REPORT ON GLOBAL WARMING AND ASSOCIATED IMPACTS

(PHASE III)

TATA ENERGY RESEARCH INSTITUTE
NEW DELHI

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Submitted to the
International Development Research Centre, Canada

Tata Energy Research Institute
New Delhi

Contents

GLOBAL ENVIRONMENTAL ISSUES RELATED TO ENERGY DEVELOPMENT

Dr. R.K. Pachauri
Dr. Prodipto Ghosh
Dr. Ligia Noronha
Ms. Sujata Gupta

Introduction

Energy use patterns together with factor & resource endowments are a major determinant of national income, living standards, welfare, growth and trade patterns of nations & regions. However, energy supply and use are also associated with major environmental and resource concerns at local, regional and global levels. This paper focuses on linkages of energy use with global environmental concerns, in particular on global warming (GW) and climate change. It also briefly discusses the systemic and conceptual linkages between the several global environmental issues.

Global Environmental Concerns

Among the major global environmental issues which confront the world today, i.e., stratospheric ozone depletion, loss of biodiversity, deforestation, and global warming (GW), the last is directly related to energy use. It is also a problem with multifarious dimensions due to several reasons. Firstly, the causes, impacts and responses to GW are shrouded in a wide range of uncertainty. Secondly, GW is intimately associated with anthropogenic activities bearing directly on living standards, economic growth, and life styles.

The actual climatic and ecological impacts of GW may be uncertain and remote, in time and space, from the human activities causing the same. This fact means that regulation and adaptation strategies for GW must be implemented on a global, multilateral basis, since unilateral efforts alone are likely to be inadequate.

The Greenhouse Effect and Global Warming

The earth receives heat radiation in the short wavelength range while the earth's surface radiates heat in the long wavelength range. Certain trace gases in the atmosphere are transparent to the incoming radiation, but opaque to terrestrial radiation. This phenomenon is similar to that taking place in a greenhouse. These trace gases, namely, water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), and tropospheric ozone (O_3), are termed as greenhouse gases (GHGs). A "natural" greenhouse effect is essential for maintaining suitable temperatures to support the planet's life systems, in the absence of which the earth's average temperature would be - 19°C, i.e., too cold to support life.

In recent decades, the world wide emissions of GHGs from anthropogenic sources have been significantly in excess of the absorptive capacity of natural sinks. This has resulted in increasing concentration of GHGs in the atmosphere, which may imply a rise in average global temperature, resulting in altered precipitation patterns over the globe, increased intensity and frequency of storms, and a rise in the mean sea level. Of the anthropogenic GHGs, the most important by any measure of global warming impacts is CO_2.

A widely cited estimate of the extent and time path of GW is by the Inter-governmental Panel on Climate Change (IPCC) estimates. This body has predicted a likely increase in average global surface temperatures of 1.1°C (above 1990's temperature) and a rise of 20 cm in sea level by 2030, if present trends in energy use continue.

A key consideration in multilateral approaches to GW is assigning responsibility for the impacts. Manifestations of GW are related not to a flux (or flow) of emissions, but to accumulations of GHGs in the atmosphere beyond the earth's capacity to remove them. Clearly, determining responsibility hinges on the question of the time path of emissions by different countries (or regions). For carbon dioxide and CFCs, such time paths by region are known within acceptable limits of error (+ 10% for CO_2). There can accordingly, be little plausible reason for focusing on current (and future emission scenarios) and excluding past emissions.

Global Warming Potential

While a suite of GHGs are together likely to induce GW, different gases in the set have quantitatively differing potentials for entrapping heat in the earth's atmosphere.

The heating potential of a gas depends not only on its radiative forcing (i.e., the capacity of the gas to absorb heat within a particular spectral range) but also its residence time in the atmosphere. For example, in the case of two gases with the same radiative forcing but with different lifetimes, the gas with a longer lifetime will have a greater potential to cause warming because it would be active for a longer duration. Recognizing this fact, the Inter-governmental Panel on Climate Change (IPCC) has arrived at the "global warming potential" (GWP) of different GHGs by taking the decay function of carbon dioxide (CO_2) and radiative forcing over a period of hundred years as the numeraire (integration time horizon = 100 years). The global warming potential of various GHG in "CO_2 equivalent" according to the IPCC are shown in Table 1.

In our view, these estimates of GWP must be considered as flawed. This is because of large uncertainties associated with the capacity of global sinks of each of the GHGs including CO_2. Moreover, these sinks are themselves impacted by human activities (e.g. deforestation), and, accordingly, the GWP of different gases may be dependent on regulatory strategies. Further, the integration period of 100 years is arbitrary, and serves to reduce the significance of long lived GHGs, i.e., the CFCs. It would be premature, given the state of current knowledge to assign such equivalence to different GHGs in a regulatory Protocol, which should therefore remain focussed on CO_2.

Limitations in Prediction and Impacts of Climate Changes

Till now, there is no direct empirical evidence of actual manifestation of climate change. However, the scientific basis of GW is well established, and there is little reason to doubt that if concentrations of GHGs in the atmosphere are allowed to increase unchecked, eventually climate change would be apparent.

The effects of increasing concentrations of GHGs on global climate are estimated using complex computer models of the atmosphere called "General Circulation Models" (GCMs). However, the predictions of GCMs are highly dependent on small changes in sensitive parameters and the inclusion in the models of the climate feedback mechanisms.

In particular, the predictions of these climate models are uncertain due to :

1/ Poorly understood ocean circulation processes

2/ Lack of knowledge of cloud formulation and feedbacks

3/ Crudely formulated hydrological processes

4/ Coarse spatial resolution and

5/ Inability to simulate realistically the present regional climate.

The predictions of current GCMs should thus, be taken only as broadly indicative of likely changes. Considerable advances in techniques of climate modeling will have to take place before confident predictions, finely tuned in time and location, would be possible.

Economic Aspects

Emissions of carbon dioxide largely result from the use of fossil fuels, the major source of commercial energy, and of methane (and nitrous oxide) from agricultural activities.

Among fossil fuels, coal is the most intensive carbon dioxide emitter, while natural gas is the least, with petroleum being closer to coal than to natural gas in GHGs intensity (in each case in terms of CO_2 emitted per joule of heat value). Electricity generation indirectly involves carbon dioxide emissions in the case of thermal generation. Energy is an ubiquitious input in all productive economic activities, including manufacturing, agriculture, transport, mining, and to a lesser degree, services. Different energy forms are (partly) substitutable with each other, and in the aggregate, in the long run. with other factor inputs, i.e., capital, labour, land and materials. Further, energy comprises important shares of public and private consumption, and is also often considered to be a "merit good" (like food, shelter, etc.). The regulation of carbon dioxide emissions thus involves significant changes in the patterns of energy supply and use. Such regulation of any one sector carries over to the whole economy through interindustry linkages, changes in inputs used, and consequent changes in factor and commodity prices, incomes, government revenues and demand patterns. It can be demonstrated through formal economic modeling that these changes will have pervasive, major impacts on GDP, relative factor rewards (i.e., distributive impacts), comparative advantage and competitiveness in trade as well as trade patterns, patterns of natural resource use, besides changes in lifestyles, both in the short term, as well as in the future.

Energy use is a major determinant of growth. Raising living standards in developing countries will clearly entail increasing energy supplies. It is however, equally clear that a world wide level of per-capita energy use dominated by fossil fuels, at current levels of industrialized countries, is environmentally unsustainable, and may have catastrophic ecological and climatic effects in the long run.

Having said this, one may recognize that actual, adverse manifestations of GW are still several decades away. The essentials of a prudent strategy in these circumstances have been stated as follows.

> "In the meantime, although the current best estimates of global warming are not so alarming as to warrant major strategic changes in energy, agriculture, etc. industrialized countries should take all reasonable and practicable steps to restrain or reduce energy consumption, utilise all fuels more efficiently, and explore economically promising alternatives to fossil fuels." (John Mason, 1991)

Equity Issues

Any restriction of emissions (current, cummulative or prospective) makes the right to emit equivalent to a scarce resource endowment, identical in economic terms to a mobile factor endowment. For this reason equity considerations are the key issue in the multilateral regulation of GW. However, there are many complexities involved in the equity dimensions of global warming. First, the linkages between anthropogenic activities causing GW and the actual impacts of GW transcend several human generations in time, and are global, but uneven, in their spatial dimension. Secondly, the linkages (or actual impacts) are uncertain, and further research cannot resolve all uncertainties in the time frame in which regulatory structures must be devised (or indeed at all).

Thirdly, the global and national economic impacts of regulation are also uncertain, and depend, at least partly, on future patterns of technological change, and institutional changes, which are themselves, uncertain.

For any workable multilateral approach to GW, it is important to evolve a formulation of equity principles which is perceived to be "fair" by a broad set of policy makers, has wide intuitive appeal across cultures, and additionally, is workable. "Rules of thumb", or approaches which do not recognize the complexities of the equity issue may lead to a dead end in negotiations, or alternatively lead to outcomes which impose unequal burdens on different countries, and on account of which the agreements may be repudiated or reneged upon.

Without abridging the generality of the above discussion, two broad equity formulations may be cited. The first is the principle of "polluter pays", (or more generally, that of "internalizing all external effects"), which means that the agent responsible for pollution pays the full extent of the social costs vested on others for his actions. This principle is regularly invoked in the considerable economics literature on market based policies for pollution regulation as a condition for economic efficiency, besides being commended for its equity content. The second is the principle of "equal per-capita entitlements" to global common property resources, including emissions rights, a reiteration of the "all men are created equal" assertion, which is the corner stone of democratic constitutions. An implication of the second principle is that of "anonymity of agents". This means that no equity formulation is acceptable unless there is complete symmetry across societies. In particular, if a given anthropogenic activity is environmentally unsustainable if carried out by any society, it cannot be allowed to be undertaken by any other society. The actual application of these principles in an inter-generational and highly uncertain context, would call for great ingenuity. However, it is possible to devise formulations of equity which embody both these principles.

Finally, one should recognize that GW has no close peers or precedents as an issue of international concern. For example, the Montreal Protocol on CFCs, or the pollution aspects of the Law of Sea Treaty, though concerned with global resources, are far more limited in scope than GW.

They involve fewer uncertainties, less pervasive economic and environmental consequences, and are more amenable to currently available technological options. These examples can thus, serve to furnish only very limited inputs to the equity formulations of GW.

The Path of Prudence

There is little that is controversial in the assertion that developed countries (DCs) are responsible for the existing accumulation of GHGs in the atmosphere through their energy and resources intensive industrial economies and lifestyles. Further, even annual small percentage growth rates of energy use in their case translate to large absolute increase in annual GHGs emissions, as compared to developing countries. Since existing GHGs emissions growth rates are unsustainable in the long term, the first imperative, ever prior to the adoption of a multilateral GHGs protocol, (which must await the resolution of several key uncertainties as well as determination of the equity issue), is a unilateral committment by all developed countries to progressive reduction in their absolute levels of GHGs emissions. Several DCs have indeed adopted or formulated such policies. Regretably however, some major DCs have not yet done so, despite significant research evidence that, at the margin, reductions in GHGs emissions may involve little, or negative economic costs in their case. Such adjustments may involve little change in lifestyles: more fuel efficient cars and appliances, greater reliance on mass transit, more efficient home heating and the like are measures that are often suggested.

In the case of developing countries, there may be scope for the adoption of "no regret" strategies, i.e., policies which commend themselves even without considering their reduced GHGs emissions benefits. Such policies may include the adoption of advanced technologies for energy generation and energy use in key energy intensive industries such as steel manufacture, and avoiding energy intensive lifestyles such as reliance on automobiles for commuting. However, despite willingness, developing countries may be constrained by limited financial resources, besides availability of technology, in adoption of such policies. There may be scope for mutually beneficial interaction between developed and developing countries in such strategies, without such cooperation being viewed as a determination of the equity question. Such cooperation may include supply of advanced technologies, together with concessional funding, to developing countries. Modes of technology transfer in such instances should take into account the differing levels of industrial capacity, technology skills, industrial and social infrastructure, and resource endowments across developing countries. The need for funding on concessional terms arises from the fact that such technologies are unlikely to be available on competitive terms.

