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Economic Development and Co2 - Emission: Economy - Environment Relation and Policy Approach to Choice of Emission Standard for Climate Control

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Economic Development and CO2-Emission : Economy - Environment Relation and Policy Approach to Choice of Emission Standard for Climate Control

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Abstract: The integrated assessment of Climate Change at global level due to anthropogenic emissions has its gaps and problems of uncertainties. The conventional approach of such assessment begins with the postulate that the growth of population and GDP of nations are destabilising factors for the equilibrium of the climate system. Some development economists consider this to be an overstatement. We have examined in this paper whether the process of economic growth brings with it such technical changes which would stabilise or cause decline in the total industrial CO2-emissions at a certain level of per capita income and beyond. The econometric analysis of the macro-economic and the CO2-emission data shows that the total CO2-emission (or that from the solid or liquid fuel sources) initially increases with the rise in per capita income and reaches a peak which is followed by a decline. This CO2-emission peaking per capita income is estimated to be $8740 (in PPP $ 1985) approximately for the total CO2-emission. However, such stabilisation of CO2-emission does not permit complacence regarding climate stabilisation in view of the likely trend of the CO2-emission of the fast growing populous developing countries like China and India. It would , in fact , be too late for the global climate to be controlled for stabilisation if the developing countries are allowed to grow and their CO2-emissions to stabilise or decline in their own due course as induced by the dynamics of industrial capitalism. This points to the necessity of addressing the problem of setting the CO2-emission standard both at the global and the national level so that the stage of CO2-emission peaking is preponed in terms of income and real time and the level of the peaking CO2-emission is also lowered. For the scientific and equitable setting of such standard, the climate research needs to remove certain gaps and ambiguities and the country level economic modelling needs to be carried out to provide better information regarding the relative costs of abatement of emissions across the countries. The problem has to be finally solved as one of political economy for global cost sharing for the C02-emission abatement which would call for international cooperation and understanding.

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Economic Development and CO2-Emission : Economy - Environment Relation and Policy Approach to Emission Standard for Climate Control

1. Introduction : Integrated Economic Assessment of Climate Change : Gaps in Analysis

The models and discussions on the integrated assessment of climate change and policies that have developed over the last more than a decade have broadly covered three major sets of issues :

(a) The assessment of the effect of the human economic activities and the demographic changes on the global environment through increased emissions of greenhouse gases . This has required an analysis of the economy-energy-environment interlinkage and interrelations.

(b) The assessment of the effect of increasing flow of greenhouse gas emissions due to economic growth on the level of concentrations of these gases after taking care of the natural rate of degradation of the gas molecules over time , the consequent increase in the radiative forcings which the gas molecules give rise to , the effect of the latter on the average global level of atmospheric temperature and its regional distribution as predicted by the models of terrestrial circulation system of water and air, and finally, the consequent differential pattern of change in the climate system and biosphere of the different regions of the world. These issues have been analysed on the basis of the scientific laws that guide the functioning of the terrestrial environment system and its relationship with the biosphere of the earth.

(c) The feedback assessment of the changes in the climate system and the biosphere on the economy and society . An analysis of the Climate - Biosphere -Economy interaction has been required for the assessment of the potential economic loss/gain that would result from the climate change in the different parts of the world for the different types of production or economic activities.

The positive behavioural analysis in these three areas have been used finally for the following purposes:

(i) to identify the policy options that exist to control the greenhouse gas emissions.

(ii) to analyse the benefit and cost of achieving alternative targets in respect of climate

control.

(iii) to arrive at an optimal policy approach for the climate change, in terms of the setting of targets of environmental standard and choice of instruments like a carbon tax or emission permit to achieve the targets.

While a substantive amount of research has been initiated in all these areas (eg. IMAGE 2.0 [1,2,6], CETA [24], DICE [25], etc.) [see also 12, 15], there are many important gaps and uncertainties in the understanding of each of the above three areas of analysis. Economists have been mostly concerned with the issues in (a) and (c) making assumptions about the relations in (b) as given by the climatologists and the earth and life scientists. In the area of economic analysis, the weakest achievement till now has been in respect of the economic assessment of the effect of a given pattern of climate change on the regional economies and on the pattern of the flow of trade in the global economy. The applied general equilibrium models developed by the economists have mostly been concerned with the effect of a choice of policy instruments like energy or carbon tax or tradeable permit system for emission to achieve certain environmental standard with a view to long run stabilisation of the global climate (e.g., Green Model [3,7]) and not for the assessment of the economic loss as such. The pioneering work of Edmonds-Reiley [10] also analyseses only the effect of the policy instruments on the choice of energy-technologies for finding out how difficult or easy it would be to delay the climate change by postponing the date to which the CO2 emission would be doubled. Nordhaus [25], however, in his DICE model incorporates the cost of climate change in the form of loss of a certain percentage of GDP as arising from sectoral economic activities, the empirical basis of the assumption as admittedly by himself, being quite weak.

Even in the area of the climate change itself there are uncertainties regarding the reliability of the climate forecasts. The methodology as adopted by the climatologists for assessing the effect of GHG emissions on the climate system has not really been one of forecasts, but rather one of scenario generation to answer what if type of questions. In other words, the climatologists are not predicting as such the extent of warming up of the earth and the consequent changes in the terrestrial environment system over a time horizon given the current trend of anthropogenic emissions. It is only asserting that if there is a large increase in the GHG concentration in the atmosphere of certain magnitude, then there is going to be certain climate change as given by the scenario analysis. However, it is often very common that the policy researchers and policy makers treat the result of scenarios as forecasts, leading to confusions. (de Freitas [5]).

Besides, the climatologists themselves are far from unanimous about whether the climate change arising from a given rise in the GHG concentration like the doubling of CO_2, is going to be worse or better in the physical sense for our planet and humanity. It is not clear if the damage function due to climate change has serious nonlinearities or whether the impact will bring about gradual change. A basic problem with the climate change impact assessment has been (a) the lack of adequate information regarding the likely future climate change and (b) the lack of knowledge of the transfer function which would work out the implication of such information when available, into the resulting bio-physical and societal changes. There exists incompleteness regarding the knowledge of the life cycle and radiative properties of the GHG gases in an atmospheric condition. Besides, the General Circulation Models which are used as primary tools for the generation of climate scenarios provide predictions with such spatial resolutions which are not compatible with those required by the transfer functions. For a given scenario of global atmospheric GHG concentration, it is difficult for these models to generate reliable regional climate statistics which would be of use for working out the possible social and economic impact and the policies for adapting to such situation (de Freitas [5], Gates [12]).

However, what has been taken as an area of much greater certainty in the entire chain of integrated assessment analysis in the effect of the growth of economic activities on the GHG emissions. The analysis of the GHG emissions shows that the CO_2 is the major GHG which accounted for 49% of the total emissions of such gases when translated into CO_2 equivalent unit in the decade of eighties (Smith [28]). The methane (CH_4) has been the second largest contributor accounting for a share of 19%, followed by the CHCs having a share of 17%, NO_2 5.0% and remaining GHGs covering the balance of 10% in the same decade.

However, as a starting point, the policy research on the subject has required the analysis of the sector and material sourcewise arising of the GHGs. Among the economic sectors it is the energy production and energy use which was responsible for a 57% share of the total GHG emissions during the eighties. The methane emission arising from the primary activities related with land use like crop production (paddy cultivation), animal enteric fermentation, arisings of animal waste, deforestation or bio-mass burning etc. accounted for about 23% of the GHG emissions in the same period, while the balance share of 20% was due to the industrial process emission (other than energy use). As the sector and the source wise distribution of the arising of the GHGs points to the importance of the use of fossil fuels and the CO_2-gas form, a large amount of discussion and analysis on the economics of global warming centred around the energy-economy and the energy-emission models with special reference to CO_2 emissions with a view to the identification of energy policy options for CO2 abatement. A substantive thrust of the analysis has been on the assessment of the economic potential of the renewable carbon-free energy sources, the carbon-based backstop technologies, and the energy conservation for the mitigation of the GHGs or the level of radiative forcing. In most of these works like the ones of Edmonds-Reiley [[10] or the OECD GREEN Model [3,7]], the energy flows and energy technology options for abatement are explicitly considered at certain level of disaggregation for the different regions of the world. These project the equilibrium path of the regional GDPs, the regional energy demand and supplies for both the primary energy and the final energy forms, the market clearing prices of energy in both regional and global markets and the CO2 emissions, assuming a scenario of demographic growth, primary energy resource availabilities and exogenous values of policy variables like carbon tax. These models which are applied general equilibrium in character consider the feedback of the energy cost on the economic activity levels. They have solved either for the optimal tax and technology for achieving a given global environmental standard or for the optimal path of the world economic growth and the supporting standard along with taxes etc., for a given utility function. The Nordhaus's DICE model [25] which illustrates the use of a Ramsay type framework to work out the optimal growth path of the world GDP and the optimal path of the global GHG emission, does not, however, consider any energy flow explicitly and assumes coefficients of direct relation between the GDP and the total GHG emissions and considers both the emission abatement cost and the cost of damage due to climate change directly in terms of percentage loss of income. However, the energy flows have been superimposed on the DICE model by others like Mori [23] to find out the level of carbon tax required to stabilise emission at the 1990 level and derive the associated changes in the level of concentration of the GHGs and rise in the global temperature.

