essentially zero. Initially deep placement was believed to improve fertilizer use efficiency by reducing nitrification and denitrification although now research indicates that it also largely prevents ammonia volatilization losses. Another advantage of deep placement of USG is that it does not inhibit the growth and nitrogen fixing activity of blue green algae in the flood water and surface soil, leading to an increase of nitrogen within the soil plant system. The negligible urea-N in the floodwater results in less stimulation of weed growth.

De Datta and Stangel **(28a)** and Hignett **(28b)** based on data obtained from International Network on Soil Fertility and Fertilizer Efficiency in Rice (INSFFER) have found that urea super granule or briquette is the most effective method for deep placement. Mud-balls are marginally better agronomically, but the labour cost involved in making them is prohibitive.

F. Water Management

Water management is an important factor influencing nitrogen use efficiency. Upadhyay and Datta found that utilization of fertilizer nitrogen was about 10 % higher under continuous flooding than under mid term drainage. **(29)** Pillai has also found nitrogen efficiency to be higher under continued submergence as compared to a intermittent flooding condition. **(30)**

Intermittent flooding of rice fields increases nitrogen loss and creation of N2O. (Erikson et al; 1985; Olmeda and Abuma 1986) **(31)**.

In a study in Northern China, by Weihan et al 1990 on the day after irrigation, the N2O flux rose to 45 ug N/m2 from a value of 15 ug N/m2 and fell to 5 ug N/m2 on the 9th day after fertilization as the soil dried. **(32)**

This fact is of consequence given that in India fertilizer application rates are higher and concentrated in irrigated areas as compared to rainfed areas. It is estimated that use of fertilizer between these two areas may vary as much as 30 kg/ha. Given that emissions are greater from irrigated lands, the trade off between methane emissions and N2O production must be better understood in the case of rice fields, where standing water conditions are prevalent and essential at the time of transplanting.

Two suggestions made regarding water management are : (a) Shallow submergence of 0-5 cm is recommended for rice. (b) While applying top dressing in rice, the field must be drained prior to application of fertilizer. Only 2-3 days after this, should water be introduced.

G. Tillage practices and Herbicide use

Puddling of soils (prior to transplanting) increases the bulk density of soils, in turn reducing the percolation rates and resulting leaching losses.

Use of herbicide leads to an improvement in N recovery by the crop. This would be because of less competition from the herbs.

H. Legumes as a N sources

There are limited studies regarding the role of N fixing crops in release of N_2O. Eichner (1990) has estimated that the level of N_2O emissions from agricultural soils cropped with legumes ranged from 0.34 to 4.6 kg N_2O ha^{-1} yr^{-1} including natural emissions associated with cultivation and emissions from N fixed by the legume crop. **(33)** These are similar and range from emissions from fertilized and unfertilized fallow soils. Since the fertilizer industry is energy intensive and uses fossil fuel energy, it would be worthwhile to explore legumes as a N source instead of ammonia or urea. In the case of legumes, symbiotic bacteria fix the Nitrogen. At present, within India, no such comparative studies of emission estimates have been done for leguminous crops.

Although other biofertilizers have been taken up for discussion later, the biofertilizer Rhizobium has been discussed at this point,due to its association with legumes. It colonizes the roots of specific legumes to form nodules, which function as producers of ammonia. As much as 100-300 kg nitrogen per hectare can be fixed by the Rhizobium legumes association. Nitrogen fixed per hectare per year by different legumes ranges from 100-150 kg for clover, 80-85 kg to cowpea, 100-300 kg for alfalfa, 90-100 kg for lentil, 50-60 kg for groundnuts, 50-55 kg for moongbean.

Information of the effects of Rhizobium inoculation, on legume yields is given below in Table 9.

Table 9. Effects of Rhizobium inoculation on legume yields

Crops	N-fertilizer (kg/ha) supplementation	% Yield increase over control	Reference
Soyabean	-	13-139	Balasundaram & Subha Rao, 1977
	-	26-92	Tilak and Subba Rao, 1978
	100	10-19	Tilak and Saxena, 1974
Pigeonpea	-	2-40	Rewari and Tilak, 1988
Chickpea	-	13-39	Rai et al, 1977
Lentil	-	17	Rewari and Tilak, 1988
	25	43	Sekhon et al, 1978
Mungbean	20	51	Singh, 1977
Cowpea	-	33-53	Bagyaraj and Hegde, 1978
Groundnut	-	11-32	Kulkarni et al, 1986
Urdbean	-	4-29	Rewari and Tilak, 1988

Source: Venkataraman, G.S., and Tilak, K.V.B.R., Biofertilizers in Sustainable Agriculture. Soil Fertility and Fertilizer Use Vol.IV, Nutrient Management and Supply System for Sustaining Agriculture in 1990s, IFFCO, New Delhi. (34)

Future Research

Slow release fertilizers

This is based on delay of availability of soluble nitrogen to the plant until the root system can compete with loss mechanisms (leaching and denitrification) and biological immobilization of the fertilizer nitrogen. Less labour is also used in the case of slow release fertilizers as compared to split application and less technical skill is also needed.

There are two categories of these fertilizers (1). chemical compounds with an inherently slow rate of dissolution for example Ureaform, Oxamide, Isobutylidene Diurea and (2) coated fertilizer having a moisture barrier on urea or any other granular conventional fertilizer for example sulphur coated urea (SCU), lac coated urea. Leaching and other losses are far less with such fertilizer use and these fertilizers are superior to urea.

Sulphur coated Urea

Sulphur coated urea is probably the most tested and most widely used. Sulphur coated urea has been found to be significantly better than a single basal application of urea and in some case even better than the best split application of urea. In 24 dry season and 60 wet season trials conducted during 1975-77 under the INSFER programme, SCU gave significantly higher yields than the best split application in 30 percent of the experiments. IRRI, 1973.

In India field experiments under AICRIP (1969, 1970) showed that SCU gave 50% more increase in yield than urea. Results from

AICAES, 1972 showed that SCU gave 470 kg/ha more grain as compared to urea. In Indonesia, Partohardjons and Fitts (1974) **(35)** found SCU to be superior to three split applications of urea under intermittent flooding whereas under constant flooding there was no difference between the two treatments.

Sulphur coated urea also reduces loss of ammonia through volatilization, permits nitrogen fixation by blue-green algae and limits concentration of urea in the flooded water at any time. Sulphur coated urea, could be used in salt affected soils, although the sulphur used in coating has to be imported from outside India.

Neem coated urea

Bains et al (1971) **(36)** has shown that treatment of urea with an acetone extract of fried and crushed neem kernal increased the efficiency of urea as a nitrogenous fertilizer. Use of neem coated urea was better or comparable to SCU and USG.

Neem-cake coated urea, has been at par with sulphur coated urea but when the residual effects on a succeeding crop were examined, sulphur coated urea was better than neem coated urea. Sulphur coated urea is particularly suitable for intermittently flooded rice ensuring that all the urea is not nitrified and denitrified through the first wetting and drying cycle.