Another strategy in the Indian situation is increased exploration activity for natural gas. Of all fossil fuels, natural gas is the least intensive emitter of GHGs. Besides, in many applications, it effectively substitutes for petroleum and coal. Conventionally, petroleum exploration has been oriented to oil, rather than natural gas bearing geological formations. Further, when natural gas is found instead of, or associated with oil, it has often been problematic to create the infrastructive (pipeline) and downstream facilitites for its use. A much criticized result, in the Indian context has been the flaring of associated gas, because of time lags in making the necessary downstream and infrastructural investments.

Specific exploration activity for natural gas as a policy response to GW would require concessional funding both for prospecting, as well as creation of hard infrastructure. Such a strategy would also need to be dove-tailed with technology transfer for end-uses. Once again, the need for concessional funding arises from the nature of the inernational market structure in the prospecting and infrastructure creation sectors.

Linkages with other Environmental Issues

Apart from the dominant global environmental issue of climate change, energy use has dense and intimate linkages with other global environmental concerns, i.e., deforestation, loss of biodiversity, and at a second order level, with ozone depletion; with issues of local and regional environmental quality and ecology; and with depletion of natural resources. The last aspect is considered more fully in the accompanying paper :

> "International Energy Policy Trends from an Oil Importing Developing Country Perspective". In this section, accordingly, we briefly discuss the linkages with some of the other global resource issues.

Deforestation, i.e., change in land use from natural forest to other uses involving significant loss of vegatative cover, results in a dimunition of the global sink capacity for carbon dioxide. Additionally, much of the biomass of the pristine forest is burned, emitting large amounts of CO_2. Forests also amend regional climate, i.e., temperature and precipitation patterns, and further, loss of forests frequently result in soil loss, as well as increased siltation of dam reservoirs, leading to reduction of hydel capacity. Finally, climate change may result in major change in vegetative cover, particularly if temperature and precipitation changes occur too rapidly for natural forests to migrate.

Closely linked with deforestation and climate change, is the question of conservation of the world's genetic resources, or biodiversity. Natural eco-systems nurture a vast array of species and varieties of plants, insects and animals. The genetic pools are typically very site specific, and the loss of even a few hundred hectares of pristine forest may mean the extinction of several distinct species. Biodiversity is valued for several important reason. First, it is essential for the development of new crop varieties suitable for altered climate patterns due to GW or the emergence of new crop diseases or pests, the alternative to which may be catastrophic disruption of the world's food supply. Secondly, they are valuable as sources of new and useful industrial (including medicinal) products. Finally, they are valued as part of the global heritage.

Ozone depletion and climate change are linked in a direct fashion. The causative agents of ozone depletion, i.e., CFCs are also major GHGs which give rise to climate change. Regulation of CFCs by the Montreal Protocol may, in the short term significantly reduce the rate of increase in global warming potential (as intuitively understood).

The global climate, stropospheric ozone, forests and biodiversity, all have characteristics of non-excludable, global public goods [Note : A "public good" is one whose consumption by one agent does not diminish the quantity available for others. A "non excludable" public good is one to which access cannot be regulated by any practicable means]. "Production" of each of these "goods" (environmental amenities) involves (social) opportunity costs across agents, which may be highly skewed. "Non production" of these goods, i.e., the reduction in supply or alteration of existing quality may also, in the long run, entail unequal costs (and, it some cases, benefits) for different agents, and at least for some, may be catastrophic.

A key result in the environmental economics literature is that because of the "free-rider problem", agents have an incentive to understate their willingness to pay for environmental goods. This would result is a less than optimal level of environmental quality, unless a global regulatory mechanism were devised.

The world community thus faces an unprecedented challenge in devising institutions and policies for keeping the resource base and life support systems of the planet secure for future generations, and doing so equitably. India's interests would lie in the creation of effective global frameworks for regulation of the global environment, which at the same time are transparently fair between societies and across generations.

Table 1. IPCC global warming potential per tonne of gas

	IPCC
Carbon dioxide	1
Methane	21
CFC-11	3500
CFC-12	7300

References :

(1) John Mason : "The Greenhouse Effecgt and Global Warming", Energy World, Februalry 1191 (Supplement).

INTERNATIONAL ENERGY POLICY ISSUES FROM AN OIL IMPORTING, DEVELOPING COUNTRY PERSPECTIVE

Dr. R.K. Pachauri
Dr. Prodipto Ghosh

Introduction

The recent events in West Asia may have several extensive, long-term implications for global fossil fuel supply. The rapidly increasing concern for the global environment, whose degradation has important connections with energy use patterns, is a second important dimension in the current international energy scene.

Energy use patterns have pervasive impacts on the economy, growth, and the international division of labour. Oil importing developing countries (OIDCs) have, thus, a deep interest in assured energy supplies at stable, low prices, the development of alternative energy technologies, and flows of funds for a transition in their development paths to higher growth rates and increased living standards, despite increasing Ricardian scarcity of energy supplies.

In this paper we first review the recent policy analytical literature in the field.

Review of Recent Studies

Several global studies on energy have been carried out since the first oil price shock in 1973-74. Some of the more prominent among them were the global studies carried out by the International Institute for Applied Systems Analysis (IIASA) and the Ford Foundation sponsored project, "Energy : The Next Twenty Years". We are now half way through the 20 year period that was covered in the Ford Foundation study, and it would perhaps be relevant to refer to the major findings of the study. While, this particular study influenced policy decisions and thinking round the world in a significant way, subsequent changes in the global energy scenario and market conditions triggered off events and influences that have resulted in deviations from the projections and predictions of the study. However, the realities that the study had identified governing global energy supplies are to a large extent relevant even today. These identified realities were, as follows :

a) "The world is not running out of energy" : It was concluded that the physical energy resources of the world were huge, at extraction costs not much more than about double those that prevailed at the time. While the use of these energy resources may be constrained by political or environmental factors, the world would certainly not be "running out" of energy in physical terms. With proper policy planning and a willingness to pay the costs, energy supply was expected to meet any reasonable projection of demand, without "gaps" or physical shortages. But it must be noted that the ability and willingness to pay for energy were critical pre-requisites for increasing supply.

b) **"Middle East oil holds greater risks, but is so valuable that the world will remain dependent on it for a long time"** : It was concluded that the world would remain critically dependent on oil "from the politically unstable Middle East", increasing the probability that otherwise minor events will result in major economic disruption or even war (an assessment that in retrospect seems prophetic). A conclusion of the study was that world dependence on West Asian oil was due to the geographic concentration of easy to produce oil, and to the high costs of alternatives- facts that cannot be much changed by attacking the oil "cartel" (and indeed, which make cartelization in oil possible). All-round efforts at increasing supply and managing demand, it was felt, could reduce this dependence, but only slowly and at high cost.

c) **"Higher energy costs cannot be avoided, but demand can be contained by letting prices rise to reflect them" :** Higher energy costs were seen as a reflection of physical facts: it was concluded that the easy sources were about gone, while the plentiful sources were expensive to use safely. Higher costs of energy need not have severe effects on economic welfare or lifestyles if they were to be properly managed. However, the authors cautioned that it would be a dangerous misconception to believe that governments can somehow provide dependable, clean, and plentiful energy cheaply. The transition from lower to higher energy costs would be easier if prices were allowed to rise reflecting the economic realities; but finding the political will and the policy instruments to deal with the income distribution and inflationary effects was expected to be difficult.

d) "Environmental effects of energy use are serious and hard to manage" : The study referred to some energy activities, which pose serious threats to human health and to the environment. It was also predicted that the need to reduce those threats would be a major cause of rising energy costs and may even limit the extent to which some particular energy resources would be used. But it was stated that a high degree of uncertainty surrounded the mechanisms and extent of damage and risks, and the costs of reducing these threats would depend critically on how the threats are defined and managed. It was found important that environmental objectives be defined carefully and pursued efficiently, so that they can be achieved as fully as possible in the long run. We see in the world of today that environmental objectives have assumed a newer and larger dimension, particularly with the realisation of global effects. The "polluter pays" principle is particularly important in this arena from both economic efficiency and equity stand points, and no deviation should be considered from this in tackling global environmental problems. (See the accompanying paper "Global Environmental Issues related to Energy Development").

e) "Conservation is an essential source of energy in large quantities" : Even at the time the study was completed, it was found that both in the short and the long run, energy conservation was often the cleanest, quickest, and cheapest way to react to the inevitable higher energy costs. Over the twenty year time horizon of the study, conservation was seen to inevitably become one of the most important energy "sources" in quantitative terms. A major observation in this regard merits direct quotation : "Because effective (energy) conservation involves the decisions of millions of diverse individuals, with a few notable exceptions it cannot realistically be mandated or managed centrally, but requires that information and incentives be provided to energy users who make their own adjustments". This fact needs to be kept in mind in defining global energy strategies too : conservation and energy efficiency gains cannot be mandated for countries and communities.

f) "Serious shocks and surprises are certain to occur" : This was another important reality identified in the study. The energy system was seen as a complex combination of technology and society. Hence, the future was certain to contain serious shocks, most probably involving short-term supply interruptions and price instability in world oil markets. Preparation for such shocks was observed as being perhaps the most important (and neglected) function of energy policy. It was also predicted that there are sure to be surprises, both pleasant and unpleasant, regarding new supply and conservation technologies, so that the long-term outcome cannot reliably be predicted. A wide range of diverse options must be maintained precisely because we do not know which ones will ultimately prove to be most feasible or acceptable. In other words, uncertainties must be taken into account in developing future energy scenarios and strategies.

g) "Sound R&D policy is essential, but there is no simple technical fix" : The role of technology was seen in a wider context than mere technical questions. New technologies of energy production and conservation were expected to be a major part of the best response to higher energy costs, and government policies toward R&D (and towards other things, such as energy pricing) would be a major influence in determining which technologies are developed and applied, and when. But no single technical solution was foreseen as the answer, nor was there much likelihood that technology in general would be able to reverse the trend toward higher energy costs.

Recent Scenario Changes

In the last several years, three major factors have acquired prominence globally, which must also influence cooperation in the evolution of a global energy policy.

1. A larger proportion of recoverable reserves of hydrocarbons exists in the Gulf region than was the case at the beginning of the 1980's.

2. The geopolitics of oil has changed substantially, particularly with the easing of east-west tensions, and the impacts of the recent Gulf war.
3. Global environmental issues, particularly the threat of global warming, would influence energy decisions and policies substantially in the years ahead.

Since the 1970s, economists have analysed the long term prospects of stable oil prices, shocked as they were after the first oil price increase of 1973-74. It is clear that the long-term ceiling on oil prices, in the event of political developments, in the W. Asian region in particular, would be provided by the development of what are termed "backstop" technologies. The concept of a backstop technology underlies the availability of a method of producing substitute energy supplies, which could be brought into operation competitively when the price of oil reaches a particular level. The cheaper the backstop technology, the lower would be the ceiling that oil prices may rise to in the long-run because consumers would, given a reasonable period of time, switchover to energy from the backstop technologies. Several world leaders in the late '70s saw the rationale of this approach and invested large sums of money for development of alternative fuels, including renewable forms of energy, which it was hoped would provide a large menu of backstop technologies to place a lid on future oil price increases.

Elements of a New Approach

Ten years ago the U.N. organised the U.N. Conference on New and Renewable Sources of Energy. Several heads of Government, participated in this conference and plans were laid for major developments in the field of new and renewable sources of energy. Unfortunately, these plans gradually evaporated or have been dormant during the last decade. In essence the last 10 years represent a period of lost opportunity globally in the evolution of viable renewable energy technologies. In the context of growing environmental concerns at the global level there is now, therefore, a renewed urgency for shaping a purposeful common approach to the global problem of finding clean and sustainable supplies of energy, which would be to the benefit of oil importing states of the North as well as South. The elements of a new approach may be as follows.