The economy-energy-emission sub-systems of most of the models on the economics of GHG emission/climate change begin with a baseline of the existing technologies and fuel options with a frozen efficiency and institutional scenario for each of the regions of the world. For the long term evaluation of the alternative growth paths it is the technology options for energy resources and energy conservation which would mainly vary from one another. The models presume the scope of emission control mainly through technical changes which would either represent the introduction of backstop technologies for energy supplies or the upgradation of technology for energy conservation. While admittedly the relation between the economic growth and the GHG emission are much better known than the other relations involved in the integrated assessments of climate change, the relation between economic output and emissions are influenced by factors other than merely the micro-level ones of technology of energy supply and energy use. The interactive relation between the macro level growth and its sectoral and institutional structure also influences the dynamics of technology so as to moderate the growth of matter and energy consumption and the rise in their entropy.

The development economists have, infact, started emphasizing that the organic process of economic growth builds into itself such structural, technical and institutional changes that it is likely to cause increasing conservation of matter and energy and thereby the stabilisation or decline in the flow, if not in the stock of concentration of the various pollutants in the natural environment. Grossman and Krueger [14] have in fact examined the reduced form relationships between per capita income and various environmental indicators which do not however, include the greenhouse gases. With reference to indicators like the urban air pollution, state of oxygen regime in river basins, concentration of heavy metals in water, etc., which are all local and not global in nature, they found no evidence that the national or local environmental quality deteriorates with economic growth. For most of their indicators the economic growth brings initially a deterioration of environmental quality which is reversed by its upturn when a country reaches a level of income PPP$ 8000 per capita, due to Kuznet's curve effect of economic growth.

The problem with the GHG emissions is that although they arise from the economic activities of the individual countries, its level of concentration in the atmosphere is affected at the global level. Secondly, a major GHG - the CO2 - is not as such a pollutant but has only a warming up effect on the atmosphere. Nevertheless, can we expect Kuznet's curve type effect of economic growth on the *absolute* level of the annual *flow* of the GHG emission particularly that of CO2 ? The actual CO2 emission from energy production or energy use can, in fact, be taken as the product of four factors as stated below (Ogawa [27]):

Emission of total CO2 = Population (p)* GDP per capita (y)* Primary energy intensity of GDP (ei)* Co2 intensity of energy (CO2ie)

Of these factors p is a demographic factor while y represents the stage of development and is very often indicative of the extent of the industrialisation. However, the energy intensity of GDP (ei) depends on both the composition of the primary energy resources and the stage of technological development of the economy in general (Kauffman [21]). The level of efficiency of use of fuel increases and the need for energy would go down with technological advancement of an economy which is accompanied by the growth process.

It has been observed that there has been an increasing conservation of matter and energy in both the developing and the developed industrial economies since the energy price shocks of 1970's. The increasing marketisation and global integration of the developing world has contributed to the increased concern for the competitiveness of tradeable products. Institutional factors have also contributed to the improved energy intensity in the development process. Besides, the sectoral product composition also changes in the different phases of growth and industrialisation causing variation in energy intensity. When the tertiary sector becomes dominant in the economy with the share of industry declining, it is likely to effect a lowering of the energy intensity and the CO2 emission intensity of GDP. The factor ei may, therefore, be influenced by a host of factors some of which are often correlated with y.

Finally, the CO2-intensity of energy captures the effect of fuel composition on the CO2 emission. The fuel composition varies from country to country or over time depending on the availability of energy resources in the country or region. The use of cleaner or carbon free fuel would also be dependent to some extent on the stage of economic and technological development which would determine the extent of economic viability of such options for a country.

It may, therefore, be contended that the interaction of the above factors of p, y, ei. and CO2IE would end up with a pattern of absolute CO2 emission from energy sources which would show a tendency for stabilisation beyond a stage of development, or for the setting in of its declining trend. Lucas [22] examined the relation between economic growth and environmental indicators including the industrial CO2 emissions. His preliminary analysis showed the total CO2 emission from all sources to exhibit a downward trend although quite weak, beyond a level of per capita income.

We also intend to examine here whether the level of the total CO2 emission at the national level (not the level of concentration in global atmosphere) would tend to stabilize or start declining with growth of per capita income at a certain stage of development with the help of panel data on income, energy consumption and CO2 emission. If the structure, technological and institutional dynamics as exhibited by the organic nature of the growth process acts as a built-in stabiliser of CO2 emission in the process of development beyond a certain stage, the assumption of long run relation between economy and GHG emission as assumed by the integrated models of economics of climate change may require to be differently made allowing for the introduction of autonomous changes in energy efficiency and CO2 emission efficiency of fuels in an appropriate way to reflect such findings. In the analysis of the following sections, we shall, therefore, analyse the partial effects of population, per capita income and energy intensity of GDP on total CO2 emission and also see if the energy intensity of GDP and the CO2 intensity of primary energy supply are, in turn, influenced by the level of percapita income itself. We shall carry out these analyses not only for the aggregate CO2 emission but also for the emissions from the different types of fuels -- solid, liquid and gaseous. In all these we would thus test the claim of the growth economists that the Kuznet's curve effect would take care of environmental problems in the context of CO2 emission and its concentration.

Given the current level of energy efficiency of the developing countries and the projected likely growth of their energy consumption in future the environmentalists would most likely emphasize that even if the above hypothesis is valid, i.e. the CO_2 emission stabilises at certain per capita income level, it may take too long for many of the countries to reach that per capita income level, and too much cumulative emission would possibly take place in the meanwhile for causing damage to the terrestrial environment system. We also address this problem by taking up the cases of China and India to analyse the intertemporal CO_2 emission implication of our econometric finding that the CO_2 emission (industrial) is likely to reach a peak followed by a decline at the level of per capita income of PPP$ 8740 (1995 prices). Finally, we would conclude by making our remarks and observations on policy implication of these analyses in respect of setting of the CO_2 emission standard for nations which itself is a political-economic issue at the global level.

2. Comparative Energy-Environmental Efficiency of the Developing and the Developed Countries.

Let us begin by a global overview of the energy-environment efficiency of the different economies in order to understand the relation between economic development and GHG emissions. The interregional scenario of income, commercial energy and CO_2 emission of the world today is characterised by a high degree of inequality in the distributions of these variables among the people of its different regions. (see Table 1 and Annexure table A1).

Table 1 Individual Country Shares in the World Totals of Population, Income, Commercial Energy & CO2
unit: (%)

Countries	Share in World Population	Share in World GDP (US $)	Share in World Primary Energy Supply	Share in World Industrial CO2 Emission
Brazil	2.83	1.88	1.39	0.95
China	21.48	1.71	9.47	11.21
India	16.19	1.15	2.69	3.1
Indonesia	3.38	0.54	0.809	0.752

Japan	2.32	26.9	6.16	4.81
USA	4.72	25.93	27.27	21.75

It is striking to note that a share of 16.19 % of the world population who lived in India in 1991 produced only 1.15% of the world income because of the constraint of capital and other resources, consuming 2.69% of the world's primary commercial energy supply and contributing to 3.10% of the world's total CO2 emission (industrial) in that year. The corresponding situation for the USA has been that only 4.72% of world population who lived in that country in 1991 produced 25.93% of the world GDP consuming 27.27% of the world's total commercial energy and contributing to 21.75% of the world's total CO2 emission (industrial only) in 1991. Thus the energy-emission data immediately point to the cross-country wide variations in the per capita primary commercial energy consumption, the per capita CO2 emission from the use of fossil fuel and industrial processes and the commercial energy intensity and the CO2 intensity of GDP. While the per capita energy consumption and CO2 emission tend to rise with increase in the per capita GDP, the energy intensity or the CO2 intensity of GDP which is one of the important efficiency indicators of the process of production is likely to decline with rise in per capita GDP, because of the accompanying higher level of technology. A higher level of integration of the higher income industrialized economies with the world market also induces energy economisation and reduction of CO2 emission because any technical change in favour of matter and energy conservation would economise cost and increase competitiveness of the products of an economy and would also yield the collateral benefit of environmental resource conservation including that of the qualities of air, water and soil etc. The institutional arrangement of increased marketisation of production in the developing countries accompanying their growth process is also expected to contribute sooner or later towards the improvement of the energy-environmental efficiency.

However, there are certain difficulties in making a cross-country comparison of the energy and the CO2-emission intensities of GDP as the comparative cross-section picture is quite sensitive to the choice of unit of measurement of income/GDP for the different countries between the US$ (based on-exchange rate of the currency) and the International $ (based on the purchasing power parity or PPP) The annexure Table A2 gives the data on per capita primary commercial energy consumption and the per capita CO2-emission as well as the energy and the CO2-emission intensities of GDP of the 16 countries. We, however, highlight in Table 2 the observations for 4 major developing and 2 major developed countries.