(b) Use of nitrification inhibitors

The basic reaction leading to major nitrogen losses through denitrification and leaching is the nitrification of the amide and ammonium nitrogen. It is essential to know which loss mechanisms must be blocked before effective means to prevent loss can be developed. The loss of nitrogen from fields after nitrification of urea or ammonium nitrogen has been significant particularly under intermittently flooded conditions. Under such conditions nitrifiction inhibitors have been widely tested.

N-serve, the first specific nitrification inhibitor effectively controls nitrification of ammonium nitrogen. Among the other nitrification inhibitors are AM, Dicyandiamide (DCD), Thio urea, ST, Potassium azide, ATC and CL - 1580. Some indigenous materials like neem cake and oil have also been tried as nitrification inhibitors. Results of use of nitrification inhibitors in the field have shown mixed results. Rajale and Prasad (1975) **(37)** and Nishihara and Tsureyschi (1968) **(38)** from Japan have shown a beneficial effect of use of these inhibitors but Patrick et al (1968) **(39)** and Turner (1977) **(40)** USA, have failed to obtain any significant yield increases in rice yields using these treatments.

(c) Coatings

Both sulphur coated urea and neem coated urea have already been discussed in the previous section on slow release fertilizers.

In India, Godrej Limited is marketing a neem extract called Nimin, (obtained during extraction of neem oil from neem seed, the neem bitterns which remain are being marketed), which is used to coat urea and slow urea hydrolysis. Neem extract is also a nitrification inhibitor, and is a strong nematicide and insect repellent, apart from serving as a coating to slow urea hydrolysis.

Use of Biofertilizer

Biofertilizers as indicated by the name includes all nutrient inputs for plant growth which are of biological origin. Waterlogged rice fields offer potential for both heterotrophic and photo autotrophic nitrogen fixing micro organisms to function and contribute to the nitrogen fertilization of rice.

Bacterial or microbial fertilizers which are included in this category are used to either fix atmospheric nitrogen or stimulate plant growth through synthesis of growth promoting substances. Rhizobium inoculant, specific for different leguminous crops is the most important. Blue green algae (Cyanobacteria) also fix atmospheric nitrogen if they are inoculated into the soil and established in paddy fields. Other bacterial fertilizers include Azotobacter and Azospirillum. The wide range of these fertilizers will not only aid in use of atmospheric nitrogen, but would also supplement the extremely low levels of present inorganic fertilizer usage.

Inorganic N fertilizers can be substituted to some extent although not wholly using biofertilizer, green manure, and organic manure. For instance in the Indo-US SSP Programme in Agriculture (1984-88) for the rice wheat cropping system, efforts to evaluate nitrogen substitution using Sesbania aculeata grown in situ, for different centres demonstrated the beneficial efforts of this on rice yield, despite increases in ammonia volatilization losses from soils of manured with green manure. Savings of fertilizer nitrogen by use of green manure for rice, were in the range of 40-60 kg N/ha. **(41)**

In India, biofertilizers in the form of suitable strains of Rhizobium and Bluegreen algae as a cheap and alternative source of N supply, is being explored. The Government has established a national centre at Ghaziabad and four regional centres at Hissar, Jabalpur, Bhubaneshwar and Bangalore. The production of rhizobium and blue green algae has commenced and the latter's reported annual production was 107.85 tonnes.

Types of Biofertilizers

Some nitrogen fixer like Rhizobia are obligate symbionts in leguminous plants, while others colonize the root zones and fix the nitrogen in close association with plants. Azospirillum is included in the latter category. The crops which have been found to respond to Azospirillum inoculation are maize, barley, oats, sorghum, and other crops. Grain productivity of cereals has increased by 5-20% using azospirillum.

Table 10. Effect of Azospirillum inoculation on crop yields

Crops	N-fertilizer (kg/ha) supplementation	% Yield increase over control	Reference
Wheat	80	16-20	Subba Rao et al, 1979
Rice	40	3-17	-do-
Maize	120	14	Kapulnik et al, 1981
Barley	40	17	Subba Rao et al, 1979
Sorghum	-	23-64	-do-
Pearl millet	-	0-37	Wani, 1988

Source: Venkataraman, G.S., and Tilak, K.V.B.R., Biofertilizers in Sustainable Agriculture. Soil Fertility and Fertilizer Use Vol.IV, Nutrient Management and Supply System for Sustaining Agriculture in 1990s, IFFCO, New Delhi.**(42)**

Azotobacter

Use of Azotobacter as a biofertilizer for cereals, millets, cotton, sugarcane, and other crops has been well documented. Application of this biofertilizer has been found to increase yield of wheat, rice, and maize by 0-30% over the control. Table 11 gives the effect of Azotobacter inoculation on crop yields.

Table 11. Effect of Azotobacter inoculation on crop yieds

Crops	Fertilizer supplementation (kg/ha)			% Yield increase over control	Reference
	N	P	K		
Wheat	120	-	-	11	Shende and Apte, 1982
	-	-	-	10-30	Sundara Rao et al, 1963
Rice	120	60	60	23	Mehrotra and Lehri, 1971
Maize	-	-	-	34	Mishustin and Shilnikova, 1969
Sorghum	-	-	-	15-20	Reddy et al, 1977
Pearl Millet	-	-	-	0-27	Wani, 1988
Onion	-	-	-	22	Joi and Shende, 1976
Tomato	-	-	-	2-24	Mehrotra and Lehri, 1971
Cotton (Fibre)					
Irrigated	63	30	-	10-20	Chahal et al, 1979
Non-irrigated		-	-	11-16	Pothiraj, 1979
Sugarcane	-	-	-	24	Hapase et al, 1984

Source: Venkataraman, G.S., and Tilak, K.V.B.R., Biofertilizers in Sustainable Agriculture. In Soil Fertility and Fertilizer Use Vol.IV, Nutrient Management and Supply System for Sustaining Agriculture in 1990s, IFFCO, New Delhi.**(43)**

Blue-Green Algae

Use of blue-green algae as a biofertilizer for rice has a lot of potential. Some production of algal biofertilizer has already commenced and rice growers have commenced using this algae.

The annual requirement as well as present production capacity of the major biofertilizers indicates a tremendous gap as well as the potential for commercial production. As much as 30 million hectares are under pulses and forage legumes and it is estimated by Tilak and Venkataraman (1990) that to cover this area 18,000 tonnes of carrier based material would be required.(44)

III. Determination of the applicability of these products and/or practices to the important agro ecological zones.

Tandon,(1989) (44a) has suggested the use of some of the new materials based on the prevalent soil and climatic conditions,for the cultivation of rice.