1. Restructuring economic systems and improving the efficiency of energy production and use, whereby the intensity of energy employed per unit of output, and particularly of fossil fuels, can be reduced as rapidly as possible. (Some possibilities in this direction are discussed later in this paper).
2. Stabilisation of energy markets to minimise the risk of sudden price changes which are harmful to both consumers and producers. This can be achieved by (i) building large, dispersed global reserves of petroleum, which several national governments or international public authorities can release during periods of turmoil or

sudden reductions in supply, (ii) enhancing the production of conventional energy overall, particularly in those regions where current production is low due to scarcity of capital, technology and other inputs, (iii) finding lasting solutions to political problems in West Asia and the Gulf region, so that the danger of armed conflict in the future, which would almost certainly disrupt oil supplies once again is minimised. While the post Gulf war situatiion may lead to lower oil prices in the short-term, it does not ensure long-term stable political relations among the OPEC cartel members, and the risk of destabilizing episodes continues to exist.

3. Changing the mix of energy with greater use of less polluting forms of energy such as natural gas, renewables and, (wherever safe and feasible), nuclear energy. A major shift in energy patterns is necessary, particularly to reduce emissions of carbon dioxide from the burning of fossil fuels. Several countries have taken unilateral steps, committing themselves to targeted reduction of carbon dioxide emissions by the year 2005, such as Germany and Australia. The equity issues involved in such global environmental concerns are discussed in the accompanying paper : "Global Environmental Issues Related to Energy Development". It must be emphasised that the developing countries would continue to increase their use of fossil fuels, since increased energy use is essential for economic

growth, their resource endowments often comprise fossil fuel such as coal, lignite and natural gas, and because shifts from traditional biomass fuels to fossil fuels and electricity is an important attribute of increasing living standards. This point can also be seen on the basis of the major disparities that exist in per capita consumption levels of commercial energy, such as the case of Bangladesh with barely 50 kgoe per capita per year, versus over 9000 kgoe per capita annually in North America.

4. Transfer of capital and technology for sustainable energy supplies in the developing countries. The developing countries are at a stage of economic development when they necessarily have to increase the intensity of energy use in attaining desirable levels of economic development. Of course, it is not necessary for the developing countries to pursue exactly the same path that was followed by the developed countries at similar stages of economic growth, but a reduction in energy intensity is still very far in the future for the poorest countries of the world. Undoubtedly, the developing countries can leapfrog some technologies, but this would not result in a reduction of energy intensity, or, in some cases, even a reduction in the rate of growth of energy intensity. But change can be initiated through the infusion of capital and technology. If one looks at the potential of natural gas use in the developing countries, for instance, the

fraction of international trade in this fuel among the developing countries is yet very small in relation to their total energy consumption. Yet, there are parts of Asia where new discoveries of natural gas are taking place at a very rapid rate. Consequently, investments in infrastructure for transportation and trade of natural gas would be essential for bringing about greater use of this fuel, which has several environmental benefits.

In essence, a change in energy policies needs to be initiated urgently by countries which have high levels of income and which are the largest users of energy per capita. The scope for restructuring in the developed countries is substantial. For instance, Mr. William Rickett, Director-General of the U.K. Energy Efficiency Office has stated that some 20% of the U.K.'s energy bill could be saved by investing in cost effective energy efficiency measures. The scope in the United States is also quite considerable. For instance, potential savings through the use of the best possible models of domestic appliances as opposed to those currently in use ranges from 50 to 87% as shown in Table 1.

A variety of actions that can be taken in improving energy efficiency as well as introducing less polluting forms of energy use would bring about major reductions in CO_2 emissions are shown in Table 2.

The United States has recently released its National Energy Strategy (NES), which has several laudable objectives, but is premised on increased overall use of energy and carbon dioxide emissions. For instance, according the NES, the total U.S. energy consumption would rise by 37% by the year 2010 and by 50% by the year 2030, compared to 1990 levels. The total consumption of energy would increase from 80 quads (quadrillion Btus) today to 120 quads by 2030. Carbon dioxide releases correspondingly would increase by 25% over the next two decades. On the other hand, the use of energy in other developed countries shows very healthy trends.

Energy efficiency gains and reduction in CO_2 emissions have to be brought about through major restructuring of economic systems and lifestyles in the next few decades in the developed countries, and particular care has to be taken that "dirty" and high energy intensity industries are not merely exported to the developing countries, since this would certainly not be part of a global solution.

It would be most useful to promote energy efficiency gains on a worldwide basis. In this context, developing countries with scarce capital would find it difficult to invest in energy conservation measures, since even investments in enhancement of energy supply are constrained by capital shortages, and institutional arrangements are overwhelmingly geared to supply increases. Funding specifically targeted for energy efficiency programmes through multilateral and bilateral sources would, therefore, be useful in the adoption and implementation of energy efficiency activities. It would also be useful to promote greater exchange of information among energy organisations in the developed and developing countries. For instance, the experience of the U.S. in promoting small scale power generation after the enactment of the Public Utilities Regulatory Policy Act (PURPA) of 1978 could be extended in several developing countries. Demand side management programmes adopted by electric utilities also provide very useful experience for renovation by utilities in the countries of the developing world.

In the field of renewables the U.N. has recently set up a group to look at the possibilities for promoting worldwide the use of renewable technologies. One major recommendation being considered is to set up a string of centres of excellence for development of renewable energy technologies in different parts of the world. While this attempt would have obvious benefits, it needs to be ensured that the centres of excellence are not new ivory towers, but serve to strengthen existing institutions and linkages to maximise the benefit of financial resources made available for this purpose. The agricultural research institutions under the CGIAR system have done valuable work over the past few decades, but one major criticism voiced against them is that they have not strengthened the capabilities of local research institutions, nor have they developed adequate linkages with then. We should not repeat this error with renewable energy research and development. In fact, the mode of operation to be followed in R & D programmes in this area should emphasise close partnership and collaboration across different countries and between institutions in the same country.

Conclusion

The long-term prospects of a stable peace in the W. Asia/Gulf region are the key to stabilization of global energy markets which are in the clear interest of oil importing developing countries. In the interests of both the producers and consumers of oil, resolution of the long-standing political crisis in the region must be given the highest priority in the international arena.

In any event, the world must pursue a broad menu of policies for transition to an era in which fossil fuels are progressively more costly. These include the development of alternative technologies, technology and capital transfers to LDCs, and institutional changes by which incentives are created for users to conserve energy. The developed countries are still profligate in energy use and this has led to a high rate of fossil fuel depletion, leading to significantly higher energy prices at the time that LDCs have sought to accelerate their growth rates. It has also led to major global environmental problems, on account of which the content of economic growth itself must be altered worldwide. A reduction in energy use intensities in DCs is imperative, even as developing countries are assisted in eschewing unsustainable patterns of growth.

Table 1

Comparison of Energy Efficiencies and Regulated Appliances

Appliance	Average Annual Energy Consumption In-Use Models	New Models	Best Commercial Model	Estimated Cost-Effective Potential[a]	Potential Saving[b] (percent)
Refrigerator [c]	1,500	1,100	750	200-400	87
Central Air Conditioner[c]	3,600	2,900	1,800	900-1200	75
Electric Water Heater[c]	4,000	3,500	1,600	1000-1500	75
Electric Range [c]	800	750	700	400-500	50
Gas Furnace[d]	730	620	480	300-480	59
Gas Water Heater[d]	270	250	200	100-150	63
Gas Range[d]	70	50	40	25-30	64

[a] Estimates are made of potential efficiency (by mid-1990s) if further cost-effective improvements already under study.

[b] Percent reduction in energy consumption from the average of those appliances in use to the best cost-effective potential.

[c] Energy consumption for these appliances measured in kilowatt-hours per year.

[d] Energy consumption for these appliances measured in therms per year.

Source : Geller, 1986b.

Table 2

Emissions Reductions from Current Policy Initiatives by 2000
(in 10^6 metric tons on a CO_2 Equivalent Basis)[a]

POLICY OPTIONS	CO_2	CO_2 as CARBON
Tree Planting	**30.0**	**9.0**
U.S. DOE Efficiency Initiatives	**92.7**	**25.3**
Commercial Buildings Lighting	8.2	2.2
Promote State Least Cost Utility Planning	30.0	8.2
Interim Building Standards	27.3	7.4
Expand Energy Analysis	20.0	5.5
HUD Adoption of Standards	2.7	0.7
U.S. DOE Renewable Initiatives	**14.0**	**3.8**
Expand Hydropower	12.2	3.3
Transfer of Photovoltaic	1.8	0.5
U.S. DOE Appliance Standards	**13.6**	**3.7**
Clean Air Act Provisions	**57.3**	**15.6**
Acid Rain	54.5	14.9
Biofuels	0.9	0.2
Natural Gas	1.8	0.5
Landfill Regulations	**160.0**	**44.0**
CFC Phaseout	**693.0**	**189.0**
TOTAL	**1060.6**	**290.0**

[a] Based on conversion to a CO_2-equivalent basis using 100 year GWPs.

GRASSLAND BIOMASS BURNING IN INDIA

Mr. O.N. Kaul
Mr. Vishwanath Shah

Introduction

In a previous paper (Kaul, 1990), the various sources/activities of forest biomass burning in India were identified and estimates made of the different types of forest biomass burnt annually, during 1980s, in the context of emissions of Greenhouse Gases (GHGs). Though this paper dealt with the burning of grasses within forest areas, it did not include grassland biomass burning outside the forests.

The present study attempts to estimate the grassland biomass burnt annually, in recent years, under various land uses in India with regard to emissions of GHGs. The estimates mentioned are indicative of the nature and extent of the problem due to extreme paucity of information and data on the subject and uncertainity of certain parameters. As such they have to be taken with due reservations. Much better information and statistics are needed to make these estimates more realistic and dependable.

Land Utilisation

Out of a total geographical area of 328.726 million ha, agricultural ecosystems in India occupy over 136.1 million ha (probably highest in the world) constituting nearly 41.4% of the total land area of the country (Table 1), agriculture being a major land use followed by forestry. Nearly 20.3% (66.858 million ha) of the total geographical area is under forests, and over 101.8 million ha (31.0%) is under other land uses including area under non-agricultural uses, barren and unculturable land, permanent pastures and grazing lands, miscellaneous tree crops and groves, culturable wastelands and fallows. No returns exist for 7.3% (23.877 million ha) of the total land area of the country.

While the land use statistics (Table 1) place the area under forests at 66.858 million ha, the area officially recorded as Forest, with or without tree cover, by the State Forest Departments is of the order of 75.18 million ha or 22.8% of the total geographical area (Anon., 1988b, 1990c). Furthermore, the reconciled estimates of actual forest cover arrived at by the National Remote Sensing Agency (NRSA) and Forest Survey of India (FSI) was only 64.2041 million ha (1987 assessment based on imagery of 1981-83) and 64.0134 million ha (1989 assessment based on 1985-87 imagery). This works out, respectively, to 19.52% (1987 assessment) and 19.47% (1989 assessment) of the total geographical area of the country (Anon., 1988b, 1990c). There has thus been a reduction of 0.19 million ha (0.29%) of forest cover over a four year period (1981-83 to 1985-87); the annual rate of loss being 47,500 ha. The actual forest cover is 85.4% and 85.1% of the officially recorded forest area (75.18 million ha) according to 1987 and 1989 estimates respectively.