Table 2: Comparative Energy Consumption and CO2 Emission (Industrial)

per Capita and per unit of GDP (current prices) in 1991

Regions	GDP per capita US$	GDP per Capita PPP$	Primary commercial Energy per capita (tonnes of oil eq.)	CO2-emission per Capita (tonnes of carbon)	Energy intensity of GDP Kg/ US.$	Energy intensity of GDP Kg/ Intl$	CO2-emission int. of GDP at factor cost Kg/ US$	CO2 emission int. of GDP Kg/ Intl $
Brazil	2680	5247	0.662	0.388	0.247	0.426	0.145	0.074
China	323	1711	0.592	0.604	1.833	0.346	1.869	0.353
India	287	1145	0.223	0.222	0.778	0.195	0.772	0.194
Indonesia	639	2827	0.32	0.256	0.502	0.113	0.401	0.091
Japan	27010	19408	3.575	2.404	0.132	0.184	0.089	0.123
USA	22203	22115	7.753	5.326	0.349	0.351	0.240	0.241

A striking point in Table 2 is that the energy and CO2 emission efficiency of the countries like Japan or the USA are subtabtially higher than those of India, China or Indonesia when we choose the measure of income in US$. The picture is reversed or the efficiency gap is substantially narrowed down if the GDP estimates are taken in the purchasing power parity dollar. The Table A2 in the annexure also shows such sharply different comparative picture of energy or CO2 emission efficiency depending on the choice of the common unit of measure for GDP across the counties. However,. for the cross-country comparison the purchasing power parity $ unit apparently makes much better sense as this would yield estimates of energy/CO2 intensity free from the volatility of exchange rates of currency and would more reliably represent the requirement of energy or environmental resources for a given real basket of commodities defining the GDP. However, any aggregation method has its own limitations. It is for this reason that none of these ratios can truly represent the physical energy or emission efficiency in the thermodynamic sense. Energy efficiency can be compared ideally across the countries only at the micro level by comparing how many joules or calories are required to produce one tonne of a commodity like steel or cement or paper of a given quality in the different countries. In such sense, it is well known that most of the industrially developed market economies have achieved a higher level of energy or CO2 emission efficiency as compared to most of the developing countries because of their higher level of technology in respect of energy or material conservation. Nevertheless, it remains a fact that the weakness of currency in general tends to underestimate the relative energy efficiency of the developing countries if the energy or emission intensities are measured with reference to GDP in US $. The ratios with reference to GDP in Intl.$ are better indicators, if any aggregate indicator of efficiency is to be used at all.

Besides, it should be noted that while the micro-level comparison would truly point to the relative energy and emission inefficiency of technologies of the developing countries, the same may not be true when we consider, the macro-level relative efficiencies of the countries mainly due to two factors. First, the product-mix and the associated sectoral weighting diagram of the developing countries are often less energy intensive (e.g., high weightage of the primary sector which has lower energy intensity per unit of value added than the industrial sector). Second, the fuel-mix of the developing economies like India, Indonesia, Brazil, etc. often contains a substantive share of renewable biomass (see Table A4) which is not included in the commercial energy estimates and the intensity ratios. The CO2-emission data do not also include any share of emission from the burning of biomass. There is nothing wrong in such exclusion so long as the biomass resource is so harvested that the stock of biomass source is maintained at the same level and the carbon is fully recycled. Since the main concern of our energy analysis is the environmental efficiency of growth or development process, the roles of product-mix and fuel-mix are important for the macro-behavioral or policy analysis. It goes in fact to the credit of many developing countries like India, Brazil and Indonesia that their product-mix and pattern of resource use contribute to the moderation of the global CO2 emission which is partly reflected in their comparative energy or emission intensity ratios with respect to GDP in international (PPP) dollar vis-a-vis the industrialised countries.

3. Factor Analysis of growth of CO2 Emission

While there is a striking inequality in the distribution of energy consumption and CO2 emission in the different regions of the world, the global environmental concern centering the CO2 emission arises not so much from the static situation of the absolute energy consumption and the levels of CO2 emissions of the different counties as from the implication of the dynamic growth process of the economies of the different regions of the world in respect of CO2 emission. Broadly speaking, an economy grows in size in two senses : (a) the size of its population, and (b) the volume of its economic activities (i.e. GDP). A factor analysis of the past growth of CO2 emissions (industrial) of the developing and the developed countries would point to the relative importance of these two growth factors (population and GDP) vis-a-vis other energy related efficiency factors (energy efficiency and fuel composition). As already pointed out the CO2 emission from the use of fossil fuel can be described to be identically equal to the product of the population (p), the per capita income (y), the energy intensity of GDP (ei), and the CO2-intensity of energy (CO2 ie), so that the growth rate of CO2 would be approximately equal to the sum of the growth rates of p, y, ei, and CO2ie in discrete time. We present in the annexure Table A7 such factor analysis of the growth of CO2 emission for the 16 countries for the period 1971-91 on the basis of GDP estimates in US $ (1987), while we present a similar analysis in terms of GDP estimates in PPP$ (1985) for the period 1971-1987 in the annexure Table A8. In both the analysis we have excluded the share of the bunker fuel in the CO2 emission from industrial process and energy sources. We have made a further variation in such analysis for only six countries be excluding the shares of both bunker fuel and cement industry in the CO2-emission to get a more precise factor analysis of the CO2 emission arising from the commercial energy use of resources only. We present these results of the latter analysis for the six countries in Table 3 & 4.

3. Annual Average Growth Rates of CO2 Emission Determining Factors (1971-1991) for GDP in US$
unit : %

Countries	Population	GDP at	Primary	CO2 Int.	CO2	Contribu-

(1)	(2)	factor cost per capita (US$ 1987) (3)	Commer- cial energy int. of GDP (4)	of Primary energy resource (5)	emission excl. share of cement & bunker fuel (6)	tion of efficiency factors in saving CO2 emission (7)**
Brazil	2.188	2.195	0.873	- 0.946	4.347	0.01
China*	1.477	5.697	- 1.720	- 0.139	5.264	0.26
India	2.204	2.089	1.368	0.544	6.343	- 0.45
Indonesia *	2.068	4.235	3.346	- 2	7.751	- 0.21
Japan	0.877	3.461	- 1.678	- 0.755	1.763	0.56
USA	0.990	1.536	- 1.552	- 0.247	0.696	0.71

* for China and Indonesia the GDP is in constant market prices (1987 US $)
for China the period covered is 1973-1991
**(7) = (-)[(4) + (5)]/[(2) +(3)]

Table 4: Annual Average Growth Rates of CO2 Emission Determining Factors (1971-1987/1988) for GDP in PPP$ 1985
Unit: %

Countries (1)	Population (2)	GDP per capita (PPP$'85) (3)	Primary commercial energy int. of GDP (4)	CO2 Int. of Primary energy resource (5)	CO2 emission excl. share of cement & bunker fuel (6)	Contribution of efficiency factors in saving CO2 emission (7)**
Brazil	2.29	2.957	0.656	- 1.425	4.495	0.15
China*	1.598	5.321	- 1.103	- 0.193	5.620	0.19
India	2.233	0.988	2.416	0.732	6.512	- 0.98
Indonesia *	2.121	4.417	2.897	- 2.2	7.297	- 0.11
Japan	0.799	3.323	-2.200	- 0.823	1.496	0.73
USA	1.01	1.971	- 1.788	- 308	0.681	0.70

* For China and Indonesia the GDP is expressed in constant market prices (1987 US$).
For Brazil and China the period covered is 1971-1987 while for others it has been 1971- 1988.
**(7) = (-) [(4) + (5)]/[(2) + (3)]

It is important to note in Tables 3 & 4 that for many developed and developing countries part of the adverse effect of economic and demographic growth has been offset by the improvement of energy-efficiency of GDP as well as of the CO2-emission intensity of aggregate primary energy resources. The abatement of growth of CO2 emission on account of these two factors has been as high as 70% and 73% of what would have been in a frozen energy efficiency of GDP and CO2 efficiency of fuel scenario in the case of USA and Japan for the period 1971-87, the economic growth being measured in terms of the rise in GDP in PPP$. The situation would not look much different even if we take the GDP measure in constant US$. However, the contribution of such efficiency factors towards the abatement of growth of CO2 emission for developing countries like Brazil or China has been much less, in the range of 15-19% while for India or Indonesia such contribution has been negative. The energy intensity of GDP has increased over time for countries like India and Indonesia, while the CO2 intensity of fuel use has increased for India and decreased for Indonesia. Tables A7 and A8 point to the relative higher abatement of the CO2 emission growth due to improvement in efficiency by the industrialised countries vis-a-vis the newly industrialising developing ones. It is, however, expected that in the initial phase of development, the process of industrialisation of the economy, and the accompanying change in its product-mix, urbanisation and infrastructural growth raise the commercial energy-intensity of GDP even if the modern technology flows into such a country. A large part of energy consumption in the developing countries is still not market dependent and comprises the inefficient burning of bio-mass (see Table A4). Increasing substitution of the inefficient noncommercial fuel by the efficient commercial fuel (particularly in the household sector) with the rise in income also contributes to the rise in the commercial energy intensity of the GDP. Increased rural electrification, greater accessibility to electrical appliances, higher connectivity of villages by all weather road leading to greater use of motorised transport, increased urbanisation of the people due to industrialisation-all tend to raise the energy intensity in terms of both per capita and per unit of GDP. In making a cross-country comparison of the growth of energy-efficiency in terms of the commercial energy intensity, one should remember that with economic growth the intensity ratio represents an increasing coverage of consumption and production activities over time for a developing economy, while the coverage is already the entirety of the economic activities for the industrialised economies.