Table 11a. Recommendations on some new fertilizer materials for increasing N efficie

State		Technique	Situation
		Rice	
Andhra Pradesh		Neem-cake mixed urea	Topdressing at panicle initiation stage
Kerala		Neem-cake mixed urea (1:5 ratio)	Top-dressing
Kerala		Soil-cured urea (6:1 ratio) stored for 24-48 hours in shade	Top-dressing
Karnataka		USG deep placed 10-15 cm (7-10 DAP between alternate hills)	Basal
Karnataka		Soil-cured urea (50-100 kg soil) kept for 24 hours	Top-dressing
Karnataka		Neem-cake blended urea (see text for detail)	Basal
Meghalaya		Soil-cured urea (5:1) stored for 48-72 hrs	Top-dressing
Meghalaya		USG or Rock-P coated urea	Basal
Orissa		USG or coated urea	Basal
Tamil Nadu		Neem-cake blended urea (20% cake by weight)	Topdressing
Tamil Nadu		Urea mixed with gypsum (1:3)	Basal
Tamil Nadu		Urea treated with coaltar (100 kg urea, 1 kg coaltar, 1.5 litres Kerosene)	Basal
Rajasthan		Soil-cured urea (5:1) stored for 24 hours	Top dressing
Rajasthan		Neem-cake treated urea (100 kg Urea, 0.5 kg coaltar, 1 litre kerosene)	Top dressing
		Other crops	
Andhra Pradesh	Chillies	Neem cake mixed with fertilizer	Basal
Tamil Nadu	Sugarcane	Neem cake blended Urea (150 kg urea plus 27.5 kg neem cake)	3 time at 30,60,90 DAP
Tamil Nadu	Banana	Neem cake coated urea	Topdressed twice in 3rd and 5th month

Source: Tandon,H.L.S., 1989.Fert.News 34:63-77.(44a)

Climate change, soil fertility and nitrogenous fertilizer use

Climate changes due to increased greenhouse gases may affect soil fertility and erosion (Kimball 1985) **(45)**. Warm temperature could increase rate of microbial decomposition of organic matter.

Sionit et al (1981 a)grew wheat under fluorescent lights in a phytotron in Hoagland solution from one to one sixteenth normal strength. **(46)** The percentage response to CO_2 enrichment remained similar through the vegetative state of growth, but by the final harvest, response to CO_2 concentration was much greater in higher nutrient levels. Nitrogen and phosphate deficiency can reduce the responsiveness of yield to CO_2.

It is evident therefore that increased application of fertilizers is likely if one is to take advantage of the potential increase in net photosynthesis resulting from the expected higher levels of CO_2. It must also be noted that India's average NPK consumption in 1990-91 was 72 kg/hectare of which 46.4 kg (64%) was nitrogenous fertilizer, 18.3 kg (25%) was phosphate and 7.7 kg (11%) was potassium fertilizer. Apart from this,the bulk of fertilizer approximately (70%) is applied in irrigated area and not in rainfed/dryland agriculture (as against 30%) leading to greater fluctuations in production from the latter. This indicates the potential for increase in fertilizer use even under the existing climatic conditions.

As regards yield quality,particularly if the protein content of food products is to be sustained, any CO_2 induced increase in production will require a commensurate increase in N fertilizer use. Salinger et al,1989 have observed that more fertilizer may also be needed for maintaining soil fertility in regions where leaching will stem from increased rainfall, as in New Zealand. **(47)** On the other hand, Bergthorsson et al, 1988 predicts that current levels of output in Iceland could be achieved with half the fertilizer input, for a 2 x CO_2 climate. **(48)**

One of the predicted events which would influence agriculture indirectly and fertilizer use directly is the likelihood of reduced soil water availability. Although the pattern of soil water changes is uncertain, three of the major GCMs have predicted decreases in soil water (GISS, GFDL, and NCAR). The significance of this decreased soil water would depend on whether this would occur during the growing or the non growing season. As far as fertilizer application is concerned soil moisture influences proper mineralization of nutrients and therefore fertilizer use efficiency.

The timing of fertilizer application would be of importance in the context of climate change. In the event of increased rainfall, particularly on sandy soils, nitrogen losses can be expected to be high.

Given that the predicted regional Indian climatic scenario is expected to have an increased amount of rainfall, this could be of consequence.

Consumption of Nitrogenous fertilizer by Region

Table 12. Consumption of Nitrogenous fertilizer by Region (1987-88 to 1989-90)

Economic classes and regions	1987-88	Consumption 1988-89	1989-90
I. Developed, All	39540	39802	38171
North America	10696	10770	11244
Europe	15599	15936	15365
Oceania	409	434	448
U.S.S.R.	11787	11587	10045
Other	1050	1050	1069
II. Developing, All	36056	39857	40907
Africa	807	836	896
Latin America	3924	3801	3880
Near East	2998	3173	3350
Far East	28309	32030	32760
Other	19	17	20
World Total (I+II)	75596	79659	79078

Developed All = Canada, USA, Europe, USSR, Australia, New Zealand, Israel, Japan and South Africa Developing All = North and Central America (excluding Canada & USA), Africa (excluding South Africa), South America, Asia (excluding Israel and Japan), and Oceania (excluding Australia, and New Zealand).

Source: 1990, FAO Fertilizer Year Book Vol 40 FAO Rome. **(49)**

Table 13. Indian Nitrogenous Fertilizer Consumption (1980-90)

Consumption of Nitrogenous Fertilizers	(Million tonnes)
1980-81	3.7
1981-82	4.1
1982-83	4.2
1983-84	5.2
1984-85	5.5
1985-86	5.7
1986-87	5.7
1987-88 (E)	5.8
1988-89 (E)	7.2
1989-90 (T)	7.9
1990-91	8.02

Source: Agricultural Statistics At a Glance, February 1990, and Fertilizer Association of India. **(50)**

Table 14. Indian Nitrogenous Fertilizers (Contents of Nitrogen)

Urea (46% Nitrogen)	
Ammonium Chloride	25% N
Calcium Ammonium Nitrate	25% N
Ammonium Sulphate	(21.00% N)
Ammonium Sulphate Nitrate	20% N 20% P2O5
Ammonium Phosphate Sulfate	16% N 20% P2O5
Diammonium Phosphate	18% N 46% P2O5
Nitrous Phosphate	15% N 15% P2O5 15% K2O
Nitrate, Soda Potash	15.00 % N
Ammonium Nitrate Limestone (or Calcium Ammonium Nitrate)	25% N

Source: Fertilizer Statistics 1990-91. Fertilizer Association of India, New Delhi **(51)**

Table 15. Indian Consumption of fertilizer - material wise 1990-91

		Despatch figures
Ammonium Sulphate		554709 Tons
Urea		13201017 Tons
Calcium Ammonium Nitrate		411862 Tons
Ammonium Chloride		76412 Tons
Diammonium Phosphate		4194970 Tons
Other complexes	19 N, 19 P, 19 K	216507 Tons
Nitrophosphate complexes	20.7 N, 20.7 P	266921 Tons
Nitrous Phosphate	15 N, 15 P, 15 K	363287 Tons
NPK complexes	12 N, 32 P, 16 K	205322 Tons
NPK complexes	10 N, 26 P, 26 K	278849 Tons
NP complexes	28 N, 28 P	336523 Tons
Ammonium Phosphate Sulphate	16 N, 20 P	71833 Tons
Ammonium Sulphate Nitrate	20 N, 20 P	539774 Tons
NP complexes	17 N, 17 P, 17 K	456784 Tons
NPK complexes	14 N, 35 P, 14 K	21332 Tons
NP complexes	23 N, 23 P	16966 Tons

Source: Fertilizer Statistics, 1990-91. Fertilizer Association of India. **(52)**

Consumption of Organic manure

Biswas, B.C. et al 1991 have estimated an annual potential of 744.57 mt. for cattle dung and 258.02 mt for buffalo dung **(53)**. This in turn has an estimated potential of 3.7 mt of N. It must be emphasized that approximately 75% of this dung is used as fuel. A village level study by Singh, R., 1990 indicates that organic manure (Compost/IFYM) is used nominally and in rainfed areas it is used in kharif while in irrigated areas it is used in rabi **(54)**. Organic manure use is greater in cash crops like potato and sugarcane and less in cereals. Unlike in the case of inorganic fertilizer data regarding organic manure consumption is not easily available.