Grass Producing Areas

Natural grasslands and cultivated fodder crops play a key role in any improved and more intensive system of land utilisation. The need for human food being uppermost, most

Table 1: Land utilisation in India

Land use	Area (Million ha)	% of the total reporting area	% of the total geographical area
1. Forests	66.858	21.9	20.3
2. Area not available for cultivation			
(a) Area under non-agricultural uses	20.809	6.8	6.3
(b) Barren and unculturable land	20.391	6.6	6.2
3. Other uncultivated land (excluding fallows)			
(a) Permanent pastures and other grazing land	11.848	3.9	3.6
(b) Land under miscellaneous tree crops and groves not included in net area sown	3.535	1.2	1.1
(c) Culturable wastelands	15.626	5.1	4.8
4. Fallow lands			
(a) Fallows other than current fallows	11.134	3.7	3.4
(b) Current fallows	18.471	6.1	5.6
5. Agriculture (Net area sown)	136.177	44.7	41.4
6. Total reporting area	304.849	100.0	
7. Area for which no returns exist	23.877		7.3
8. Total geographical area	328.726		100.0

Note: Area officially recorded as Forest (with or without tree cover), by the Forest Departments, is 75.18 million ha (22.8% of the total geographical area) (Anon., 1988b, 1990c).

Source: Anon. (1990b).

of the cultivable land has been brought under food crops, leaving mainly the rough, unproductive and eroded lands for grass production to serve as natural grasslands, the optimum development of which is a matter of great national importance.

Grass and grazing constitute the major source of fodder in India. While grasses as fodder are not cultivated on any scale in the country, most of the grass production is obtained from forest areas dealt with previously (Kaul, 1990). Other grass producing areas by major categories of land use (Table 1) include (i) Permanent pastures and other grazing land, (ii) Land under miscellaneous tree crops and groves, (iii) Culturable wastelands, (iv) Fallow lands other than current fallows, and (v) Area under non-agricultural uses (strips along railway lines, canals and roads only as explained in the succeeding paragraph).

By definition, as given in the Nine-fold Land Use Classification (Anon., 1987) followed in the compilation of agricultural statistics in India, the land use category - Area under non-agricultural uses - stands for all lands occupied by buildings, roads, railways, or under water, i.e., rivers and canals and other lands put to uses other than agriculture. Consequently, the only grass producing areas available under this land use category are strips along railway lines, canals and roads as mentioned in the preceeding paragraph.

Extent of Grass Producing Areas

Table 2 indicates the extent of grass producing areas in the country by five major categories of land use just mentioned. It is observed that the total area available for the purpose is 43.959 million ha consituting over 13.37% of the total geographical area. While the figures of area mentioned against S. Nos. 1,2,3 and 4 in Table 2 are those as given in Table 1 for these categories of land use, the figures against S. Nos. 5 (a), (b) and (c) - Area under non-agricultural uses - have been obtained in the manner described hereafter.

Table 2: Area available for grass production by major categories of land use

Sl. No.	Land use	Area (Million ha)
1.	Permanent pastures and other grazing land	11.848
2.	Land under miscellaneous tree crops and groves	3.535
3.	Culturable wastelands	15.626
4.	Fallows other than current fallows	11.134
	Total	42.143
5.	Area under non-agricultural uses	
	a) Strips along railway lines	0.070
	c) Strips along canals	0.061
	b) Strips along roads	1.685
	Total	1.816
	Total (1+2+3+4+5)	43.859
6.	Total area available for grass production as % of total geographical area (328.726 million ha)	13.37

Source: Table 1 for figures against S. Nos. 1,2,3 and 4. Figures against S. Nos. 5 (a), (b) and (c) are calculated values (see text).

The Indian Railways have a total land area of about 0.337 million ha vested in them (Anon., 1989) which is utilised as shown in Table 3. For obvious reasons, the only area available for grass production with the Indian Railways is that under items 3 (Afforestation - 0.034 million ha) and 5 (Vacant land - 0.036 million ha) of Table 3 which is to the tune of 0.070 million ha.

Table 3: Land utilisation by Indian Railways.

Item	Area (Million ha)
1) Track and structures	0.225
2) Cultivation under "Grow More Food" scheme	0.038
3) Afforestation	0.034
4) Commercial licensing and encroachments	0.004
5) Vacant land	0.036
Total	0.337

Source: Anon. (1989)

As the data on statewise distribution of land utilisation by the Indian Railways (Table 3) have not been reported separately, the area available for grass production along railway lines, in different states, has been estimated as set in Table 4 (Col. 4). In arriving at these estimates it has been assumed that the area available in a particular state is proportional to the route Km of railway line in that state. This presumption may not, however, be wholly correct.

Table 4: Estimated area available for grass production along railway lines by states

State/Union Territory	Route Km of railway line	% of total route Km	Area available (ha)
(1)	(2)	(3)	(4)
Andhra Pradesh	5,021	8.10	5,670
Arunachal Pradesh	-	-	-
Assam	2,338	3.77	2,639
Bihar	5,305	8.56	5,992
Goa	79	0.13	91
Gujarat	5,553	8.96	6,272
Haryana	1,500	2.42	1,694
Himachal Pradesh	256	0.41	287
Jammu & Kashmir	77	0.12	84
Karnataka	3,029	4.89	3,423
Kerala	927	1.50	1,050
Madhya Pradesh	5,764	9.30	6,510
Maharashtra	5,431	8.76	6,132
Manipur	-	-	-
Meghalaya	-	-	-
Mizoram	-	-	-
Nagaland	9	0.01	7
Orissa	1,982	3.20	2,240
Punjab	2,145	3.46	2,422
Rajasthan	5,611	9.05	6,335
Sikkim	-	-	-
Tamil Nadu	3,937	6.35	4,445
Tripura	35	0.06	42
Uttar Pradesh	8,914	14.40	10,080
West Bengal	3,857	6.22	4,354
Andaman & Nicobar Islands	-	-	-
Chandigarh	11	0.02	14
Dadra & Nagar Haveli	-	-	-
Daman & Diu	-	-	-
Delhi	168	0.27	189
Lakshadweep	-	-	-
Pondicherry	27	0.04	28
All India	61,976	100.00	70,000

Source: Anon. (1989) for Col. 2. Figures in Cols. 3 and 4 are calculated values (see text).

The total length of main canals in the country, alongside which strips of land are available for grass production, is not directly known. It has, however, been reported that the total length of roads in India under the control of the Irrigation Department, in 1988, was of the order of 61,087 Km (Anon., 1990a). As the bulk of these roads run along the canals, it is presumed that the total length of main canals is also of the same magnitude (61,087 Km). Further, assuming that a land width of 10 m, on an average, is available on both sides of a canal, the total area available along the main canals of the country works out to 61,087 ha. The statewise distribution of this area is presented in Table 5 (Col. 4) which corresponds to the length of roads under the Irrigation Department in the respective states.

The total road length in India by various categories of roads, which was over 1.843 million km in 1988, is given in Table 6. The categories of roads included are (1) Public Works Department (PWD) roads, (2) Panchayat Raj roads, (3) Urban roads, and (4) Project roads. It will be seen that PWD and Panchayat Raj roads constitute nearly 81% (1,492,550 km) of the total road system in the country, followed by Project roads (11.25%) and Urban roads (7.78%).

For obvious reasons, there is no land available for grass production alongside Urban roads (Table 6) as they mostly run through cities/towns (Municipal roads), various complexes of the armed forces (Military Engineering Services

Table 5: Estimated area available for grass production along canals by states

State/Union Territory	Road length under Irrigation Department (Km)	Length of canal (Km)	Area available (ha)
(1)	(2)	(3)	(4)
Andhra Pradesh	1,096	1,096	1,096
Arunachal Pradesh	-	-	-
Assam	104	104	104
Bihar	-	-	-
Goa	-	-	-
Gujarat	1,110	1,110	1,110
Haryana	-	-	-
Himachal Pradesh	-	-	-
Jammu & Kashmir	315	315	315
Karnataka	6,256	6,256	6,256
Kerala	1,255	1,255	1,255
Madhya Pradesh	1,998	1,998	1,998
Maharashtra	2,056	2,056	2,056
Manipur	-	-	-
Meghalaya	-	-	-
Mizoram	-	-	-
Nagaland	-	-	-
Orissa	2,294	2,294	2,294
Punjab	8,831	8,831	8,831
Rajasthan	8,650	8,650	8,650
Sikkim	-	-	-
Tamil Nadu	1,321	1,321	1,321
Tripura	-	-	-
Uttar Pradesh	24,570	24,570	24,570
West Bengal	1,231	1,231	1,231
Andaman & Nicobar Islands	-	-	-
Chandigarh	-	-	-
Dadra & Nagar Haveli	-	-	-
Daman & Diu	-	-	-
Delhi	-	-	-
Lakshadweep	-	-	-
Pondicherry	-	-	-
All India	61,087	61,087	61,087

Source: Anon. (1990a) for Col. 2. Figures in Cols. 3 and 4 are calculated values.

Table 6: Total road length by various categories of roads in 1988

Category	Road length (Km)
(1)	(2)
1. PWD roads	
a) National highways	32,333
b) State highways	112,499
c) Other PWD roads	536,632
Total	681,464 (36.97)
2. Panchayat Raj roads	
a) Zilla Parishad roads	300,356
b) CD/Panchayat Samiti roads	224,981
c) Village Panchayat roads	285,749
Total	811,086 (44.00)
Total (1+2)	1,492,550 (80.97)
3. Urban roads	
a) Municipal roads	124,089
b) MES roads	10,352
c) Railway roads	8,492
d) Port roads	604
Total	143,537 (7.78)
4. Project roads	
a) Forest Department	130,542
b) Irrigation Department	61,087
c) Electricity Department	2,489
d) Steel Authority	2,096
e) Coal Mines Authority	2,159
f) Sugar Cane Authority	8,959
Total	207,332 (11.25)
All India (1+2+3+4)	1,843,419 (100.00)

Note: Figures in brackets are % of total road length.
Source: Anon. (1990a).

(MES) roads), railway establishments (Railway roads) and ports (Port roads). These roads have, therefore, been excluded from the purview of this study.

Similarly, with regard to Project roads (Table 6), no land is available for grass production alongside the roads belonging to the Electricity Department and Steel, Coal Mines and Sugar Cane Authorities as they are mostly localised roads within project areas. The roads in the charge of the Forest Department have been dealt with previously (Kaul, 1990) as these roads are constructed only in forest areas. Land availability along the roads of the Irrigation Department has already been considered as strips of land available alongside the canals. Accordingly, all Project roads have also been left out from the present study.

Having excluded the Urban and Project roads, the only roads alongside which strips of land are available for grass production are (1) PWD roads (National and State Highways and other PWD roads) and (2) Panchayat Raj roads (Zilla Parishad, Community Development (CD)/Panchayat Samiti and Village Panchayat roads) which extend over a length of 1,492,550 km (Table 6). The statewise distribution of these roads has been presented in Table 7, which reflects that while the states of Andhra Pradesh, Karnataka, Kerala, Maharashtra, Orissa, Tamil Nadu and Uttar Pradesh have over 100,000 Km of PWD and Panchayat Raj roads, the other states have much less length of these roads

Table 7: Statewise length of PWD and Panchayat Raj roads

State/Union Territory	Road length by categories (Km)						
	PWD roads			Panchayat Raj roads			Total
	National highways	State highways	Other PWD roads	Zilla Parishad roads	CD/Panchayat Samiti roads	Village Panchayat roads	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Andhra Pradesh	2,352	8,647	25,364	45,917	42,625	-	124,905
Arunachal Pradesh	368	-	5,177	-	-	561	6,106
Assam	2,227	1,895	24,822	-	27,371	-	56,315
Bihar	2,188	4,192	11,932	47,010	-	-	65,322
Goa	224	231	3,853	-	-	1,546	5,854
Gujarat	1,421	9,520	3,186	48,049	-	-	62,176
Haryana	656	3,136	18,854	-	-	-	22,646
Himachal Pradesh	589	3,652	15,109	-	345	-	19,695
Jammu & Kashmir	648	688	7,671	-	1,961	-	10,968
Karnataka	1,968	7,912	68,896	-	25,890	5,668	110,334
Kerala	817	2,044	17,764	-	5,917	90,301	116,843
Madhya Pradesh	2,756	11,833	68,979	-	-	-	83,568
Maharashtra	2,955	30,548	22,297	110,616	-	-	166,416
Manipur	434	547	3,409	-	1,612	-	6,002
Meghalaya	460	917	4,022	-	311	-	5,710
Mizoram	384	40	2,834	-	-	-	3,258
Nagaland	113	398	5,373	-	1,503	-	7,387
Orissa	1,624	2,927	11,735	-	25,454	134,883	176,623
Punjab	977	1,963	33,037	-	-	-	35,977
Rajasthan	2,521	7,442	43,560	-	34,798	-	88,321
Sikkim	62	225	1,180	-	-	-	1,467
Tamil Nadu	1,884	1,885	43,262	-	55,452	48,515	150,998
Tripura	198	136	4,929	-	-	4,275	9,538
Uttar Pradesh	2,755	7,983	76,095	24,659	-	-	111,492
West Bengal	1,630	3,455	11,853	24,105	-	-	41,043
Andaman & Nicobar Islands	-	247	432	-	-	-	679
Chandigarh	15	-	40	-	-	-	55
Dadra & Nagar Haveli	-	-	315	-	-	-	315
Daman & Diu		I N C L U D E D		I N	G O A		
Delhi	84	-	286	-	-	-	370
Lakshadweep	-	-	-	-	-	-	-
Pondicherry	23	36	366	-	1,742	-	2,167
All India	32,333	112,499	536,632	300,356	224,981	285,749	1,492,550

Source: Anon. (1990a)

In estimating the extent of area available for grass uction along PWD and Panchayat Raj roads, the following eria/assumptions have been adopted/made.