Any country would, however, reach a stage of development when the commercial energy-intensity of GDP would reach a peak and after which its value start declining. In the mature stage of capitalist development, the product-mix changes in favour of the service sector whose products are less energy intensive. The infrastrucutral development also reaches its maximum extent and the substitution of non-commercial fuels by commercial ones would be complete at a certain level of development of an economy. It is quite natural, therefore, that the energy-intensity of GDP would be going down at the aggregate level after the attainment of a certain level of per capita GDP and infrastructural development. However, there exists always an autonomous trend of technical change in favour of energy and resource conservation for any given industrial process due to the increased competitiveness that the industry has to face over time even when the economy has not reached the saturation level in the sphere of infrastructure. The energy and material conserving technical change may start dominating the opposing forces of infrastuctural expansion and commercial-noncommercial fuel substitution even before the infrastructural saturation is reached by an economy. The level of per capita GDP at which the commercial energy-intensity of GDP reaches its peak and the level of the peak itself, vary from country to country depending on the structure of the economy, geography, climate, size of population, natural resource endowments, the extent of integration with the global market, the socio-economic environment and political values. It may be noted that China's energy intensity of GDP (PPP$) has been declining since 1978 while that of India is increasing although the level of commercial energy intensity of India is substantively lower than that of China (see the annexure Table A6) and neither of the two countries has reached the stage of maximum development of their infrastructure.

Although the CO2-intensity of the total primary commercial energy used by an economy is largely determined by the indigenous availability of energy resources, it also varies with the level of per capita income and accompanying technological development. A cleaner and more efficient fuel has, in general, lower CO2 intensity per tonne of oil equivalent of the fuel. However, the development of such CO2-emission efficient fuel resource may require the mobilisation of a higher amount of capital. For example, the burning of oil releases 1.5 times the CO2 as released from the burning of natural gas of an oil releases 1.5 times the CO2 as released from the burning of natural gas of an oil equivalent. Similarly, the burning of coal releases twice as much of the CO2 as released from natural gas of a thermal equivalent amount. There are also renewable carbon free primary resources (nuclear, hydel, solar, wind, etc.) or carbon free coal or oil based fuel cell technologies whose use would involve lower CO2-intensity for the same amount of primary commercial energy resources in oil equivalent unit. As most of these carbon intensive primary resource based energy technologies would require a higher level of technological achievement and higher mobilisation of capital, it is expected that the CO2 intensity of fuel is likely to decline only with higher level of per capita income.

4. Economic Growth and CO2 Emission

It appears from our observations of the preceding section that the absolute CO2-emission is determined not only directly but also indirectly by the level of per capita GDP through its effects on the energy-intensity of GDP and CO2-intensity of primary commercial energy. In order to examine the existence of Kuznet's curve effect in the behaviour of the total CO2 emission of an economy over the different phases of development, we have estimated a few alternative simple econometric fixed effects models to explain the macro economy-CO2-emission relationship incorporating dummy variables for the 16 countries of our sample. The estimation of the fixed effects models of the paper have been made by ordinary least square method. We present the results in Tables 5-6 for explaining the behaviour of the total industrial CO2 emission and also the source-wise emissions from the major fuels-solid, liquid and gaseous. The data on CO2 emission have been obtained from the published source of the Oakridge National Laboratory [26, 33]. The income data are taken as GDP in PPP 1985$ from the Penn Table (Summers and Heston [30]) and the time series for the individual countries covers the period 1971-1987/88. The other data on population and energy consumption have been taken from the World Bank [31, 32] and the OECD [16, 19] sources.

Table 5: Regression Model Results on Total Industrial CO2 Emissions-(Z) and CO2 Emission from Solid (ZS)

	Model on Z	Model on ZS
Explanatory Variables	Dep. variable: Z '000 T of C	Dep. Variable: ZS '000 T of C
GDP per capita in PPP 85$: y	51.613 (5.047)	37.487 (5.10)
(y^2) / (10^6)	- 4639.388 (-4.948)	-4403.531 (-6.534)
(y^3 / (10^9)	128. 829 (4.462)	165.044 (7.953)
Population in million: P	717.837 (13.024)	598. 37 (15.104)
Country dummies	16	16
No. of observations	268	268
adjusted R^2	0.9952	0.9839
F-statistic	2774.45	821.26

The figures in bracket are t-statistic

Table 6: Regression Model Results on CO2 emission from (a) Liquid Fuel including the share of gas flaring: ZO and (b) Natural Gas: ZG.

Explanatory Variables*	Model on ZO, Dep. Var: ZO '000 T of C	Model on ZG Dep. Var. LN (ZG) '000 T of C
LN(Y)		2.529 (18.499)
y	6.276** (1:744)	
(y^2) / (10^6)	- 537.755 (-3.5467)	
p	97.168 (2.901)	
Energy intensity of GDP:EI		5.572 (8.102)
Country dummies	16	15
No. of Observations	268	251
Adjusted R^2	0.9899	0.9477
F statistic	1393.28	268.75

The figures in brackets represent the values of the t-statistic.

* The explanatory variable notations have the same meaning and unit of measurement as indicated in Table 5.

** The coefficient is significant at 8.23% level.

(a) Effect on Total CO2 Emission

For the total CO2 emission a model of best fit for estimating its relationship has been one which is polynomial of third degree in y, i.e., per capita GDP and linear in p, i.e., population (see Table5). The model yields the result that the absolute total industrial CO_2 emission will reach a maximum at a per capita income of PPP$ 8741 and a minimum at PPP$ 15297 for stationary population. The absolute total CO_2 emission will decline in the income range PPP $ 8740 to $ 15300, while it will rise, although slowly, in the per capita income range beyond PPP$ 15300. The population growth, on the other hand, would contribute to the increased CO_2 emission at the rate of 0.717 tonne per capita per annum.

It may not appear very clear why the total CO_2 emission (Z) would rise at a very high level of per capita GDP reversing the declining trend. It needs more detailed cross-country analysis of the sectoral behaviour of energy consumption at the different stages of development. The life style of people as characterised by the intensive or extensive use of electricity and transport may contribute to the increasing CO_2 emission beyond certain stage of development. The cross-country comparison of data on income and CO_2 emission between the USA and Canada, on the one hand, and the other OECD countries on the other, in fact, suggests such hypothesis. However, in the context of the control of CO_2 emission in the developing countries, what is more important is the estimation of the level of per capita GDP at which marginal CO_2-emission becomes zero and becomes negative for immediately higher level of per capita income.

It is interesting to note here that all the OECD countries in our sample of 16 countries had a per capita income above PPP$ 8740 for most part of the 17 year period (1971-'88) with a low population growth over the period and exhibited either a definite declining trend of CO_2 emission or a fluctuating time path of CO_2 emission around a moderately declining trend with growth in per capita income. The only two countries in our sample which exceed the PPP$ 15300 (approx) level of per capita income at which the total CO_2 emission is expected to have an upturn are the USA and Canada. It seems that the data of Canada and USA have influenced the shape of the curve and have contributed to the significance and sign of the coefficient of the term of degree 3 in the polynomial function part of the regression equation involving the per capita GDP among other variables. The per capita income of one of the developing countries in our sample has been, on the other hand, ever anywhere near the PPP$ 8740 of benchmark in the period of our coverage. All of them show a clearly rising trend of the absolute CO_2 emission with annual growth rate of emission ranging between 5 and 8 per cent except for Brazil and Indonesia. The differential experience of the latter two countries can be explained by their very different endowment of natural resources and sectoral product-composition of the economies.

(b) Effects on CO_2 from Solids

Individual fuel group-wise analysis shows that the total CO_2-emission from the solids

(ZS) to be partly a polynomial relation of degree 3 in per capita GDP and partly linear in population (see Table 5). Such a model predicts the levels of per capita income which are the turning points in the behaviour of the total CO2 emission from solids under a situation of stationary population. The first turning point has been PPP$ 6242 when the emission from the solids would attain a peak and subsequently decline with growth in per capita income. At the higher level of per capita income around which the total emission from the solid would again start rising, is found to be PPP$ 11275. The partial effect of demographic growth on incremental CO2 emission from solid is found to be 0.60 tonne per annum as per the model. It is only the OECD countries of our sample which have crossed the PPP$ 6242 level of per capita income. It is also interesting to note that quite a number of OECD countries in our sample had rising per capita income approaching the estimated point of upturn of emission from solids, if not actually exceeding it. For these countries, the ZS has not shown a definite declining trend, particularly in the eighties. For some countries like Canada, USA, Japan and Italy the CO2 emission from solids had in fact risen over most of the period of our consideration, in consistency with the results of the model on aggregate CO2 emission.