Projections of Future Fertilizer Use

Projections of future fertilizer use have been made by the Planning Commission for 1994-95 is 14.78 MT (NIC, Planning Commission) and for 2000 it is predicted at 17.61 MT **(55)**. There remain some uncertainities in the actual use due to recent changes in government fertilizer policy.

Estimation of N2O Emissions from Fertilizer Use

Methodology

The approach used for calculating N2O emissions resulting from nitrogenous fertilizer use, is based on the amount of N fertilizer consumed, emission coefficient (fraction of N per unit of fertilizer applied that evolves as N2O and a factor used to convert emissions from N2O-N to molecular N2O (the conversion factor is 44/28 representing the molecular weight of N2O)

Total N2O emissions (tons) = Total nitrogen fertilizer consumed (tons) X N2O-N Emission coefficient X 44/28.

Using a global average emission coefficient obtained by dividing average global N_2O emission from N fertilizer divided by amount of N fertilizer. This was calculated to be 0.029 =2.05 Tg N_2O/70.5 MMT N fertilizer for 1985.

Global consumption of N fertilizer, in 1984-85 was obtained from the FAO Fertilizer Yearbook (FAO) for the same year. Applying this emission coefficient (0.029) to the total nitrogen fertilizer consumption of India, yields the total N_2O emissions for the country in 1984-85. For e.g. N fertilizer consumption in India in 1984-85 was 5.7 MMT (Million Metric Tons).

5.7 x 0.029 = 0.1653 Tg N_2O per year.

More recent fertilizer consumption statistics for the world and for India, show that in 1989-90, global nitrogenous fertilizer consumption was approximately 79 MMT and for India nitrogenous fertilizer consumption was 7.4 MMT. Based on these consumption figures and the general emission coefficient for 1989-90 the estimated N_2O emissions are :

Emission coefficient is calculated as the average global N_2O emissions from nitrogen fertilizer divided by the amount of nitrogenous fertilizer consumed globally.

This is equal to 0.026 = 2.05 TgN_2O/yr/79 MMT for 1989-90.

Global N_2O emissions in 1989-90 were 79.0 x 0.026 =2.054 Tg N_2O.

Indian N_2O emissions in 1989-90, were 7.4x 0.026 =0.1924 Tg N_2O.

In order to overcome the deficiency of using a single emission coefficient across diverse fertilizer types, it is possible instead to use the emission coefficients estimated for individual fertilizer types. The emission coefficient in this case is expressed as the percentage of total N in the fertilizer that evolves as N_2O. Since the estimates of the emission coefficients from different sources vary significantly one could either use the range of such emission coefficients or one could use a point estimate based on the median value of the range.

The categories are as follows:

1. Urea
2. Ammonium Nitrate & Ammonium Salts
3. Nitrate
4. Anhydrous Ammonia
5. Other Nitrogenous & other complex fertilizers

The median values of N_2O-N produced for each of these five categories are from Eichner, 1990.

Fertilizer type	% N_2O-N produced (Median value)
1. Urea	0.11
2. Ammonium Nitrate & Ammonium salts	0.12
3. Nitrate	0.03
4. Anhydrous Ammonia	1.63
5. Other Nitrogenous & other complex fertilizers	0.11

For the calculation of emissions from nitrogenous fertilizer us within India, Eichner's (1990) median values have been used **(56)** Wherever Eichner's median values were not available instead the sourc was Ahuja, D.R., Anthropogenic emissions of Greenhouse Gases Estimation of Regional Fluxes. Draft Office of Policy Analysis Environmental Protection Agency **(57)**.

In India, fertilizer consumption data although not exhaustive is available for the year 1990-91, which is used in the calculations below:

Table 16.

Sl.No	Fertilizer type	(1) 1990-91 Fertilizer consumption Source:FAI (58)	(2) Nitrogen content (%)	(3) % Release N2O-N	Emission factor (2)x(3) x44/28	Emission in Tons N2O produced Consumption. Emission Factor
1.	Urea	13201017	46.00	0.11	0.0795142	1049668.3
2.	Ammonium Sulphate	554709	20.6	0.12	0.0388457	21548.06
3.	Calcium Ammonium Nitrate	411862	25.00	0.12	0.0471428	19416.33
4.	Ammonium Chloride	76412	25.00	0.10 *	0.0392857	3001.90
5.	Diammonium Phosphate	4194970	18.00	0.10 *	0.0282857	118657.66
6.	Other Nitrogen Fertilizers (NP)	1077194	22.00	0.11	0.380285	40964.07
7.	Other Complex Fertilizers (NPK)	2240270	(10 - 28)	0.11		67228.47
8.	Nitrous Phosphate	363287	15.00	0.10 *	0.0235714	8563.18
9.	Ammonium Sulphate Nitrate	539774	20.00	0.12	0.0377142	20357.14
10.	Ammonium Phosphate Sulphate	71833	16.00	0.10 *	0.0251428	1806.08
11.	Nitrate Soda Potash	NA				
						1351211.19

Based on the above methodology, India's contribution of nitrous oxide due to nitrogenous fertilizer in 1990-91 was 1.35 Tg.

Estimation of Nitrous oxide from complex fertilizers

Sl.No	Fertilizer type	(1) 1990-91 Fertilizer consumption Source:FAI	(2) Nitrogen content (%)	(3) % Release N2O-N	Emission factor (2)x(3) x44/28	Emission i Tons N2O produced Consumptio Emission F
7.1	28-28-0	336520	28	0.11	0.0484	16287.57
7.2	12-32-16	205320	12	0.11	0.0207428	4258.92
7.3	10-26-26	278850	10	0.11	0.172857	4820.12
7.4	15-15-15	363290	15	0.11	0.259285	[illegible]
7.5	19-19-19	216510	19	0.11	0.328428	7110.81
7.6	17-17-17	456780	17	0.11	0.293857	13422.81
7.7	14-35-14	213300	14	0.11	0.0242000	5161.86
7.8	23-23-0	169700	23	0.11	0.397571	6746.79

Source: Fertilizer Statistics, 1990-91. Fertilizer Association of India. New Delhi (58).

** % Release for Ammonium Chloride, Diammonium Phosphate, Nitrous Phosphate **(59)**. Other unmarked release N2O N are from OECD/OCDE Greenhouse gas estimation of sources and sinks **(60)**.

Assumption made while using fertilizer despatch figures is that it is the closest estimate of fertilizer consumption, in the absence of consumption figures.