1) The standards for construction of the above categories of roads followed in the present study are indicated in Table 8 which also reflects the available land widths alongside these roads.

2) All PWD and Panchayat Raj roads in the states of Arunachal Pradesh, Himachal Pradesh, Jammu and Kashmir, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, Uttar Pradesh (eight hill districts only) and West Bengal (Darjeeling District only) have been treated as hill roads for the purpose of this study. 3) As the length of the above roads in the eight hill districts of Uttar Pradesh and Darjeeling District of West Bengal are not reported separately, these road lengths have been estimated on the basis of respective road densities of various categories of roads in these two states (Table 9).

4) Based on (2) and (3) above, the length of PWD and Panchayat Raj roads in the hills and the plains of the country is shown in Table 10.

Using the data presented in Tables 7, 8 (Cols 4 and 7) and 9 (Cols. 4 and 7), the estimated area available for grass production alongside PWD and Panchayat Raj roads comes to over 1.685 million ha (Table 11), the maximum area (786,266 ha) available being along Other PWD roads.

In summary, the availability of land alongside railway lines, canals and various categories of roads, in the country, adds upto over 1.816 million ha (Table 12), with roads contributing the major share (93.0%) of the area.

Table 8: Construction standards for different categories of roads

Category	Plain and rolling terrain			Mountaineous and steep terrain		
	Land width (m)	Formation width (m)	Land width availa-ble (m)	Land width (m)	Formation width (m)	Land width availa-ble (m)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1. PWD roads						
a) National Highways	45.0	12.0	33.0	24.0	7.45	16.55
b) State Highways	45.0	12.0	33.0	24.0	7.45	16.55
c) Other PWD roads	25.0	10.0	15.0	18.0	5.95	12.05
2. Panchayat Raj roads						
a) Zilla Parishad roads	15.0	8.0	7.0	15.0	5.95	9.05
b) CD/Panchayat samiti roads	12.0	7.5	4.5	9.0	5.20	3.80
c) Village Panchayat roads	12.0	7.5	4.5	9.0	5.20	3.80

Note: Figures in Col. 6 are inclusive of parapets (usual width 0.6 m) and side drains (usual width 0.6 m).

Source: Adapted from Anon. (1982a, 1983); Kadiyali (1983) and Khanna (1986).

Table 9: Road densities of PWD and Panchayat Raj roads in Uttar Pradesh and West Bengal

Category	Uttar Pradesh			West Bengal		
	Total road length (Km)	Road density	Road length in 8 hill districts (Km)	Total road length (Km)	Road density	Road length in Darjeeling District (Km)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1. PWD roads						
a) National Highways	2,755	0.94	479	1,630	1.84	56
b) State Highways	7,983	2.71	1,386	3,455	3.89	120
c) Other PWD roads	76,095	25.85	13,214	11,853	13.36	411
2. Panchayat Raj road						
a) Zilla Parishad roads	24,659	8.38	4,282	24,105	27.16	835
b) CD/Panchayat samiti roads	-	-	-	-	-	-
c) Village Panchayat roads	-	-	-	-	-	-
Total	111,492		19,361	41,043		1,422

Note: 1) Road density is expressed as road length (Km) per 100 Sq. Km of area.

2) Geographical areas of Uttar Pradesh and West Bengal are 294,411 and 88,752 Sq. Km respectively (Anon., 1990a).

3) Geographical areas of 8 hill districts of Uttar Pradesh and Darjeeling District of West Bengal are 51,112 and 3,075 Sq. Km respectively (Anon., 1982b).

Source: Table 7 for figures in Cols. 2 and 5. Figures in Cols. 3, 4, 6 and 7 are calculated values.

Table 10: Length of PWD and Panchayat Raj roads in hills and plains

Category	Road length (Km)		
	Plains	Hills	Total
1. PWD roads			
a) National highways	28,542	3,791	32,333
b) State highways	104,390	8,109	112,499
c) Other PWD roads	473,303	63,329	536,632
Total	606,235	75,229	681,464
2. Panchayat Raj roads			
a) Zilla Parishad roads	295,239	5,117	300,356
b) CD/Panchayat Samiti roads	219,249	5,732	224,981
c) Village Panchayat roads	280,913	4,836	285,749
Total	795,401	15,685	811,086
All India (1+2)	1,401,636	90,914	1,492,550

Table 11: Estimated area available for grass production along PWD and Panchayat Raj roads by states

State/Union Territory	Area available (ha)						
	PWD roads			Panchayat Raj roads			Total
	National highways	State highways	Other PWD roads	Zilla Parishad roads	CD/Panchayat Samiti roads	Village Panchayat roads	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Andhra Pradesh	7,762	28,535	38,046	32,142	19,181	-	125,666
Arunachal Pradesh	609	-	6,238	-	-	213	7,060
Assam	7,349	6,254	37,233	-	12,317	-	63,153
Bihar	7,220	13,834	17,898	32,907	-	-	71,859
Goa	739	762	5,779	-	-	696	7,976
Gujarat	4,689	31,416	4,779	33,634	-	-	74,518
Haryana	2,165	10,349	28,281	-	-	-	40,795
Himachal Pradesh	975	6,044	18,206	-	131	-	25,356
Jammu & Kashmir	1,072	1,139	9,244	-	745	-	12,200
Karnataka	6,494	26,110	103,344	-	11,651	2,551	150,150
Kerala	2,696	6,745	26,646	-	2,663	40,635	79,385
Madhya Pradesh	9,095	39,049	103,469	-	-	-	151,613
Maharashtra	9,752	100,808	33,445	77,431	-	-	221,436
Manipur	718	905	4,108	-	613	-	6,344
Meghalaya	761	1,518	4,847	-	118	-	7,244
Mizoram	636	66	3,415	-	-	-	4,117
Nagaland	187	659	6,474	-	571	-	7,891
Orissa	5,359	9,659	17,603	-	11,454	60,697	104,772
Punjab	3,224	6,478	49,555	-	-	-	59,257
Rajasthan	8,319	24,559	65,340	-	15,659	-	113,877
Sikkim	103	372	1,422	-	-	-	1,897
Tamil Nadu	6,217	6,220	64,893	-	24,953	21,832	124,115
Tripura	328	225	5,939	-	-	1,624	8,116
Uttar Pradesh	8,304	24,064	110,245	18,139	-	-	160,752
West Bengal	5,287	11,203	17,658	17,045	-	-	51,193
Andaman & Nicobar Islands	-	815	648	-	-	-	1,463
Chandigarh	50	-	60	-	-	-	110
Dadra & Nagar Haveli	-	-	473	-	-	-	473
Daman & Diu		I N C L U D E D		I N		G O A	
Delhi	277	-	429	-	-	-	706
Lakshadweep	-	-	-	-	-	-	-
Pondicherry	76	119	549	-	784	-	1,528
All India	100,463	357,907	786,266	211,298	100,840	128,249	1,685,022

Table 12: Estimated area available for grass production along railway lines, canals and roads

State/Union Territory	Area available (ha)			
	Railway lines	Canals	Roads	Total
(1)	(2)	(3)	(4)	(5)
Andhra Pradesh	5,670	1,096	125,666	132,432
Arunachal Pradesh	-	-	7,060	7,060
Assam	2,639	104	63,153	65,896
Bihar	5,992	-	71,859	77,851
Goa	91	-	7,976	8,067
Gujarat	6,272	1,110	74,518	81,900
Haryana	1,694	-	40,795	42,489
Himachal Pradesh	287	-	25,356	25,643
Jammu & Kashmir	84	315	12,200	12,599
Karnataka	3,423	6,256	150,150	159,829
Kerala	1,050	1,255	79,385	81,690
Madhya Pradesh	6,510	1,998	151,613	160,121
Maharashtra	6,132	2,056	221,436	229,624
Manipur	-	-	6,344	6,344
Meghalaya	-	-	7,244	7,244
Mizoram	-	-	4,117	4,117
Nagaland	7	-	7,891	7,898
Orissa	2,240	2,294	104,772	109,306
Punjab	2,422	8,831	59,257	70,510
Rajasthan	6,335	8,650	113,877	128,862
Tamil Nadu	4,445	1,321	124,115	129,881
Sikkim	-	-	1,897	1,897
Tripura	42	-	8,116	8,158
Uttar Pradesh	10,080	24,570	160,752	195,402
West Bengal	4,354	1,231	51,193	56,778
Andaman & Nicobar Islands	-	-	1,463	1,463
Chandigarh	14	-	110	124
Dadra & Nagar Haveli	-	-	473	473
Daman & Diu	-	-	(a)	(a)
Delhi	189	-	706	895
Lakshadweep	-	-	-	-
Pondicherry	28	-	1,528	1,556
All India	70,000	61,087	1,685,022	1,816,109
% of total	3.6	93.0	3.4	100.00

Note: (a): Included in Goa.

Source: Tables 4 , 5 and 11 for figures in Cols. 2, 3, and 4 respectively.

Table 13 sets the area available for grass production, in the country, by the five major categories of land use referred to earlier in different states. It will be observed (Table 13) that the total area available is to the tune of 43.959 million ha, the largest area of 15.626 million ha (35.6%) being under Culturable wastelands followed by Permanent pastures and other grazing land (27.0%), Fallows other than current fallows (25.3%), Miscellaneous tree crops and groves (8.0%) and Area under non-agricultural uses (railways, canals and roads) (4.1%).

Table 13: Statewise area available for grass production by major catagories of land use

State/Union Territory	Area (000 ha) under						
	Permanent pastures & other grazing land	Misc. tree crops and groves	Culturable wastelands	Fallows other than current fallows	Total	Non-agricultural uses (railways, canals, and roads)	Grand Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Andhra Pradesh	881	264	864	1,451	3,460	132	3,592
Arunachal Pradesh	-	48	-	57	105	7	112
Assam	184	247	104	84	619	66	685
Bihar	137	257	398	1,082	1,874	78	1,952
Goa	1	1	87	-	89	8	97
Gujarat	846	4	1,950	43	2,843	82	2,925
Haryana	30	2	22	5	59	42	101
Himachal Pradesh	1,216	44	125	17	1,402	26	1,428
Jammu & Kashmir	125	75	149	7	356	13	369
Karnataka	1,135	326	458	417	2,336	160	2,496
Kerala	3	41	115	29	188	82	270
Madhya Pradesh	2,790	138	1,656	886	5,470	160	5,630
Maharashtra	1,381	196	1,012	1,287	3,876	230	4,106
Manipur	-	24	-	-	24	6	30
Meghalaya	17	145	454	261	877	7	884
Mizoram	4	3	74	259	340	4	344
Nagaland	-	124	96	105	325	8	333
Orissa	711	719	463	321	2,214	109	2,323
Punjab	4	5	39	(b)	48	71	119
Rajasthan	1,817	32	5,986	3,006	10,841	129	10,970
Sikkim	69	5	1	9	84	2	86
Tamil Nadu	134	149	289	849	1,421	130	1,551
Tripura	-	43	1	1	45	8	53
Uttar Pradesh	349	532	1,099	856	2,836	195	3,031
West Bengal	7	57	176	86	326	57	383
Andaman & Nicobar Islands	5	41	3	3	52	1	53
Chandigarh	-	(b)	(b)	(b)	(b)	(b)	(b)
Dadra & Nagar Haveli	1	-	(b)	(b)	1	(b)	1
Daman & Diu	-	(b)	4	-	4	(a)	4
Delhi	1	1	9	12	23	1	24
Lakshadeep	-	-	-	-	-	-	-
Pondicherry	(b)	2	2	1	5	2	7
All India	11,848	3,535	15,626	11,134	42,143	1,816	43,959
Percent of total	27.0	8.0	35.6	25.3	95.9	4.1	100.0

Note: (a): Included in Goa

(b): Below 500 ha.