(c) Effects on CO2 from Liquids

The model representing the behaviour of the CO2 emission from liquid fuel (ZO) yielded somewhat differnet results from those of the solid fuels. Such emission comprises not only the CO2 emission from the burning of liquid fuel but also that from gas flaring, as most of the gas flaring takes place in the process of oil production. The model which fitted well to the data for analysis its relationship with growth is an additive separable function quadratic in per capita income and linear in population (see Table 6). Such a model indicates that for a situation of stationary population, the aggregate CO2 emission will first rise and attain a peak at PPP$ 5835 after which ZO will decline without further reversal of the trend. It also estimates of the incremental effect of population on CO2 emission to be around 0.100 t per capita per annum, for unchanged per capita income and /or fuel composition.

It is thus interesting to note that with economic growth the CO2 emission from oil will tend to decline while that arising from solid fuel may not decline beyond a point. In other words there is likely to be greater dependence on the solid fossil fuel as compared to the liquid in the long run development process of an economy, in general, if the past world experience over the last two decades can be extrapolated in future. This apparent greater conservation of liquid fuel which is substantially more effective and involves less CO2 emission than solid, and its substitution by the latter with growth in per capita income and industrialisation can however be explained in terms of relative price movement of liquid and solid over the last two decades. In future the lower substitutability of oil in certain end uses like transport and rise in the share of OPEC in the total world oil production as an inevitable consequence of the pattern of regional distribution of the discovered world oil reserves, are likely to put upward pressure on the future world oil prices in the long run. This would make the extrapolation of such results into future not unrealistic.

(d) Effects on CO2 from Natural Gas

The behavioural relation of CO2 emission from natural gas (ZG) with economic growth and development is radically different from that for oil. Natural gas is thermodynamically the most efficient and environmentally clean fuel. Its market has been regional and not global like that of oil. As a result its price has been less volatile. This is explained by the fact that there is no serious problem of non-substitutability of the gas by other fuel, nor has it been subjected to so much of political and economic sensitivity as in the case of oil. The best fit model which double log on aggregate GDP and semi-log on energy intensity of GDP shows the GDP-elasticity of CO2 emission from gas to be quite high implying indefinite increase in the total CO2 emission from gas with rise in per capita income (Table 6). For all the countries of our sample except the USA, the CO2 emission from gas has, infact, risen substantially over the last two decades as per the Oak Ridge Laboratory data confirming the model's observation.

(e) Effects on Energy Efficiency, Power Intensity of GDP and CO2 Intensity of Fuels

As energy efficiency is a major determinant of the behaviour of CO2 we have also made an independent estimate of the behaviour of energy efficiency (EI) with economic development. The model on EI shows that the commercial energy intensity would decline with rise in the log of GDP (there for also with GDP or Y) for any given power-intensity of GDP (PWI). It however also shows the partial effect of the power intensity of GDP to be positive in raising the energy intensity of GDP of an economy so long as the per capita GDP is below a certain level. As the model considers a cross-product term of y and PWI among the regressions it shows in fact such effect to be positive so long as the per capita income is below PPP$ 16870. Thus, for almost the entire range of variation of per capita income as mostly experienced by the countries of our sample till 1987, the rise in the power intensity of GDP would have only an adverse effect on the overall energy-efficiency indicator of an economy.

The role of electricity in determining the energy intensity of an economy as implied by such results is not at all unexpected. As already mentioned, a newly industrialising economy goes through a transformation in the form of increased electrification of its rural and urban areas and increased use of electricity in all types of activities replacing other forms of energy in the initial phase of development. In the later phase of mature growth too, the life style of people becomes increasingly dependent on power and electronics. The model on the behaviour of the total power generation for consumption (TPW) provides the GDP elasticity of power to be 1.471 at the global level implying a sharp rise in the power intensity of GDP with rise in income (GDP) in the relevant domain of its variation in the future (see Table 7). As the power generation requires transformation of the primary energy resources into electrical energy, rise in the power intensity of GDP is likely to result in the rise in the absolute level as well as the percentage share of the use of primary energy resources for the purpose of power generation. The CO2 emission is thus indirectly quite significantly influenced by the power intensity of GDP.

As already mentioned, technology influences the CO2 emission not only through the energy efficiency indicators like the energy intensity of GDP, but also through the fuel composition of energy because of the differential emission implications of the different fuels due to the differences in their respective material properties. We have tried to see in an econometric model on the behaviour of the CO2-intensity of commercial energy (CO2ie), whether the CO2 intensity of the total primary commercial energy supplies (which is determined by the fuel composition) is in turn influenced by the level of development or the per capita income (y) and the level of energy intensity of GDP (ei). As the model has a significant cross-product term in y*ei, its result says that the CO2 intensity of primary commercial energy rises with y, so long as energy intensity of GDP, i.e., ei is exceeding 0.495 oil equivalent kg per PPP$ (85) of GDP. The sign of the effect would be opposite whenever the estimate of ei falls short of 0.495 which will be achieved at a certain level of per capita income and above.

The upshot of the above analysis of the relation between CO2 emission and economic growth is that once a country can stabilise its population, its consumption of fossil fuel in the form of solid and liquid will behave in a manner that the CO2 emission in aggregate as well as from both these individual sources will stabilise at certain level of per capita income (PPP$ 8740 for the total CO2 emission, PPP$ 6242 for CO2 emission from solid and PPP$ 5835 for that from liquid) beyond which it is likely to decline in absolute magnitude. It is only the CO2 emission from the use of gas which is likely to grow indefinitely with economic growth with high GDP elasticity. However, in the aggregate CO2 emission from all industrial sources including the emission from industrial processes like cement production will start declining once the per capita income has reached a level in the range of 8700-8800 in PPP $, provided the population is stabilised. Further econometric analyses of the behaviour of the energy intensity of GDP and the CO2 intensity of energy have shown that with the growth in per capita income the technology is expected to change in a manner so as to cause a decline in the energy intensity of GDP, while the fuel mix might change to raise the CO2-intensity of primary energy initially. The share of CO2-intensive fuels like coal is likely to go up in the initial phase of industrialisation because of the increased electrification of the economy and coal is increasingly used to indirectly supply energy through electric power with growth in income and development in technology. However, as the technology improves and the energy-intensity of GDP declines the fuel substitution is likely to occur in favour of the relatively carbon free fuels contributing to the decline in the CO2 intensity of fuel-mix. As a result, the technology effect of the development process is likely to offset the adverse environmental effect in the form of CO2 emission that would have arisen from growth with frozen technology scenario. Besides, the organic composition of the development process induces a structural change in the economy at a higher stage of development which also contributes to the reduction of CO2-emission.

Table 7. Regression Model Results on Energy and Power Intensities of GDP (EI, PWI) and CO2-Intensity of Primary Energy (CO2IE)

Explanatory Variables *	Model on EI Dep. Var: EI Kg/ PPP $ (1985)	Model on PW I Dep. var.: LN(TPW) PW in TWH	Model on CO2IE Dep. Var : CO2IE Tonne/Tonne
LNY	- 0.0571 (-7.278)	1.471 (26.099)	
y			- 0.000241 (- 6.776)
Power-Intensity of GDP: PWI	0.7912 (19.261)		
y*PWI	- 0.0000469 (-18.404)		

EI			- 6.64298 (-7.399)
y*EI			0.000487 (4.5295)
Country Dummies	16	16	16
No. of Observation	268	268	268
Adjusted R^2	0.9781	0.987	0.723
F-statistic	671.23	1202.79	37.74

The figures in bracket are the values of t-statisitc

* Explanatory variable notations have the same meaning and unit of measurement as indicated in Table 5 and 6.

(f) Is Policy Intervention Necessary ?

There would nevertheless remain the following question regarding the necessity of policy intervention in connection with the problem of global warming. If rise in the CO2 concentration in the atmosphere is going to induce climate change which might cause damage to our economic activities and human well being in the long run, can we, in general, allow a policy of non-intervention with the growth and development process except for the stabilisation of population, in view of our model results ? Given the IPCC's assumption of the future GDP growth rates of the different regions of the world and the coefficients of explanatory variables including those of the country dummies of the models as estimated, one can work out a rough estimate of the date of stabilisation of CO2 emission and the level at which it is going to be stabilised in the different parts of the world. However, the aggregate global population which would be reached when the developing world crosses the threshold of CO2 emission stabilising per capita income are very likely to be considered to be too large, given the deliberations of the IPCC and the goal of emission stabilisation of the UN Framework Convention of Climate Change. These bodies set targets of reduction of the CO2 emission to a fraction of the 1990 level at some future date like 2010 or 2020. It would also in all probability be too late for any climate stabilisation.

It may be noted here that the stabilisation of any GHG emission is only a necessary condition for climate stabilisation or moderation of climate change but not sufficient. It is the pre-existing level of the stock of CO2 concentration along with the level of flow, stabilised or not, that would matter among other factors in determining the rate of accumulation of CO_2 concentration and its impact on the climate system. It is therefore quite possible that by allowing a business as usual scenario, we end up with stabilisation of flow of CO_2 emission globally at too late a date and at too high a level of flow of CO_2 emission with linearly rising level of concentration of CO_2 at a pace which might have quite an adverse impact on the climate system. In such an eventuality, it is of course important to identify the policy options that need to be considered for intervention in the existing development process of the various countries of the world economy so that the CO_2 stabilising per capita income level and the date of CO_2 stabilisation are respectively lower and earlier and the peak CO_2 emission level is lower as well. As a risk avoiding strategy, the UNFCCC has considered the stabilisation of the CO_2 emission not at the existing level but at a percentage of the 1990 level.