Another approach to estimate N2O emissions could be by including cropwise consumption of N fertilizer. It would not be possible to use this approach for India because although there is district level data of fertilizer consumption data cropwise, there are no emission estimates from individual crops to make the estimation.

Conclusions of Fertilizer and Climate Change Study

Inadequacy of equipment for direct measurement of nitrous oxide evolving from the soil surface, in India. Normally measurements in India have been indirect using labelled nitrogen i.e. 15N

The limited time period for which emissions are sampled due to the high expenditure involved, assumes that the emissions from fertilizer use remain the same even after the sampling period. Most of the emission factors which have been estimated for various fertilizer types are under well fertilized conditions. In India, firstly the present NPK fertilizer consumption is only about 72 kg/ha which compares poorly with neighbouring countries even within the Asian region. Another fact which deserves attention is that fertilizer consumption is greater in the irrigated rather than the rainfed areas and may vary as much as 30 kg/ha between these two regions.

Eichner (1990) based on three experiments has estimated that the level of emissions from agricultural soils cropped with legumes ranged from 0.34 to 4.6 kg $N_2O ha^{-1} yr^{-1}$; this range includes natural emissions, emissions associated with cultivation and emissions from N fixed by the legume crop **(61)**. Inspite of these estimates being limited by the fact that they do not consider effects of residual nitrogen fixed by the previous season's legume crop, prior cropping history and other management factors; they would be of concern if leguminous fields are found to emit more than fertilized fields, especially if legumes are considered as an alternative to nitrogenous fertilizer.

An improvement in N use efficiency is needed in itself to meet **our** fertilizer demand which has been estimated at 17.61MT **for the year** 2000. Tandon (1989) has estimated that even a 10% **increase** in efficiency by 2000 A.D. would reduce the N needs of **India by about** 1.5 mt annually **(62)**. The low N use efficiency particularly of kharif cereals is of concern, given that nearly 40% of fertilizer consumption is by the rice crop.

While noting the potential of biofertilizers in supplementing and saving inorganic nitrogenous fertilizer, it is also important to note that green manure (Sesbania aculeata) has associated with it higher ammonia volatilization losses. Recent experiments by the National Physical Laboratory have shown higher methane losses associated with green manured rice fields. This is of significance from the global warming standpoint. Examination of potential for modification of fertilizers must take into consideration the availability of material indigenously, for instance neem is being used for coating urea instead of sulphur which would need to be exported. In the case of neem extract for instance, it is produced as a side product.

As to whether India is a significant contributor of nitrous oxide the answer is definitely negative. Given our low consumption of nitrogenous fertilizer, and the estimated emission of 1.35 Tg for 1990-91, this is evident.

Direct measurements of N2O emissions within India are very limited at present and this study would be more meaningful with such an inclusion. It would be pertinent to mention that no clear trend exists between emisions and type of soil system, so merely extrapolating from other measurements does not hold any meaning.

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`PRINCIPLES' AND `COMMITMENTS' TO LIMIT CLIMATE CHANGE : A COMMENTARY

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ABSTRACT

This paper reviews the salient aspects of some of the documents that have emerged from the Intergovernmental Negotiating Committee (INC) on Climate Change. It discusses these aspects in the light of issues of development, national sovernighty, achievability and equity.

This paper assesses the salient aspects of the documents that have emerged at the INC negotiations on Climate Change.[1, 2] A convention on climate change would need to manage the rate and extent of greenhouse gas (GHG) emissions as these are taken to be the causes of a potential climate change. Managing the rate and extent of GHG emissions would necessarily have to target those activities that contribute to these emissions. Table 1 summarizes the contributions to emissions by activities. It is clear from the range of activities involved that a convention would involve constraints to be imposed on national development paths, especially on those components that are energy driven, fossil fuel based and resource intensive. Constraints would necessarily limit choices available to a nation, create a need for greater information about alternatives and involve painful and costly transitions to less climate damaging development paths. It is clear that the issues underlying climate change whether at the level of causes or at the level of responses are intimately connected with issues of development.

There are two main sets of documents emerging from the negotiations at the INC-those relating to Principles and those relating to Commitments and related mechanisms. The set relating to Principles is a summary of the various positions taken on what should be considered as guidelines within which commitments should be based. A chapter on Principles in a Convention in general trends to provide orientation for the commitments and obligations that follow and are thus an important section of a convention. The identification of such principles by the Parties is a reflection of their concerns with the implications of the subtantive outcome of the main body of the convention.

The set relating to Commitments and related mechanisms refer to the obligations and the means to achieve these being negotiated in pursuance of the objective othe convention and in accordance with the Principles established.

This paper limits itself to a discussion of the Principle and the Commitments on sources and sinks.

COMMON CONCERN OF MANKIND

The document on Principles for a framework convention on climate change declares the problem of climate change to be one of a "common concern of mankind". What is considered a common concern of mankind is (i) the fact of climate change and (ii) the reduced absorptive capacity of the planet to limit climate change. The notion of "common concern of mankind" in the climate change negotiations is analogous to the notion of "common heritage of mankind" in the seabed negotiations, introduced in 1967 by the Maltese delegation. The use of the word heritage implied rights and created the need for the establishment of rules by which the exploitation of ocean resources beyond national jurisdiction would be governed, and the institutions capable of acting on behalf of mankind as a whole. Obviously, the problem of climate change can not be seen as a common heritage problem, but one of common concern of mankind. However, the problem was caused by an overuse of global atmospheric resources and natural sinks and hence a reponse strategy requires that rules be established and institutions created to allow all of mankind a share in these global resources. Thus, while the problem of climate change is one of common concern of mankind, the future sharing in global atmospheric commons translates into a problem of operationalizing the notion of "common heritage of mankind" as applied to the global atmospheric resources.

It is significant that the word "mankind" is used rather than the more easily comprehensible term "international community" or "all states". It is used, however, to indicate that the problem is of concern, not just of all states and their inhabitants as of now, but also to future generations, and to peoples who have not as yet attained full independence. So immediately the notion of "commonalty" and "intergenerational" are brought into the area of discourse. It is very clear,however, that "mankind" is only the object whose interests have to be considered in any policy decisions taken, and not the active subject in any response strategy, which calls for the participation of "all states in the international community in accordance with the means at their disposal and their capabilities".

While the fact of climate change and the reduced absorptive capacity of the planet to limit such change calls for a response and a common interest in preserving those components of the planet's absorptive capacity,it is not clear that all inhabitants have equal rights to all sinks. (Pt. 2, Alternative (i) and (ii).[1] Some sinks, for example, forests are not "global commons" a comment often heard of forests in recent times. Forests are located within a nation's territory and as such are subject to its sovereignty. The principle of national sovereignty over resources has been held to mean (i) that nations having such sovereignty can deny access to or use of such resources to other nations or (ii) that it can allow such use and access on terms and conditions that it chooses[3].

To now to begin to treat forests as a global commons as, for example, the atmosphere or the oceans beyond national jurisdiction, is to deny nations the control over resources within their national jurisdiction. This is not to say, however, that a nation has the freedom to pursue any resource policy it chooses without regard to the damage that it may cause to the environment of another. Emerging principles of international environmental law on various other resource uses do indicate the existence of international constraints on a nation's freedom to develop its national resources. The main difference between the impacts of other environmental laws or conventions to regulate use of environmental pollutants and a convention to regulate GHGs is that the range of activities that could be impacted and constrained is much larger as is indicated in Table I.