Source: Anon. (1990b) for figures in Cols. 2, 3, 4 and 5. Table 12 for figures in Col. 7.

Grassland Cover Types

As a result of an ecological survey of natural grasslands in India, Dabadghao and Shankarnarayan (1973) have recognised five major grassland cover types in the country as mentioned below. Each cover type has been designated on the basis of the dominant grass species on protected sites (Dabadghao, 1960).

1. Sehima-Dichanthium Type
   (Central and Southern semi-arid areas)

2. Dichanthium-Cenchrus-Lasiurus Type
   (Dry and arid areas)

3. Phragmites-Saccharum-Impereta Type
   (Subtropics - high humid)

4. Themeda-Arundinella Type
   (Submontane region)

5. Temperate Alpine Type
   (High hills of Northern montane belt)

In recognising these cover types, conclusions reached by earlier authors (Champion and Seth, 1968; Whyte, 1964) on the ecological status of Indian grasslands have been kept in view, namely, that grasslands in India do not occur as a climatic climax but generally represent secondary seres, and that wherever they are relatively stable, they constitute a biotic climax maintained under the influence of fire and grazing in various combinations.

The distribution pattern of various cover types shows that their occurrence is primarily governed by climatic factors and chiefly by latitudinal influence (Dabadghao and Shankarnarayan, 1973). Thus the tropical Sehima-Dichanthium cover is quite distinct from the subtropical Dichanthium-

Cenchrus-Lasiurus, Phragmites-Saccharum-Imperata, and Themeda-Arundinella covers. The latter are again quite different from the Temperate Alpine cover.

The second factor, in order of importance appears to be topography, particularly altitude, which is shown by the distribution of subtropical grass covers, two of which, namely, Phragmites -Saccharum-Imperata and Dichanthium-Cenchrus-Lasiurus covers occur in the plains, while Themeda-Arundinella is restricted to the northern hills.

Altitude appears to accentuate the latitudinal influence in the distribution of grass covers in the northern montane region. Thus Themeda-Arundinella cover is restricted to a maximum of 2,200 m within the same latitude, beyond which only species of Temperate Alpine cover exist.

After climate and topography, the soil factor and more particularly the soil moisture relationship, seems to be important in determining the occurence of grass covers. Thus in the northern plains, increase in soil moisture, determines the distribution of the Phragmites-Saccharum-Imperata cover. Conversely, the gradual deterioration of soil moisture from optimum through critical towards very low moisture availability governs the presence of Dichanthium-Cenchrus-Lasiurus cover. In this cover wherever soil moisture rises in excess of the requirements, species of Phragmites-Sacchrum-Imperata invariably occupy the site.

Table 14 shows the statewise estimated area under each of the five grassland cover types mentioned earlier, in terms of the area available for grass production in different states (Table 13). The figures in Table 14 have been obtained by superimposing the map of each state on the map showing grassland cover types of India (Dabadghao and Shankarnarayan, 1973). The total grassland area in a state (Table 13) was then allotted to different grassland cover types in proportion to their occurrence in that state. It will be seen (Table 14) that the maximum area of 25.388 million ha (57.8%) is under Sehima-Dichanthium Type, followed by Dichanthium-Cenchrus-Lasiurus Type (24.0%). The Temperate Alpine Type constitutes only 0.767 million ha (1.8%), the area under the other two types being almost the same.

Grassland Productivity

By and large most of the grasslands in India are degraded, overgrazed and in very poor condition. The productivity of these grasslands is, therefore, very low and varies widely with the type and condition of the grasslands. It has been reported that the productivity of grass in forest areas is generally higher than in other grass producing areas (Permanent pastures and grazing land, Miscellaneous tree crops and groves, Culturable wastelands, Fallow lands and Lands under non-agricultural uses) and that the production of dry grass generally varies from 0.5 to 6.0 tonnes/ha/year; the average grass yield from forest areas and other grass producing areas being taken to be about 3 and 1.5 tonnes/ha/year respectively (Anon., 1988a). However, biomass studies carried out in different grassland cover types of India (Dabadghao and Shankarnarayan, 1973; Singh, 1988;

Pathak, 1990; Deb Roy, 1990) indicate that the productivity of these grassland types varies with different seral stages reaching its maximum at the climax stage (Table 15).

Table 14: Estimated area under various grassland cover types

State/Union Territory	Area (000 ha) under					Total
	Sehima-Dichanthium type	Dicanthium-Cenchrus-Lasiurus type	Phragmites-Saccharum-Impereta type	Themeda-Arundinella type	Temperate Alpine type	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Andhra Pradesh	3,592	-	-	-	-	3,592
Arunachal Pradesh	-	-	-	69	43	112
Assam	-	-	466	219	-	685
Bihar	742	-	1,210	-	-	1,952
Goa	97	-	-	-	-	97
Gujarat	1,346	1,579	-	-	-	2,925
Haryana	-	81	20	-	-	101
Himachal Pradesh	-	-	-	1,157	271	1,428
Jammu & Kashmir	-	-	-	214	155	369
Karnataka	2,496	-	-	-	-	2,496
Kerala	270	-	-	-	-	270
Madhya Pradesh	5,349	-	281	-	-	5,630
Maharashtra	4,106	-	-	-	-	4,106
Manipur	-	-	-	30	-	30
Meghalaya	-	-	-	884	-	884
Mizoram	-	-	-	344	-	344
Nagaland	-	-	-	333	-	333
Orissa	2,323	-	-	-	-	2,323
Punjab	-	38	81	-	-	119
Rajasthan	3,401	7,569	-	-	-	10,970
Sikkim	-	-	-	-	86	86
Tamil Nadu	1,551	-	-	-	-	1,551
Tripura	-	-	-	53	-	53
Uttar Pradesh	-	1,273	1,273	273	212	3,031
West Bengal	50	-	333	-	-	383
Andaman & Nicobar Islands	53	-	-	-	-	53
Chandigarh	-	-	(a)	-	-	(a)
Dadra & Nagar Haveli	1	-	-	-	-	1
Daman & Diu	4	-	-	-	-	4
Delhi	-	24	-	-	-	24
Lakshdeep	-	-	-	-	-	-
Pondicherry	7	-	-	-	-	7
All India	25,388	10,564	3,664	3,576	767	43,959
% of total	57.8	24.0	8.3	8.1	1.8	100.00

Note: (a): Below 500 ha.

Table 15: Grassland productivity by types

Grass cover	Productity (tonnes/ha dry wt.) at	
	Lowest seral stage	Climax stage
Sehima-Dichanthium Type	0.2	3.5
Dichanthium-Cenchrus-Lasiurus Type	1.0	3.0
Phragmites-Saccharum-Impereta Type	1.0	5.0
Themeda-Arundinella Type	0.5	2.2
Temperate Alpine Type	NA	4.0

Note: NA: Not available.
Source: Dabadghao and Shankarnarayan (1973), Singh (1988), Pathak (1990), Deb Roy (1990).

In view of the highly degraded condition of Indian grasslands, the productivity of various grassland cover types (except Temperate Alpine Type) could be safely assumed to be at their respective lowest seral stages as given in Table 15. With regard to Temperate Alpine Type, productivity at the lowest seral stage, is not available (Table 15). Further, these grasslands are in a much better condition and less degraded as compared to grasslands under other cover types. As such it would be prudent to assume an average productivity of 2 tonnes/ha for this cover type. Accordingly, Table 16 reflects the total annual aboveground grass biomass production (1988) by various grassland cover types, which is of the order of 22.628 million tonnes. It is further

Table 16: Total annual aboveground biomass production by grass cover types

Grass cover	Area		Average productivity (tonnes/ha dry wt) at lowest seral stage	Aboveground biomass production	
	Million ha	% of total		Million tonnes	% of total
(1)	(2)	(3)	(4)	(5)	(6)
Sehima-Dichanthium Type	25.388	57.8	0.2	5.078	22.5
Dichanthium-Cenchrus-Lasiurus Type	10.564	24.0	1.0	10.564	46.7
Phragmites-Saccharum-Impereta Type	3.664	8.3	1.0	3.664	16.1
Themeda-Arundinella Type	3.576	8.1	0.5	1.788	7.9
Temperate Alpine Type	0.767	1.8	2.0 (a)	1.534	6.8
Total	43.959	100.0		22.628	100.0

Note: (a): Assumed (see text)

Source: Table 14 for figures in Col. 2 and 3 and Table 15 for figures in Col.4.

observed that the maximum production of 10.564 million tonnes is available from Dichanthium-Cenchrus-Lasiurus Type which occupies only 24.0% (10.564 million ha) of the total grasslands in the country. Conversely, while Sehima-Dichanthium Type extends over an area of 25.388 million ha (57.8%), it produces only 22.5% (5.078 million tonnes) of the total grass production. The aboveground grass biomass in the other 3 types varies from about 7% (Temperate Alpine Type) to 16% (Phragmites-Saccharum-Imperata Type).

Conclusion

The available aboveground grass biomass by various grassland types, during 1988, has been indicated in Table 16 (Col. 5). While a large quantity of this biomass may be burnt annually (mainly through deliberate action of the local villagers who set fire to these grasslands for inducing luscious growth of grass for better grazing) the total grass biomass actually burnt is presently not known. Any estimates, therefore, made in this regard, would only be educated guesses to be taken with caution. Furthermore, there are some major drawbacks in the data presented in Table 16. Firstly, the areas shown under each grassland cover type are only calculated estimates, in the absence of non-availability of data, which may or may not be correct. Secondly, the productivity shown against these types is taken at the lowest seral stage (for reasons mentioned) which induces an element of reservation. It is, therefore, very clear that the total avaialable biomass shown in Table 16 (Col. 5) would only be an approximation.

It also needs to be mentioned here that not all the grasslands are subject to annual fires and wherever they occur, grasses are neither burnt over the whole area nor are they completely burnt. For example, fires never occur in Temperate Alpine Cover Type. Similarly, fires are common only in shifting cultivation areas in the Northeastern region of the country and not in regular grasslands. Fires are also rather uncommon alongside canals and roads, the long stretches of which have been brought under tree plantations.

Taking the above facts into consideration it would be prudent to exclude the Temperate Alpine Cover Type from the purview of burning. In the absence of any data, it would also be safe to assume that in other grassland types only about 50% of the area is burnt with a burning efficiency of 50% as all the material does not get burnt. Accordingly, the aboveground grassland biomass burnt during 1988 is set in Table 17.