In view of the above, it is worth focussing attention of the policy researchers to the assessment of growth of CO_2 emission by the large incremental CO_2-emitting nations in the coming decades. As we have already noticed that the OECD countries have mostly approached the stabilisation of the aggregate CO_2 emission although at a high level, it would be the populous developing countries like China and India which would be largely contributing an increasing share of the total flow of CO_2 emission over time in the future. If the incremental CO_2 emission is abated for the major developing countries with high demographic pressure, a large part of the problem of dealing with global warming would, in fact, be taken care of. As country level modelling is easier and more reliable than most of the global models, it is important to develop country level models for major developing countries like China, India, Indonesia, Brazil etc., for assessing (a) the potential of CO_2 emission for an assumed economic and demographic growth and oil price scenario, (b) the policy options for the reduction of growth of CO_2 emission for achieving a target global environmental quality with reference to climate stabilisation, and (c) the supporting requirement of international cooperation for sharing the costs of such CO_2 abatement, if necessary.

5. Growth Potential of CO_2 emission by China, India and the USA:

In view of our observations in the preceding paragraph we would now like to digress to make a few preliminary observations on the possible future growth pattern of CO_2 emission of the two countries with largest population-China and India-based on our data sources as already referred to. While the models of Tables 5 to 7 indicate in general the responsiveness of CO_2 emissions with respect to variables relating to economic and demographic growth and technical change, they are not by themselves adequate to project accurately the future CO_2 emission scenario even with the use of the estimated coefficients of the country dummy variables. After analysing the emission-energy-income data (income data in US $) for India and China for the period 1971-1991, we have obtained the comparative elasticity values and future growth rates of total CO_2, energy and power as presented in Tables 8 and 9. We show in Table 8, the comparative GDP-elasticity values of these variables for China, India and the USA based on time series regression analysis side by side with what were yielded by the models of the previous section using the panel data.

Table 8. The GDP-elasticity of Total CO_2 emission, Total Primary Commercial Energy and Power

GDP elasticity of	India	China	USA	Models 1C, 4C, 6
Total CO_2 emission (assuming ei fixed)	1.222 (1.421)	0.954 (0.661)	0.9686	0.916

Total Primary Energy (assuming power intensity of GDP fixed)	0.902 (1.273)	0.651 (0.635)	0.8059*	0.726
Total Power Generation Requirement	1.812	0.9856	1.097	1.471

Figures in brackets represent the elasticity values without the assumption of fixity of ei or pwi.

* Power intensity of GDP not being assumed fixed. However, the near unity value of GDP-elasticity of power for USA would make this estimate approximately valid for a situation of unchanged power intensity of GDP as well.

For the IPCC assumptions regarding the future growth rate of GDP [see 11,12], the elasticities as presented in Table 8 would yield the alternative growth rates of CO2, the total primary commercial energy (TPCE) consumption and power generation requirement (TPW) as given in Table 9 depending on the alternative choice of elasticity values based on the results of the country specific time series result or the panel data analysis.

Table 9. Projected Annual Average Growth Rates of Total CO2 emission, Total Commercial Energy and Electric Power.
Unit: (%)

country	GDP growth	Per Capita	CO2-emiss-	CO2-emiss-	Total Primar	Total primary	Total Power	Total Power

	rate	GDP	ion (for unchanged energy intensity) A*	ion (for unchanged energy intensity) B*	y Comm. Energy Consumption (for unchanged power intensity) A*	Comm. Energy Consumption (for unchanged power intensity) B*	generation Requirement A*	generation Requirement B*
China	3.48	2.78	3.32	3.19	2.265	2.53	3.43	5.12
India	3.8	2.31	4.64	3.48	3.43	2.76	6.89	5.59
USA	2.0	1.96	1.94	1.83	1.83	1.45	2.19	2.94

* The scenario 'A' assumes elasticities yielded by country-wise time series analysis and the scenario 'B' assumes the elasticities based on panel data as presented in the earlier section.

It may be noted that for India we have chosen here the future economic growth rate assumption of the IPCC 1S92A scenario for Other Asia (i.e., Asia excluding the Former Soviet Union and China). Given the estimated PPP income percapita for China (1985 prices) in 1990 as $ 2413, it will take China 47 years from 1990 to reach the CO2 stabilising per capita income of PPP$ 8740, although the population growth is not expected to stabilise by that time in China. In reality China's GDP per capita growth (in PPP $) has been around 7.415% in the decade of eighties which is much higher than what has been assumed by the IPCC for modelling future projections. However, even with the IPCC assumption regarding the GDP growth China's CO2 emission will grow in the range of 3.2% to 3.3% per annum approximately, if the energy intensity remains unchanged. It is however true that the energy intensity of China is declining due to technical changes and increasing concern for international cost competitiveness as induced by China's economic and institutional reforms. These forces are expected to reduce the commercial energy intensity and the CO2 intensity of GDP over this 47-50 year period and contribute towards the stabilisation of the aggregate CO2 emission at a possibly earlier date.

In the case of India, much longer time (about 103 years) is, however, expected to be taken to reach the PPP per capita income level of $ 8740, given the estimated per capita PPP income in 1985 prices to be $ 838 in 1990 and the assumption of 2.31% per capita GDP growth rate for the entire period, which is the same as one of the IPCC for the average of Other Asia for the 60 year period 1990-2050. As in the case of China, the growth rate assumption for India is lower than the actual per capita growth rate of 2.9% (in PPP$) of the decade of the eighties. In any case, as per such GDP and population growth rates the total CO2 emission is expected to increase at an annual average rate in the range of 3.5% to 4.6% per annum for fixed energy intensity of GDP, at least for the next 60 years as per the current trend. India's energy-intensity of GDP is in fact increasing over time in its current phase of development. However, our models tell us that as India attains a higher level of industrialisation and per capita income, she would achieve at a later stage declining energy intensity of GDP. This should enable her to stabilise the absolute CO2-emission by the end of the 21st. century as by that time the population will hopefully stabilise too.

As compared to China and India, the industrially advanced large economies like the USA will have a much slower growth rate of CO2 emission as per the frozen energy efficiency scenario because of the lower future projection of growth rate of the economy. However, the increasing energy efficiency has already enabled these countries to reach a stage of almost stabilisation of the aggregate CO2 emission. The above observations thus make it amply clear that if the dynamic experience of economic growth and industrial capitalism as reflected in the cross-section-time series data provides the basis for extrapolation of the pattern of energy efficiency and CO2 emission in the future, China and India would make too large incremental CO2 emissions in the atmosphere over too long a period, before their CO2 emissions are stabilised. It may be considered too late to do anything for stabilising the climate, if that is considered important. One can appreciate the seriousness of the problem if one also takes account of the existing sectoral source wise pattern of CO2 emission, its future dynamics and the scope of conservation or fuel substitution offered by the different sectors as per the pure guidance of the market.

Any sectoral analysis of CO2 emission of the cross-country data would suggest that the future development of the infrastructure of the power utility and the transport in the developing economies and the rise in the level of their household income would tend to raise the absolute levels of sectoral CO2 emissions as well as the percentage share for some of these sectors (see annexure Table A3.1, A 3.2 and A 5). The low substitutability of technology in the transport sector, the low ability to pay for energy by the poor households and the concern for the availability of cheap power for international competitiveness would make it difficult to curb the CO2 emission of such economies to any significant extent if the unregulated market forces are to guide the energy technologies. The requirement of a long time horizon for the stabilisation of the CO2 emission in these economies is thus a likely consequence if we intend to allow the dynamics of technology to follow its due course as guided by the market without any intervention.

6. Policy approach to the setting of CO2 Emission Standard

What should then be our policy approach for the setting of CO2 emission standard with a view to control the climate in the long run ? In view of the uncertainties and gaps in the area of climatology regarding the forecast of climate change, the first task that becomes important is to at least ascertain if the effect of the rise in CO2 and other GHG concentrations on the temperature and the patterns of air circulation, ocean current, precipitation etc. is going to be gradual in nature throughout, or whether the concerned functions would exhibit features of serious non-linearities/discontinuities implying structural shift in the relations at certain level of global warming. While in the case of gradual transformation adaptation to climate change would be a feasible policy option worth considering vis-a-vis the mitigation of climate change, the problem becomes more serious in the eventuality of the latter. It becomes therefore important to find out if there exists any threshold level of concentration of CO2 and other GHGs, and the corresponding atmospheric temperature at which the non-linear effects may raise the marginal cost of atmospheric change in terms of economic loss sharply. In view of the uncertainties, what is important is not the ascertaining of the precise value of the marginal cost of damage due to climate change, but the critical level of concentration of CO2 beyond which the risk of catastrophic changes in the earth's geography and climate becomes suddenly high making adaptation to the changed environment very difficult, if any such threshold exists. The global air quality standard can be fixed as per such scientific research finding regarding the safety standard for the global environment.