It is important to differentiate between "global" and "local" commons in the sense that the latter while being an international public good is primarily of immense national economic value. Forests are both private and public goods in the sense that if only their economic products are considered , i.e., timber and other woods, minor forest produce, recreation values, etc., one can use the principle of exclusiveness to regulate use. But forests also perform environmental services and when these are provided to one nation they are provided to all nations and there is no mechanisms to exclude nations from these services. To allow and enable forests to function as an international good requires that the owner of the resource i.e., the nation, to be compensated for whatever loss it perceives to bear or actually bears for having to preserve forests for the wider public good.

Unlike the perception prevalent in law of the sea negotiations, wherein a new resource- ocean resources, especially deep sea manganese nodules - was seen to expand the production possibility frontier, the case of climate change involves a response strategy that may call for a reduced use of resources, for example, coal and petroleum resources or timber production. This could imply a reduction of production possibilities and perhaps, even growth, unless international policy measures are taken to avoid this limitation. In the sea-bed negotiations, the notion of "common heritage of mankind" came to be increasingly seen as a factor that promoted some outcomes and inhibited others.[4] It can be said that by declaring the problem of climate change to be one of a common concern of mankind a similar effect is sought to be obtained. The principle that declares climate change as a common concern of mankind can be argued to have both a positive and a negative aspect to it. On the negative side it could be construed to mean that states, while pursuing their own national polices have the responsibility not to cause <u>undue</u> damage to the environment in areas beyond national jurisdiction.

On the positive side, it implies that states having accepted that the problem of climate change is of common concern to all mankind have the responsibility to increase the capabilities and resources of the international community to cope with the problem be it in terms of technology, financial or institutional resources and capabilities.

INCLUSIVENESS

The fact that climate change is a global problem requiring global solutions makes it essential that any agreement so devised has to allow for inclusiveness at all levels (i) of actors (ii) of the gases and activities contributing to the problem and (iii) of the range of anticipated consequences. While a lot of mention is made about the need for global sacrifices as part of the global solutions, it has been pointed out that while developing countries such as India, would be prepared to join in the larger mitigative effort, sacrifices should largely come from those countries who have the responsibility for causing the problem.[5]

The section on Principles states clearly the need for "universal participation" in a response strategy and also puts the need to adopt a "comprehensive approach" across all GHG emissions on the negotiating agenda. The "comprehensive approach" avoids limiting measures to control GHGs just to CO2, or to one source (energy) or merely to sources and not sinks. A number of countries support this approach , among others, U.S.A., Canada, Norway, the erstwhile USSR, Saudi Arabia, Kuwait nd Australia. Most of these countries are either large coal or oil/gas producers and exporters and/or large consumers. The key arguments put forward for a comprehensive approach are:(i) that it seeks to address the full problem in all its aspects (ii) it provides the flexibility to take into account individual differences between countries, thereby, allowing GHG reduction strategies to complement other national environmental goals (iii) it seeks to develop an effective programme of action based on consensus an joint commitment to a target (iv) it recognizes the interrelationship between national and international action and (v) it recognizes the current areas of scientific uncertainty.[6] On the other hand, the "partial approach" tends to favour the coverage of CO2 alone, and fossil CO2 rather than that emerging from biotic sources, and on sources rather than sinks. It is important to remember that the range of gases included in the control regime and the time horizon will affect the distribution of responsibility of emissions across countries and would therefore be of importance in any negotiation. While comprehensiveness is theoretically a more appealing approach, regime effectiveness may call for a more gradualist response strategy to take account of the technical feasibility and efficiency of control of various sources and gases and the different historic contributions to concentration levels and levels of development and capabilities of states in adopting mitigating strategies. For a control regime to be effective, it is necessary that GHGs that are to become the target of action be limited to those gases:

(i) where measurement is possible and consensus exists about the availability and reliability of emission data. Certainty regarding data varies across GHGs. For example, fossil fuel CO2 and CFC emissions are known to within +/- 5%; Estimates of CO_2 emissions from deforestation and land use vary between +/- 50%; methane emissions from different sources and countries are rarely known better than +/- 30%.[7] Hence a case exists for controlling those gases where the range of uncertainty is least, which in this case are CFCs and fossil fuel CO_2.

(ii) which are controllable by policies and existing technologies

(iii) which form part of formal economic activity and do not involve basic human subsistence activities. As levels of uncertainty change and more is known about the consequences of GHG concentrations and about the impact of actions taken at the first stage, this coverage can be extended. These requirements point to the best immediate targets of action to be fossil CO_2 and CFCs. However as the latter is already included under the Montreal Protocol, carbon dioxide emerges as the primary candidate for initial action.

PRECAUTIONARY PRINCIPLE

The Precautionary principle calls for action in the absence of full scientific certainty. Although the wording links it directly to measures to meet the climate challenge in a cost effective manner, in substantive content the principle would translate into a "no regrets approach" which commonly refers to action planned or taken to meet national goals outside of the climate change problem but which also tend to reduce the pace of GHG build-up. A broad complementarity between objectives of economic growth and those concerned with global climate change are evident in measures to increase energy efficiency. For example, more realistic energy pricing would stimulate end use efficiencies and thereby reduce the CO2 intensity of growth but it would also reduce the demand for energy and hence the investment resources for energy required to meet growth objectives. The tremendous impact of energy efficiency on CO2 concentrations on be seen in the scenarios given in Lovins et al (1981/83) The stark contrast with the highest published scenario, that of Edmund et al(1984) is given in Table 2.

COMMON BUT DIFFERENTIATED RESPONSIBILITY

The crucial element of the convention would be the operationalizing of the "common but differentiated responsibility" to the problem of climate change because herein lies the heart of the question of equity or fairness. To stabilize climate change requires stabilization and even reduction of emissions of GHGs. Who should do what and why should they do what they are required to do are the crucial questions. Differentiated responsibility gets translated into differentiated commitments for countries taking into account the circumstances of different groups of countries. Italy provides a broad classificatgion to illustrate this:

(a) Least developed countries

(b) Small island

(c) developing countries with a substantial industrial sector

(d) Oil producing developing countries

(e) Newly Industrializing Countries

(f) Countries with economies in transition (e.g. Eastern Europe and the Commonwealth of Independent States, (CIS)[11]

(g) Non-OECD countries

Within the EEC too, there is a considerable difference in levels of development requiring that the circumstances of the less developed be reflected in any commitments that are made for the countries of the EEC.

In the run up to a possible convention a number of rationales have been put forward in support of various allocation schemes. Various equity rationalshave been on way be advanced as basis for such allocation.[7]

(a) Egalitarianism which refers to equal rights per person to a resource, in this case the right to emit GHGs. This translates to a form of per capita allocations. A strong version of this is found in Fujii (1990) who bases his system of accounts for GHG emissions on the equity ratinale that 'everyone has an equal emission quota irrespective of both the country he or she lives in and the generation he or she belongs to'.[8] This, therefore, requires that anthropogenic emissions of GHGs converge at a common per capita level in the future.