Table 17: Aboveground grass biomass burnt during 1988

Grass cover	Annual area burnt	Aboveground biomass	Biomass burnt annually
	(Million ha)	(Million tonnes dry wt)	
Sehima-Dichanthium Type	12.694	2.539	1.270
Dichanthium-Cenchrus-Lasiurus Type	5.282	5.282	2.641
Phragmites-Saccharum-Impereta Type	1.832	1.832	0.916
Themeda-Arundinella Type	1.788	0.894	0.447
Temperate Alpine Type	-	-	-
Total	21.596	10.547	5.274

Carbon = 5.274 x 0.45 = 2.374 Million tonnes

It is observed (Table 17) that a total of 5.274 million tonnes (dry weight) of grass biomass was burnt during 1988. The total amount of carbon involved for emission of GHGs would be to the tune of 2.374 (5.274 x 0.45) million tonnes. These estimates could at best be taken as a pointer to the magnitude of the problem in the absence of any adequate statistics.

References

1. Anonymous. (1982a). Recommendations about the alignment survey and geometric design of hill roads (First revision). The Indian Roads Congress, New Delhi.

2. Anonymous. (1982b). Report of the Task Force for the Study of Eco-Development in the Himalayan Region. Planning Commission, Govt. of India, New Delhi.

3. Anonymous. (1983). Pocketbook for highway engineers. Indian Roads Congress, New Delhi.

4. Anonymous. (1987). Handbook of agriculture. Indian Council of Agricultural Research, New Delhi. 5. Anonymous. (1988a). Report of the Committee on Fodder and Grasses. National Wastelands Development Board, Ministry of Environment and Forests, Govt. of India, New Delhi.

6. Anonymous. (1988b). The state of forest report 1987. Forest Survey of India, Dehra Dun.

7. Anonymous. (1989). Indian railways - Year book 1987-88. Ministry of Railways (Railway Board), Govt. of India, New Delhi.

8. Anonymous. (1990a). Basic road statistics of India 1987-88. Transport Research Division, Ministry of Surface Transport, Govt. of India, New Delhi.

9. Anonymous. (1990b). Land use statistics, 1986-87 and 1987-88. Ministry of Agriculture, Govt. of India, New Delhi. (Memiographed)

10. Anonymous. (1990c). The state of forest report 1989. Forest Survey of India, Dehra Dun.

11. Champion, H.G. and Seth, S.K. (1968). General silviculture for India. Manager of Publications, Delhi.

12. Dabadghao, P.M. (1960). Types of grass covers of India and their management. Proc. Eighth International Grassland Congress, United Kingdom.

13. Dabadghao, P.M. and Shankarnarayan, K.A. (1973). The grass covers of India. Indian Council of Agricultural Research, New Delhi.

14. Deb Roy, R. (1990). Personal communication.

15. Kadiyali, L.R. (1983). Traffic engineering and transport planning. Khanna Publishers, Delhi.

16. Kaul, O.N. (1990) Forest biomass burning in India. Tata Energy Research Institute, New Delhi.

17. Khanna, P.N. (1986). Indian practical civil engineers' handbook. Engineers' Publishers, New Delhi.

18. Pathak, P.S. (1990). Personal communication.

19. Singh, Panjab. (1988). Rangeland reconstruction and management for optimising biomass production. In. Rangeland resource and management. (Edited Panjab Singh and P.S. Pathak). Proc. National Rangeland Symposium. Range Management Society of India, Indian Grassland and Fodder Research Institute, Jhansi.

20. Whyte, R.O. (1964). The grassland and fodder resources of India. Indian Council of Agricultural Research, New Delhi.

ACCELERATED HYDROELECTRIC CAPACITY ADDITION FOR LIMITATION OF GHG EMISSIONS

Dr. Ajay Mathur

Abstract

Electricity capacity additions in India during the eighth and ninth Plan periods will fall far short of planned targets, primarily because of increasing financial constraints. This would probably lead to a rapid growth of diesel-based generation capacity (in agriculture and industry) to cater to burgeoning electricity demand. It is estimated that hydroelectric capacity additions during the nineties would be about 17,965 MW as against the planned target of 33,498 MW during this period. The difference of 15,533 MW between the estimated and planned capacity additions is judged to the incremental potential of an accelerated hydroelectric power programme designed to limit the emission of greenhouse gases, particularly carbon dioxide. The cost of this additional capacity is estimated to be Rs.258 billion. Carbon dioxide emissions from the load location-based diesel generating sets providing the electrical energy equipment of 15,533 MW of grid-based hydroelectric capacity would be 66 million tonnes of carbon per year. The specific cost of carbon dioxide emission limitation due to the accelerated hydroelectric programme is, therefore, Rs.3,909 per tonne of carbon. In addition, the current requirement of afforesting an area twice in size of forest land area which is affected by hydro power projects will serve to further sequester atmospheric carbon.

Introduction

The total potential for economic hydro electricity in India is about 600 TWh of firm annual electric energy which is the equivalent of 85,000 MW of installed capacity at 60% load factor. Assuming that hydro power plants of various types would be operating at an energy load factor of about 40%, the installed capacity would be about 125,000 MW. Out of this available potential, only about 20% (18,566 MW) have presently been exploited with the completion of projects up to the end of the 7th Plan. Thus, a vast hydro potential remains to be developed. In addition to this conventional hydro power potential, the Central Electricity Authority (CEA) has also identified a number of pumped storage hydro schemes totaling about 96,000 MW in various regions of the country[1].

The share of hydro electricity in the current mix of installed capacity in the country is about 33%, considerably less than the recommended share of 40%[2]. During the eighth and ninth plans, a total addition of 102,884 MW of installed capacity was envisaged by the 8th Plan Working Group on Power[3], of which additional planned hydroelectric capacity was 33,498 MW. Table 1 shows the Working Group's planned capacity addition targets. In the past three years, however, these targets have been progressively reduced with increasing constraints on budgetary resources, and presently firm financial commitments are available only for 20,736 MW of capacity addition during the 8th Plan period, of which 5,273

MW is hydroelectric capacity. The Working Group, on the other hand, had planned for total capacity addition of 38,781 MW during the Eighth Plan, of which 8,135 MW would have been hydroelectric capacity. Given the constraint on resources, it is also unlikely that the 9th Plan targets would be met.

Table 1: Capacity Addition Targets During the Nineties

Region	Capacity Addition During the 8th Plan				Capacity Addition During the 8th Plan			
	Thermal	Hydro	Nu-clear	Total	Thermal	Hydro	Nu-clear	Total
Northern	7424	2836	235	10495	6446	11676	2470	20592
Western	7887	2299	470	10656	8300	4893	1470	14663
Southern	5963	1660	-	7623	9920	2855	4940	17715
Eastern	7375	1307	-	8382	4600	3514	-	8108
North-Eastern	1292	33	-	1625	600	2425	-	3025
All India	29941	8135	705	38781	29866	25363	8880	64103

Source: Report of the 8th Plan Working Group on Power, Planning Commission, Government of Indian, 1988.

Expected Hydroelectric Capacity during Nineties

Expected additions to installed capacity are no longer correlated to planned targets due to financial constraints. However, it should also be pointed out that the 8th Plan Working Group targets called for much more rapid capacity addition than did previous plan targets. Typically, hydroelectric capacity has grown at a rate of about 6% per annum, whereas the 8th Plan Working Group envisaged a near 11% annual growth rate during the nineties. It is hypothesized here that future growth will follow the same trend as historical growth because of overall macroeconomic limitations.

Figure 1 shows the growth of hydroelectric power in India. Assuming that future growth continues at the same rate (approximately 6% per annum), the addition during the 8th Plan period would be 7780 MW, and 10,185 MW during the 9th Plan. Consequently, the total hydroelectric installed capacity in the country at the end of the 9th Plan period (1990-2000) would be 36,531 MW.

This expected capacity addition during the nineties (17,965 MW) is substantially less than the 8th Plan Working Group's capacity addition target of 33,498 MW during the same period. Consequently, there is a potential for a further installation of 15,533 MW of hydroelectric power by the year 2000 if capital is available.

Costs of Hydroelectric Power

The installed cost of hydroelectric projects varies widely, and most experts prefer a location-specific and head-specific cost estimate. To a first approximation, however, a specific cost for hydro electricity would be desirable so as to assess the total incremental cost of the addition of a further 15,533 MW of hydro power by 2000.

Table 2 lists the costs of recently approved hydro power projects[4]. The costs of these projects have been updated to 1990 costs here and the specific costs at 1990 prices are also shown in Table 2. Barring four instances, the specific costs range between Rs.14,074 and Rs.21,051 per kWh of installed capacity. Of the four projects outside this

Installed Hydroelectric Capacity in India

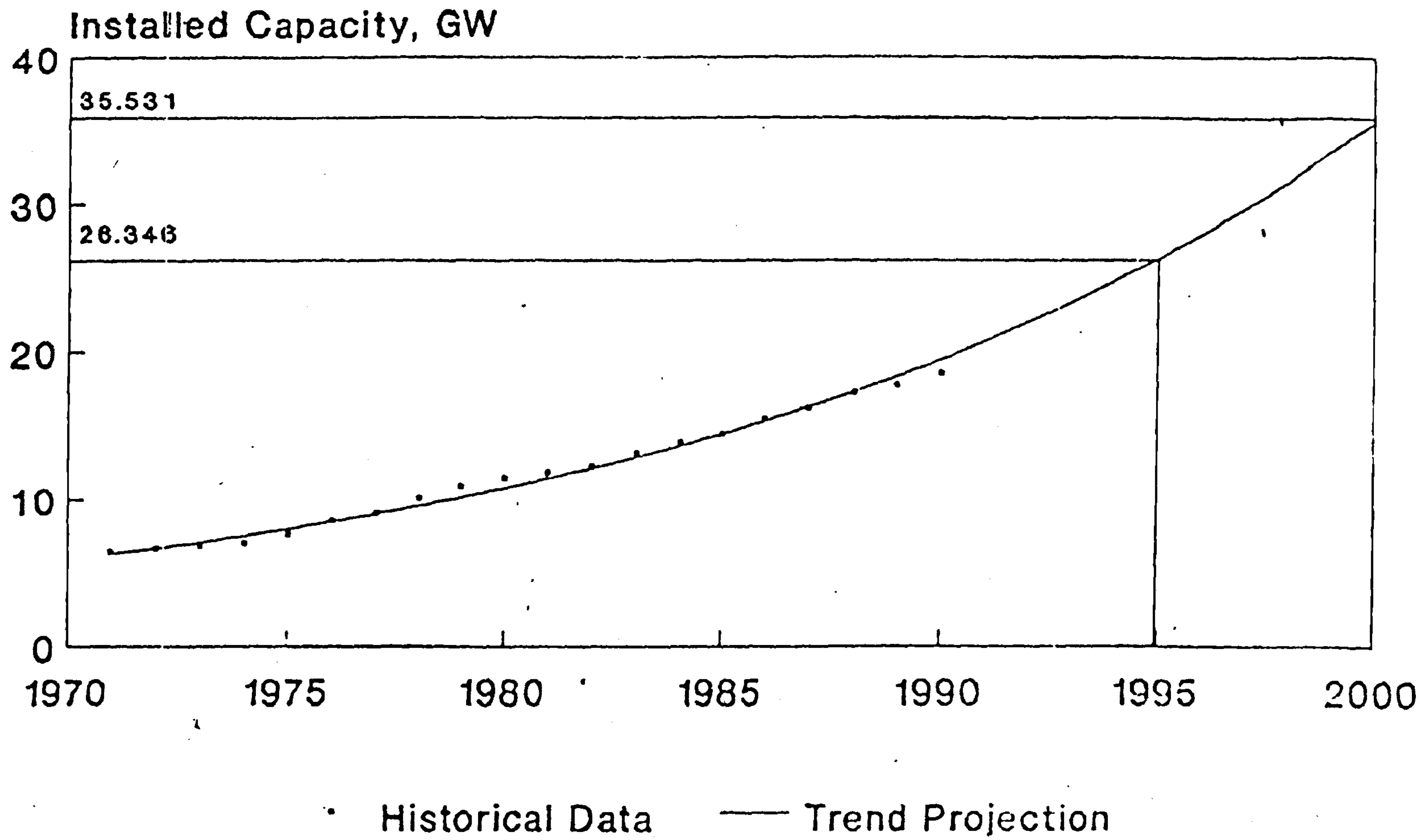


Figure 1

Source: CEA, Public Electricity Supply, All India Statistics, General Review 1986-87, Government of India, 1990.

cost range, one is the Sardar Sarovar project, whose costs are almost certainly going to be much high than those estimated in 1984 because of increased cost of rehabilitation. On the other hand, the highest specific cost is that of the project with the lowest installed capacity (Dadupur Hydro Power Project (HPP) with an installed capacity of 4 x 1.5 MW). The two other projects which have considerably lower costs (Nagarjunsagar Right Canal HPP and Kakkad HPP) are both extensions of existing projects in which the capital costs are much lower than for new projects because of existing infrastructure.