Once the global air quality is decided with reference to the CO2 emission along with other GHGs, the policy researchers have to work out the distribution of the responsibility of GHG emission abatement at the global level among the individual countries and accordingly set the national emission standards. The distributions of the past, the present and the expected future CO2 emissions may be widely different from the distribution of the economic opportunities of CO2 abatement across the nations. Again the distribution of the opportunities of abatement may not correspond to the distribution of the ability to pay for the abatement of the GHG emissions among the different countries (see Smith et. al [29]). Some of the poorer developing countries may have tremendous opportunities of reducing CO2 emission in a short time horizon, but may require the mobilisation of a large amount of capital resources. The availability and the costs of the different options of CO2 abatement comprising among others technological upgradation for energy conservation, fuel substitution in favour of relatively less carbon intensive fuel (like natural gas), backstop technologies based on renewables like biomass, solar and wind resources, application of fuel cell, magneto hydrodynamics and hydrogen, CO2 sequestration and CO2 removal and storage would vary from country to country (see e.g. [20]). The policy decision for setting standards for the individual countries would require the consideration of the global cost minimisation for the control of the climate as well as that of equity with reference to the distribution of the burden of global cost among the nations. The comparison among the schedules of marginal cost of the alternative standards for GHG emission or radiative forcing of the different countries may as such warrant imposition of stringent standards for the developing countries like China or India in the interest of global cost minimisation. However, given their ability to pay, such imposition would cause deceleration of their pace of development, if there is no international cooperation in the form of inter country transfer of resources for meeting the costs. While the climate change problem addresses the problem of intergenerational equity, the choice of policy options for resolving the problem would thus inevitably lead us to the intragenerational equity issue.

With reference to the relation between the human face of development and the global environment , it is also important to emphasize here the well known fact that the economic growth contributes not only to the accumulation of man made capital, but also to the quality of life of the people in terms of infant mortality rate, life expectancy, literacy rate, status of women, higher level of skill formation, etc. The human resource development would induce an effect towards both : (a) the stabilisation of the size of the population and (b) the innovative ability of the people and the pace of technical change of a society. Both (a) and (b) would in turn contribute directly and indirectly to the stabilisation or setting in of a declining trend of CO2 and other GHG emissions from human activities. Besides, the accumulation of man made capital and human capital would also enable a society to effect a better adaptation to climate change to the extent it takes place as a gradual process, or to cope with any unfortunate catastrophic change which unpredictably occurs due to the combination of problems of non-linearities of the relationships of climate variables as well as those of uncertainty involved in this area of the science.

In view of these it would not be a wise decision to fix ambitious GHG emission targets for the developing countries or at the global level in the high abatement cost range and sacrifice economic growth to any significant extent. What would be wiser as a strategy is to set a target of GHG emission reduction over a certain time horizon and then go on revising it upwards over time in the long run approaching the level which is needed to avert any high risk situation of catastrophic climate change or high marginal damage cost due to non-linearities in the involved relationships. In other words, assuming risk aversion and climate stabilisation to be laudable objectives in the interest of human well being at the global level, climate control should be phased over time in a situation of high cost beyond a range of GHG emission reduction. However, the stabilisation of climate cannot also be a too prolonged process since the cumulative emission may be too high for any climate stabilisation and the crucial climate variables may threaten to reach the threshold levels. It may, therefore, be important for the global community to share the global cost of climate control not in proportion to the costs incurred within the national boundaries but to cooperate to effect a substantive international transfer of resources among the nations for the purpose. Besides, the industrialised countries may even be required optimally to make some sacrifice in the form of change in the life style to make it more environment friendly and slow down their own pace of growth, if necessary, in order to allow the emission of GHG of the poorer countries to grow for sometime and yet enable the global community to reach a situation of climate stabilisation. All these would, of course, pose serious problems of international political economy which are to be resolved at the global level.

7. Concluding Remarks.

As we have observed, the integrated assessment of climate change at the global level due to anthropogenic emissions has its gaps and problems of uncertainties. The conventional approach of such assessment begins with the postulate that population and economic growth are destructive for the global environment and would be destabilising the climate system because of the existence of bound on the carrying capacity of nature. This viewpoint is considered to be too pessimistic by some of the developing economies. We have shown that economic growth brings with it an evolution of technology which induces stabilisation or decline in the absolute level of CO2-the major GHG-emission when the per capita income exceeds the level of PPP $ 8740 (in 1985 prices) approximately. But can we afford to be complacent about climate stabilisation in view of such stabilisation of CO2 gas emission at a certain stage of development ? We have shown that if we allow the CO2 emission of the major populous developing countries like India and China to stabilise in its due course it may be too late for the climate to stabilise since too much of cumulative emission might take place in the intervening period. This may, in fact, threaten problems of calamities due to climate change involving very high cost of damage at the margin.

For developing a correct policy approach for the choice of standard for the CO2 emission at the global and the national level, it is therefore important, first of all, to remove some of the uncertainties in climate research and ascertain whether there exists a critical level of concentration of GHGs which would describe a threshold beyond which there are risks of unpredictable behaviour of climate or behaviour with serious non-linear adverse effect, and if so what that level is. Secondly, a choice for aversion of risk due to such possible adverse effect would warrant the introduction of a phased program of climate control and GHG emission reduction including CO2 emission and the setting of targets for such reductions for the different regions of the world in the different time frames. Such targets may be revised over time as new research output gives new information, removes some of the uncertainties and gives better estimates of the critical values of the climate variables or policy parameters. In order to base these targets scientifically , country level economic modelling of GHG emissions control would be complimentary to the global modelling for the integrated assessment of climate change.

Finally, the choice of GHG (CO2) emission standard at the national level involves an additional problem of solving for the distribution of the responsibility of certain reduction of CO2 emission at global level among the different countries. Even if the climate research indicates the threshold level of CO2 concentration in the atmosphere to be such that most of the developing countries need to prepone the stabilisation or reversal of the rising trend of the CO2 emission much before the stage of per capita income PPP$ 8740, there would still remain a degree of freedom in respect of the level of CO2 emission abatement and the time frame of its achievement by the individual countries. In order to optimally choose the CO2 or GHG emission standard at national level the twin considerations of global cost economisation of the reduction of emission and that of equity arising from the divergence between the cross country distribution of cost effective opportunities of such abatement and that of ability to pay it will have to be taken into account. The country level economic modelling of restriction of the GHG emissions would provide important informational input for such decision problem (see e.g. [4,9] in the Indian context). The problem of setting the CO2 emission standard would thus in the ultimate analysis reduce to be the one of international political economy for the sharing of the global cost for climate control. This would require more of country level interdisciplinary research than what the current priorities suggest, specially the creation of a sound knowledge base in the developing economies for effective and fair global planning and international negotiations in the interest of saving our terrestrial environment system.

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Table A1 : Shares in World GDP (US$), Population, Energy Consumption and CO2 Emission of Selected Countries Unit %

Countries	Population	GDP (US $ 1987)	Total Primary Commercial Energy	Industrial Emission of CO2
Brazil	2.83	1.88	1.39	0.95
Canada	0.51	2.69	2.92	1.81
China	21.48	1.71	9.47	11.21
Egypt	1.0	0.15	0.44	0.36
France	1.07	5.54	3.23	1.65
Germany	1.5	7.28	4.83	4.28
India	16.19	1.15	2.69	3.10
Indonesia	3.39	0.54	0.81	0.75
Italy	1.08	5.32	2.21	1.78
Japan	2.32	15.46	6.16	4.81
Netherlands	0.28	1.34	0.97	0.61
Nigeria	1.85	1.58	0.23	0.41
Pakistan	2.16	0.21	0.36	0.3
Philippines	1.18	0.21	0.26	0.2
UK	1.08	4.67	3.03	2.55
USA	4.72	25.93	27.27	21.75
Total for the sample	62.64	75.66	66.27	56.52
World Absolute Levels	5351 million	US $ 21639.12 billion	7186.393 m.t.oe	6188 million tonnes of carbon

Table A2 :Comparative Energy Intensity and CO2 Emission Intensity Per Capita and Per Unit of GDP

Regions	GDP per Capita US$ (87)	GDP per Capita PPP$ (85)	Primary Commercial Energy per Capita (tonnes of oil eq.)	CO2 emission per Capita (tonnes of carbon)	Energy Intensity of GDP at factor cost kg/US$	Energy Intensity of GDP kg/PPP $	CO2 emission Intensity of GDP at factor cost kg/US$	CO2 emission intensity of GDP kg/PPP $
Egypt	612	3602	0.586	0.416	0.958	0.163	0.68	0.115
Nigeria	345	1540	0.164	0.253	0.475	0.106	0.735	0.165
China	323	1711	0.592	0.604	1.833	0.346	1.869	0.353
India	287	1145	0.223	0.222	0.778	0.195	0.772	0.194
Indonesia.	639	2827	0.321	0.257	0.502	0.113	0.401	0.091
Japan	27010	19408	3.575	2.404	0.132	0.184	0.089	0.124
Pakista	391	2067	0.225	0.161	0.576	0.109	0.413	0.078
Philippines	718	2476	0.292	0.193	0.407	0.118	0.269	0.078
France	21040	18419	4.078	1.791	0.194	0.221	0.085	0.097
Germany	19654	19715	4.336	3.304	0.221	0.22	0.168	0.168
Italy	19905	17019	2.746	1.901	0.138	0.161	0.095	0.112
Netherlands	19253	16763	4.604	2.512	0.239	0.275	0.13	0.15
UK	17526	16329	3.781	2.735	0.216	0.232	0.156	0.167
Canada	21319	19103	7.681	4.105	0.36	0.402	0.193	0.215