(b) Willingness to pay reflecting the ability and possible national impacts of climate change. Translating "willingness to pay" as being the more usual "willingness to pay to avoid adverse impacts" may however prove to be inequitous, because a number of the victims of the impacts of climate change may not have any responsibility for causing the problem nor the means to pay to avoid the consequences. It is therefore preferable to limit the translation of the term to the ability to pay .

(c) **Historical Polluter Pays Principle and compensation to victims.** The PPP has been formally accepted by the OECD countries in other pollution contexts. The PPP means

> ...that the polluter should bear the expenses of carrying out ...measures decided by public authorities to ensure that the environment is in an acceptable state. In other words, the cost of these measures should be reflected in the cost of goods and services which cause pollution in production and/or consumption. Such measures should not be accompanied by subsidies that would create significant distortions in international trade and investment.[9]

A number of advantages have been claimed for the PPP, namely, those from the standpoint of equity, induced shifts in demand patterns, alleviation of residual damage and trade neutrality.[10] Very briefly, the equity argument is that consumers of the final products do at least in part internalize the environmental costs in proportion to their expenditures on the products. Thus, those that consume the polluting products pay for the pollution caused to others. Since the costs of damage caused are reflected in the prices of products, it is expected that demand patterns will change away from the polluting product. It is also argued that residual damage will be reduced since the PPP will create incentives to recover waste material thus reducing the volume of solid waste.

The OECD Polluter Pays Principle as applied in the domestic context, for example in the case of oil spills, has come to be interpreted as implying that if a polluter is to bear the costs of measures to prevent and control an actual or threatened oil spill, because he is liable, than it follows from the PPP that he should bear all costs and not merely the additional costs. All costs refer to fixed costs involved in

-control of oil spills where the party libale has been identified

-control of other oil spills;

-other functions (e.g. coastal monitoring)[11]

If this reasoning is extended to liability for causing the problem of climate change through increased GHG concentrations, it can be argued that the developed countries should bear all costs involved in measures to prevent and mitigate climate change as well as adaptive mesures required to cope with climate change.

The Group of 77 and China supported by some other delegations have been arguing that these countries must receive financial transfers in compensation for the incremental costs that they will have to bear in adopting measures to combat climate change. The argument is for the transfer of resources that are "new, additional and adequate". "New" refers to financial flows that are not considered as assistance or aid, but as compensation to adopt measures to combat climate change. This follows directly from the interpretation given to the Polluter Pays Principle in the national context by OECD countries. "Additionality" refers to flows in addition to the target set by the United Nations for ODA flows at 0.7 per cent of GNP to assist developemnt efforts of developing countries."Adequate" refers to the compensatory flows meeting the full incremental cost of the measures that developing countries would adopt to meet global climate concerns. "Full incremental costs" of responding to climate change refers to the costs incurred both at the level of governments and firms to comply with convention obligations. This would, for example, include the costs of insurance cover for countries that will have to face damages from the effects of sea-level rise. It has been pointed out by the delegate from Papua New Guinea that the effects of a sea level rise would soon not be insurable on the world's insurance markets, and hence there was need to ensure access to a global insurance pool for those countries needing catastrophe cover.

(d) Status quo Rights i.e. that current rate of emissions constitute status quo rights having been so established by custom and usage. This argument claims that according to the common law of "adverse possession" industrial countries are entitled to their higher rates of emission. This is an unacceptable argument since it claims that those who have polluted should be allowed to pollute idefinetely, and amounts in fact to rewarding those responsible for the problem of climate change with further rights to emit greenhouse gases.

Whatever the criterion used to allocate rights to emissions, it seems likely that countries will plea special circumstances in order to either change their initial allocations, or to make a case for compensatory side payments. In this case, the formula employed will only be useful as a departure point for the final outcomes.

Grubb et al refer to a practical distinction that can be made between these various equity rationales according to whether they are based on a burden criteria or responsibility criteria. It seems evident from the INC's document's reference to a polluter pays principle that it is a responsibility based criteria rather than the burden criteria that is being supported in the negotiations. However, the fact that the obligation to protect climate is being distributed according to the differential capabilities of states also points to a recognition of the burden that could be imposed by such an obligation on states at different levels of development and capabilities.

Mitigation strategies can be broadly classified as (i) limiting GHG emissions and (ii) adopting a less climate damaging development path. while the two are not mutually exclusive the focus of attention in each set of strategies is different as would be the set of actors. Limitation of emissions would call for (i) a curtailing of present activities that are fossil fuel based (ii) reduction of practices that are GHG intensive (iii) phasing out CFC production and use (iv) management of landfills. In addition, most of these measures would have to be in the short and medium term. The need for action in a short time frame would involve sacrifices and painful transitions. Adopting a less climate damaging development paths is a strategy that allows for a longer time frame, without calling for specific limits in the short and medium term. It would involve a movement to non-fossil fuels, energy efficient technology, etc. There seems to be a strong case for developing countries to press harder for technology transfer packages for various efficiency and non-fossil fuel technologies rather than for larger shares of whatever overall carbon pie is to be meted out. This is because while developing countries will need to depend on fossil fuels in the short and medium term, over the longer run they would be better off not to invest heavily in fossil fuels as they would be internationally disadvantaged relative to the industrialized world which would by then have invested and be enjoying the products of advanced efficient technologies adopted earlier on in the controlled situation.

If we accept the "first polluter pays principle" and carbon emissions per capita criterion as a measure in the assessment of responsibilities for historic concentrations, a tentative cut-off point to determine the countries that should have specific quantitative emission limitation targets could be of say 0.5 tonnes per capita (cumulative) and 2 tonnes per capita (current) carbon emissions per year (8). According to the IIASA assessment this would include the following countries and regions: North America, Oceania, W. Europe, USSR, Eastern Europe (1987 definition) and Japan (fig. 10) Action However, has to take into account that whatever is prescribed has to be both acceptable and doable. One way of doing this is to adopt a different strategy to achieve (i) stabilization of emissions and (ii) reduction of emissions. Stabilization of emissions should be required on an individual basis by countries. The argument here is that no great hardship is going to be fostered on the peoples of the industrialized countries if they are asked to level off emissions say, at current levels either through adopting more efficient technologies to provide them with energy services they already have access to or to trim off extravagance through more efficient pricing policies. However, countries could have the option to implement part or whole of their reduction of emissions targets either individually, jointly, or in cooperation with other, especially countries with no quantitative commitments as suggested by Norway. These arrangements could involve projects which help these latter countries to move to a path of less climate damaging development and could take the form of joint agreements in more environmentally friendly resource projects such as natural gas, minihydel, wind, solar, etc. or in the transfer of technology that could improve the efficiency of power systems in less developed countries, or even debt for nature swaps. However, it should be possible for the monitoring agency to clearly establish that such projects are in effect reducing carbon emissions that would have occurred in the absence of such projects before such reductions can be credited against the emission reduction targets of the contributor country. In the absence of such verification and transparency of national actions, the exercise could amount to being no more than an accounting gimmickry and will fail in the very purpose for what it was intended - to reduce global CO_2 emissions in a cost effective manner. It should be emphasized that at the current level of understanding of the mechanisms of sinks, credits for reducing CO_2 emissions through joint implementation should be allowed only against projects that aim at reducing sources of CO_2 emissions and not for sink creation. It is also necessary to avoid linking fossil and biotic carbon emissions through allowing trade-offs between fossil carbon emission reductions and net reforestation. Krause et al provide cogent arguments to avoid such an offset approach: (13)

(a) Reforestation and forest preservation provide only temporary emission reductions until biomass levels in replanted areas have steadied. By contrast, fossil carbon substitutions can provide emission reductions as time goes on.