Table 2: Capital Cost of Hydro Power Projects

Project	Installed Capacity (MW)	Cost of Project (million Rs.)	Year of Approval	Current Cost (1990 prices) (million Rs.)	Specific Cost (Rs./kW)
High Head					
Andhra	3x5	97.4	1976	295.2	19677
Bairasul	3x60	922.2	1977	2634.9	14638
Sanjay Vidyut Pariyojana	3x40	1256.2	1983	2129.2	17743
Puyankutty	2x120	2500.0	1984	3968.3	16534
Likim	3x8	464.8	198	505.2	21051
Medium Head					
Kakkad	2x25	186.0	1976	563.6	11273
Umiam-Umtru Stage IV	2x30	387.9	1978	994.6	16577
Doyang	3x35	963.1	1981	1926.2	18345
Sawalkot	3x200	6869.1	1985	10407.7	17346
Larji	3x42	1688.5	1986	2483.1	19707
Low Head					
Nagarajunasagar Right Canal	2x30	181.9	1977	519.7	8662
Lower Mettur	8x15	836.0	1978	2143.6	17863
Dadupur	4x1.5	74.1	1981	148.2	24700
Sardar Sarovar	6x200 + 5x50	10634.0	1984	16615.6	11459
Satanur	2x75	1520.0	1987	2111.1	14074

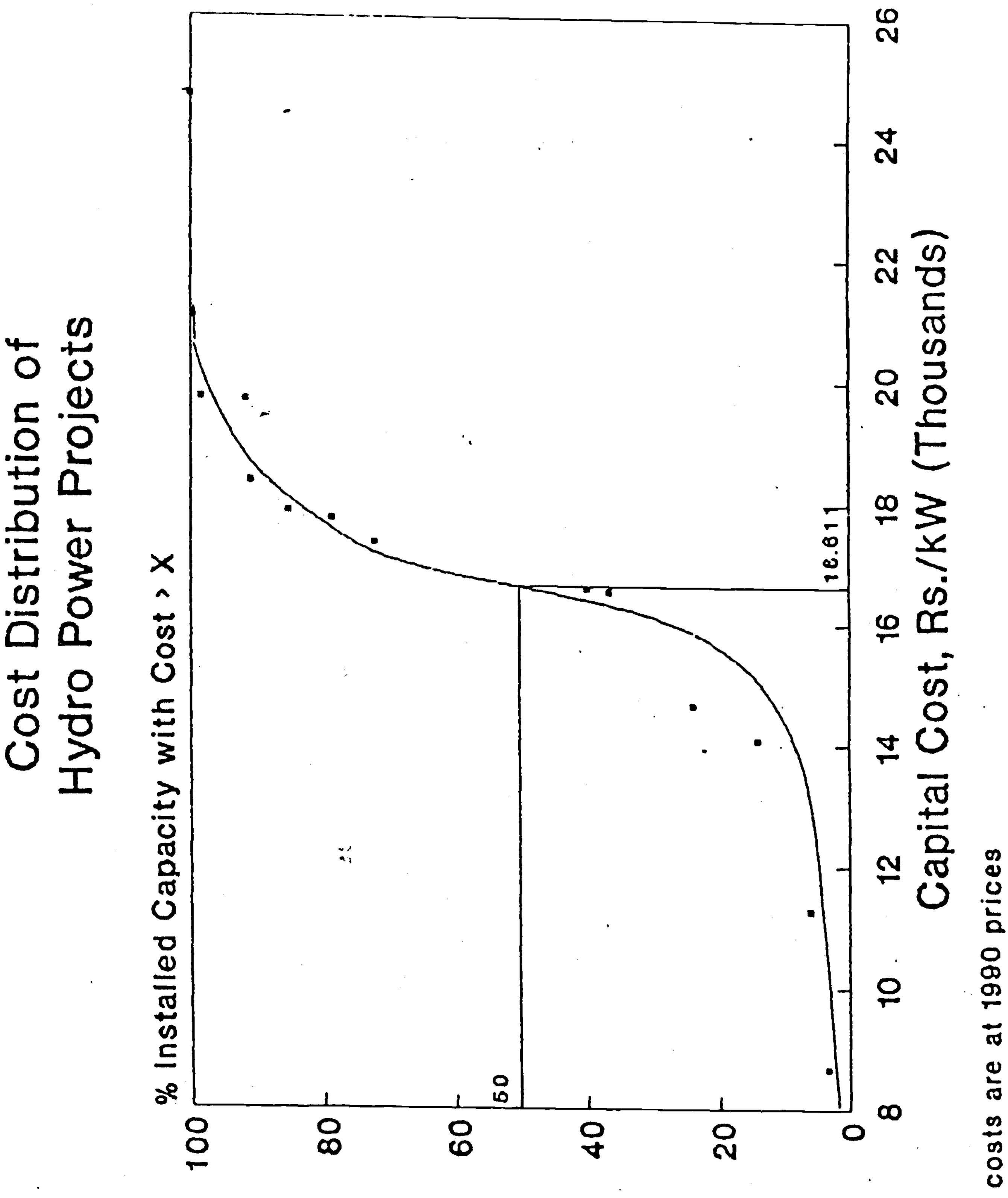
Source: T.R. Satish Chandran, "Economics of Power Generation: Issues and Choices", in Electrical Energy and Environment, Indian National Academy of Engineering, New Delhi, 1990

This sample (with the exception of Sardar Sarovar Project for which the cost specified in Table 2 is certainly not the final approved cost) can, therefore, be considered representative of the various types of hydroelectric schemes that will be built in the country. Figure 2 shows the cumulative cost distribution of the projects in the sample (with the exception of the Sardar Sarovar Project). The specific project cost is plotted on the horizontal axis, and the percentage of total installed capacity in the sample with specific cost less than the specific cost on the horizontal axis is plotted on the vertical axis. Figure 2 shows that only 10% of capacity costs less than Rs.14,000/kW, and almost all capacity costs less than Rs.21,000/kW. The median project cost is Rs.16,611/kW.

Consequently, for future hydroelectric projects, an average cost of Rs.16,611 per kW seems to be an appropriate first-cut approximation. The incremental cost of an accelerated hydro electric programme aimed at adding an extra 15,533 MW of hydro electric capacity by 2000 (beyond that considered feasible under the present economic situation) would be Rs.258 billion.

CO_2 Emission Reduction Due to Hydroelectric Projects

The 8th Plan Working Group report set targets for installed capacity addition based on projected demand for electricity. The reduction in capacity addition due to capital constraints would not decrease electricity demand, but would instead probably lead to an increased use of diesel-based generating



Cost Distribution of
Hydro Power Projects
% Installed Capacity with Cost > X
100
80
60
50
40
20
0
8
10
12
14
16
16.611
18
20
22
24
26
Capital Cost, Rs./kW (Thousands)
All costs are at 1990 prices

Figure 2

sets in industry and in agriculture. It is assumed here that the accelerated hydro electricity programme would reduce the addition of this diesel-based generation.

Based on current performance level of hydroelectric projects, a 1,000 MW HPP would provide 3.29 GWh of electric energy annually to the grid (based on a net generation level of 3291 kWh per KW of installed hydro capacity[5]). With 22% T&D losses, the electric energy supplied to a consumer from the 1,000 MW HPP would be 2.56 GWh. To generate equivalent electricity from diesel-based capacity, 6.633 million liters of diesel would be required annually. This estimate is based on a diesel requirement of 0.37 liters per kWh generated and auxiliary consumption of 4.27%[5]. The CO_2 emissions resulting from these diesel use would be 4.25 million tonnes of carbon (Mt C).

Consequently, carbon dioxide emissions would be limited by 66 Mt C due to addition of 15,533 MW of hydro power at a cost of Rs.258 billion. Specific cost of CO_2 emission limitation, therefore, works out to Rs.3,909 per tonne of carbon.

Carbon Sink Loss Due to Submergence

Most hydroelectric projects are located in regions which are rich in forests, and some of forest area is almost always submerged due to the construction of river valley projects. A total of 0.502 million hectares of forests land was submerged between 1951 and 1980 due to the construction of dams and reservoirs for HPPs[6]. The total contribution to this area to carbon dioxide sequestration would be a maximum of 2.25 million tonnes of carbon per annum (based on an annual growth of 10 tonnes of wood per hectare, with a 45% carbon content). In addition, if all the wood in the reservoir area was burnt before submergence, about 22 tonnes of carbon would be released per hectare, implying a total emission of 11 million tonnes of carbon. This emission is accounted for in historical data as carbon dioxide emissions from land use changes.

After 1980, all projects (including HPPs) which require forest land are required to afforest an area which is double the forest land area acquired, and project costs include the cost of this afforestation. For example, Table 3 shows afforestation programmes associated with NHPC projects[7]. It can also be argued that new plantations sequester carbon at a more rapid rate than mature forests, and consequently the overall absorption by plantations would be higher than the carbon sink loss due to forest submergence. There is, of course, a difference in time scales - plantations will sequester carbon at a latter date whereas the sink would be removed earlier. However, to a first approximation, it can be assumed that the submerged forests and new plantations balance out the loss and gain of carbon sinks.

Table 3: Afforestation Programmes of NHPC Projects

Sl. No.	Name of the Project	No. of Trees Affected	No. of Trees to be Planted	Schedule of Plantation	Plants Planted So Far	Plants Survived
1.	Chamera	40,000	46,00000	1984 to 1995	23,92,242	13,58279
2.	Dulhasti	687	2,00000	86087 to 88-89	4,64,662	2,80,000
3.	Uri	4,000	3,14000	86-87 to '70-71	1,56,000	93,600
4.	Dulhasti Trans.	9,000	20,00000	87-88 to 92-93	4,21,150	3,11,935
5.	Uri Trans.	4,400	6,60000	88-89 to 92-93	98,550	97,844
6.	Tanakpur	17,368	8,75000	88-89 to 92-93	3,24,800	3,24,800
7.	Salal*	–	–	–	6,14,876	3,96,481
8.	Loktak*	–	–	–	2,81,150	2,14,920
9.	Baira Siul*	–	–	–	1,59,519	–
	Total				49,12,949	30,77,859

*Voluntary Afforestation

Source: M A Hai, B S K Naidu and D C Purohit, "Hydroelectric Power and Environment", in Electric Energy and Environment, Indian National Academy of Engineering, New Delhi, 1990.

References

[1] J K Bhasin and R N Srivastava, "Planning for Power Development Upto 2020 A.D.", in Electric Energy and Environment, India National Academy for Engineering, New Delhi, 1990.

[2] Report of the Committee on Power, Planning Commission, Government of India, New Delhi, 1980.

[3] Report of the 8th Plant Working Group on Power, Planning Commission, Government of India, New Delhi, 1989.

[4] T R Satish Chandran, "Economics of Power Generation: Issues and Choices", in Electric Energy and Environment, Indian National Academy of Engineering, New Delhi, 1990.

[5] Public Electric Supply - All India Statistics General Review 1986-87, Central Electricity Authority, Government of India, New Delhi, 1990.

[6] India's Forests, Ministry of Environment & Forests, Government of India, 1987.

[7] M A Hai, B S K Naidu and D C Purohit, Hydroelectric Power and Environment, in Electric Energy and Environment, Indian National Science Academy of Engineering, New Delhi, 1990.