USA	22203	22115	7.754	5.326	0.349	0.351	0.24	0.241
Brazil	2680	5247	0.662	0.389	0.247	0.126	0.145	0.074

Table A3.1 Sectoral Energy Consumption (Incl.Share of indirect use through Power) for Selected Countries (1991)

unit: million tonne of oil equivalent

Country/ Sector	Brazil	China	India	Indonesia	USA	Japan
Industry	32.21	414.78	102.5	24.44	616.67	188.6
Transport	36.99	50.83	30.71	12.8	499.85	91.39
Agricult.	4.4	36.71	21.93	1.05	14.99	7.65
commerc. services	5.29	30.84	9.51	1.84	332.71	48.32
Residential	11.21	111.71	26.32	11.12	431.75	68.92
Total	90.1	644.87	190.97	51.23	1895.97	404.88

Table A3.2 Sectoral CO2 Emission (Incl.Share of indirect use through Power) for Selected Countries (1991)
unit: million tonne of Carbon

Country/ Sector	Brazil	China*	India	Indonesia	USA	Japan
Industry	22.1	430.55	112.15	21.76	434.16	149.58
Transport	27.8	46.16	24.8	11.98	408.97	70.35
Agricult.	2.83	34.88	22.4	0.98	12.27	5.9
commerc. services	1.12	30.03	9.29	1.63	211.76	30.31

Residential	5.05	111.54	23.37	10.18	278.76	41.67
Total	58.9	653.16	192.01	46.53	1345.92	297.81

* Data for China are given for 1990

TableA4: Primary Commercial and Non-Commercial Energy Use (1991)
Unit :million tonne of oil equivalent

Regions	Total Primary Commercial Energy Supply	Total Non-Commercial Renewable Resource Supply	Total Prinary Energy Resources Consumed
Egypt	31.43	1.02	32.45
Nigeria	16.2	23.91	40.11
China	680.72	48.18	728.9
India	193.39	65.79	259.18
Indones -ia	58.15	35	93.15
Japan	442.96	0	442.96
Pakista- n	26.11	6.84	32.95
Philippi -nes	18.36	9.14	27.5
France	232.45	3.94	236.39
German -y	347.34	2.66	350
Italy	158.74	0.98	159.72
Netherl- ands	69.52	0.22	69.74
UK	217.79	0.72	218.51

Canada	209.69	8.6	218.29
USA	1959.38	97.76	2057.14
Brazil	100.24	59.89	160.13

Table A5: Sectoral Share of CO2 Emision incl. that of Indirect Use of Fuels through Power

unit %

Countries/ sector	Brazil 1981	Brazil 1991	China 1980	China 1990	India 1981	India 1991
Industry	45.96	37.52	64.92	65.89	56.15	58.41
Transport	41.65	47.2	4.87	7.06	24.34	12.92
Agricult.	4.05	4.81	8.32	5.34	5.65	11.66
commerc. services	2.25	1.9	2.93	4.6	2.8	4.84
Residential	6.09	8.57	18.96	17.07	11.06	12.17
Total	100	100	100	100	100	100
Share of Power	3.68	4.4	17.67	23.39	26.19	42.84

Countries/ sector	Indonesial-1981	Indonesia 1991	USA 1981	USA 1991	Japan 1981	Japan 1991
Industry	42.18	46.78	36.14	32.26	56.65	50.23
Transport	28	25.75	27.68	30.39	19.17	23.62
Agricult.	0	2.1	0.9	0.91	1.24	1.98
commerc. services	2.69	3.5	14.13	15.73	11.37	10.18
Residential	27.13	21.87	21.15	20.71	11.54	13.99
Total	100	100	100	100	100	100

Share of Power	9.52	19.49	30.26	34.058	26.94	29.29

Table A6: Trend of Energy and CO2 Emission Intensities of GDP (PPP $ 1985) for China, India and USA
Unit: kg/PPP$

Year	China Energy Int.	China CO2-Int.	India Energy Int	India CO2 Int.	USA Energy Int.	USA CO2 Int.
1971	0.306	0.312	0.169	0.151	0.594	0.429
1972	0.317	0.32	0.18	0.161	0.6	0.429
1973	0.306	0.308	0.182	0.166	0.573	0.424
1974	0.309	0.308	0.197	0.174	0.578	0.413
1975	0.333	0.334	0.194	0.176	0.575	0.403
1976	0.365	0.367	0.202	0.183	0.575	0.408
1977	0.381	0.379	0.201	0.207	0.568	0.393
1978	0.378	0.374	0.196	0.198	0.55	0.379
1979	0.36	0.358	0.221	0.218	0.535	0.372
1980	0.333	0.328	0.218	0.221	0.516	0.361
1981	0.312	0.309	0.231	0.228	0.491	0.339
1982	0.303	0.309	0.232	0.235	0.482	0.33
1983	0.289	0.296	0.232	0.239	0.463	0.317
1984	0.277	0.284	0.237	0.243	0.449	0.304

1985	0.261	0.271	0.244	0.252	0.441	0.299
1986	0.26	0.27	0.253	0.258	0.425	0.289
1987	0.256	0.261	0.258	0.261	0.426	0.288
1988	NA	NA	0.254	0.255	0.425	0.291

Table A7: Factor Analysis of Growth of CO2 Emission on the basis of GDP at Factor cost in US $'87 1971-1991

Unit:%

Annual Average Growth Rates Of Factors

Countries (1)	Population (2)	GDP per Capita (3)	Energy Int. of GDP (4)	CO2 Int. of Energy (5)	Co2 Emission (6)	Contr. of Efficiency Factors in Saving CO2 emission (7)*
Brazil	2.188	2.196	0.873	-1.202	4.589	7.502
Canada	1.302	2.117	-1.753	-0.54	0.914	70.594
China **	1.477	7.258	-1.721	0.066	5.481	18.955
Egypt	2.353	4.439	0.717	-0.948	6.641	3.403
France	0.538	2.113	-0.68	-2.798	-0.89	131.237
Germany	0.101	2.477	-.0.687	-0.52	1.347	46.809
India	2.204	2.089	1.368	0.541	6.339	-44.47
Indonesia **	2.068	4.236	3.346	-1.797	7.976	-24.582
Italy	0.331	2.569	-1.353	-0.025	1.542	47.479
Japan	0.799	3.462	-1.678	-0.744	1.774	56.858
Nether-	0.667	1.736	-0.923	-1.009	0.444	80.436

lands						
Nigeria	3.01	-0.363	7.66	-4.623	5.39	-114.701
Pakistan	3.128	2.506	1.084	-1.088	5.695	0.071
Philippines	2.462	0.876	0.513	-1.379	2.457	25.945
UK	0.152	1.942	-1.899	-0.714	-0.759	124.814
USA	0.986	1.536	-1.552	-0.254	0.689	71.614

* (7)=(-)[(4)+(5)]*100/[(2)+(3)]
** GDP taken in market price. For China the period covered is 1973-1991.

Table A8: Factor Analysis of Growth of CO2 Emission on the basis of GDP in PPP $'85 1971-1988 Unit: %

Annual Average Growth Rates Of Factors

Countries (1)	Population (2)	GDP per Capita (3)	Energy Int. of GDP (4)	CO2 Int. of Energy (5)	Co2 Emission (6)	Contr. of Efficiency Factors in Saving CO2 emission (7)*
Brazil **	2.291	3.28	0.656	-1.337	4.588	12.224
Canada	1.087	2.232	-1.499	-0.372	1.415	56.374
China **	1.598	5.321	-1.103	-0.012	5.811	16.119
Egypt	2.365	4.299	1.487	-0.98	7.291	-7.61
France	0.51	1.903	-0.751	-3.479	-1.882	175.268
Germany	-0.017	2.13	0.4	-3.068	-0.624	126.218
India	2.233	0.988	2.416	0.718	6.498	-97.293
Indonesia	2.121	4.417	2.91	-1.975	7.567	-14.293
Italy	0.357	3.085	-2.04	-0.011	1.331	59.598
Japan	0.877	3.417	2.2	-0.82	1.499	-32.133

netherland-s	0.662	1.581	-0.973	-1.598	-0.36	114.664
Nigeria	3.03	-1.93	10.067	-5.283	5.339	-434.857
Pakistan ***	3.12	1.733	1.582	-1.148	5.343	-8.926
Philippines	2.49	1.495	-0.33	-1.433	2.194	44.225
UK	0.119	2.346	-2.421	-0.746	-0.759	128.481
USA	1.009	1.971	-1.949	-0.314	0.675	75.945

* (7)=(-)[(4)+(5)]*100/[(2)+(3)]

** The period covered is 1971-1987 *** The period covered is 1971-1986

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