(b) Compared to fossil fuel consumption, net reforestation and deforestation rates are hard to measure and verify.

(c) The offset approach could reinforce the misguided notion that any kind of tree planting is environmentally and socially benign and sustainable.

(d) It could be difficult to coordinate the necessary national policy-making process in developing countries with the emission - offset agenda of energy supply companies.

(e) Linkages between the fossil fuel area and reforestation could aggravate problems of developed country interference in the affairs of developing countries.

RIGHT TO DEVELOPMENT

The section on Principles lists the right to development as an ineienable human right and the developing world is making this principle a sine qua non for any participation. The implications of this principle is that no commitment or obligations will be accepted by the developing countries unless it is clear that these will in no way inhibit their ability to develop. By introducing this principle the developing world is in a way, seeking to ensure that the action programmes undertaken to limit climate change do not impact on its development opportunities.

The developmental concern provide a strong incentive for a developing country to free-ride and a strong argument to introduce cross linkages between environment and socio-economic issues into the convention. Participating and adhering to a convention may reduce its production possibilities and it could, therefore, be better off enjoying the benefits of reduced GHG emissions without having to bear the costs of limitation strategies. The need to draw up a convention that allows for cross linkages between emission reductions and socio-economic concern is thus necessary to ensure participation and adherence. This would also be of interest to those developed countries who believe that they would be better off outside the convention as they perceive the costs of limiting emissions as too high, but who may see the incorporation of other environmental & economic concerns i.e., control of soil erosion, reduced desertification & population programmes as attractive inducements for participation

CONCULSION

The discussion of some of the principles that are guiding the commitments and obligations indicates that for an international regime to be successful in terms of acceptability, equity and cost effectiveness, it is necessary that attention be paid to developmental concers, to issues of differential responsibility and capability of nations and the uncertainty aspects of the greenhouse gas emission climate change is indeed a common concern to all, but the responsibility and the capability to respond to it is so varied across nations that it requires enormous political will to make a global solution possible.

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(12) INC A/AC.237/Misc.7, 15 August 1991, p 48.

(13) F. Krause, W. Bach & J.Koomey Energy Policy in the Greenhouse: From Warming Fate to warming Limit Earthscan Publications Ltd., London, chapter I.7, p.I.7-6.

TABLE I

CONTRIBUTION IN GHGH EMISSIONS BY ACTIVITIES
(% of total gas emissions)

ACTIVITY	SHARE	GHG
FOSSIL FUEL USE	(81%)	
DEFORESTATION	(17%)	CO_2
CEMENT MANUFACTURE	(2%)	
PADDY CULTIVATION	(30%)	
LIVESTOCK KEEPING	(20%)	
BIOMASS BURNING	(17%)	CH_4
LANDFILLS	(11%)	
COAL MINING	(9%)	
NATURAL GAS	(12%)	
FOSSIL FUEL USE	(43%)	
FERTILIZER USE	(25%)	N_2O
BIOMASS BURNING	(25%)	
CULTIVATED LANDS	(7%)	
INDUSTRIAL ACTIVITY		CFCS

Sources : Quoted in D. Ahuja, Extended Abstract of `Estimation of India's current contribution to anthropogenic emissions of greenhouse gases', [to be published] May 1989.

TABLE II

Energy use, C-emissions and CO_2-concentration for the highest and the lowest scenario

Energy scenario	No.	year	Fossil fuel use (TW) oil	gas	coal	total annual	cumulative from 1980	reserves to be exhausted in year	C-Emission (Gt) total annual	cumulative from 1980	CO_2 conc. ppm
		1900	0.02	0.01	0.63	0.66			0.5		293
		1980	3.70	1.69	2.44	7.83	7.83		4.96	4.96	338
		1990	4.31	2.40	4.38	11.09	104.03		7.13	66.49	360
Oak-Ridge A		2000	4.92	3.11	6.31	14.34	232.79		9.30	149.74	386
		2010	6.39	4.03	10.39	20.82	411.80		13.76	267.28	425
(Edmonds		2020	7.86	4.96	14.48	27.29	655.58		18.21	429.35	479
et al., 1984)	1	2030	10.88	5.34	20.14	36.36	971.90	2026*	24.63	641.87	551
		2040	15.46	5.17	27.39	48.02	1399.63	or	33.03	934.37	656
		2050	20.04	5.01	34.63	59.68	1943.96	2065**	41.42	1310.77	794
		2060	30.81	4.35	44.27	79.43	2649.37		55.39	1801.77	982
		2070	41.58	3.69	53.91	99.18	3552.26		69.36	2432.45	1234
		2080	52.34	3.08	63.55	118.98	4652.80		83.35	3202.89	1550
		2090	63.11	2.58	73.19	138.89	5952		97.39	4113.54	1932
		2100	73.88	2.17	82.83	158.88	7450.75		111.45	5164.77	2474
		1900	0.02	0.01	0.63	0.66			0.5		293
		1980	3.70	1.69	2.44	7.83	7.83		4.96	4.96	338
		1990	3.15	1.73	2.40	7.27	87.22		4.59	55.21	357
		2000	1.77	1.52	1.77	5.05	147.72		3.13	93.08	377
Efficiency		2010	1.26	1.12	1.31	3.69	190.72		2.29	119.75	380
		2020	0.75	0.73	0.84	2.32	220.09	will	1.44	137.95	382
(Lovins et al.,	5	2030	0.24	0.34	0.38	0.96	235.82	not be	0.59	147.66	381
1981/83)		2040	0.10	0.17	0.19	0.46	242.54	reached	0.28	151.78	378
		2050	0.04	0.09	0.09	0.21	245.61		0.13	153.65	375
		2060	0.01	0.04	0.04	0.10	247.03		0.06	154.51	373
		2070	<0.01	0.02	0.02	0.05	247.69		0.03	154.91	370
		2080	<0.01	0.01	0.01	0.02	248.01		0.01	155.10	368
		2090	<0.01	<0.01	<0.01	0.01	248.16		<0.01	155.19	366
		2100	<0.01	<0.01	<0.01	0.01	248.23		<0.01	155.23	364

* Economically recoverable fossil fuel reserves are ca. 836 TW* and those probably technically recoverable are ca. 3084 TW** (Ziegler and Holighaus, 1979)

Source : Energy Policy in the Greenhouse : From Warming Fate to Warming Limt by Florentin Krause, Wilfrid Bach & Jon Koomey, Published by Earthscan Publications Ltd, 1990, pp. 1.2-11.

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