MONOGRAPH

PROSPECTS AND POLICIES FOR LOW CARBON ECONOMIC GROWTH OF INDIA

Ramprasad Sengupta

NATIONAL INSTITUTE OF PUBLIC FINANCE & POLICY

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Preface

In the context of international discussions on the disastrous consequences of climate change and the need for exploring the options for sustainable development, the Institute organised a roundtable on Fiscal and Non-Fiscal Instruments for Sustainable Development in India. U. Sankar, from Madras School of Economics and Prof. Ramprasad Sengupta, Jawaharlal Nehru University were invited to prepare papers on the subject. Both Prof. Sankar and Prof. Sengpta are two of the foremost experts on environment and development. We are extremely grateful to them for having taken up this task of exploring fiscal and non-fiscal instruments for sustainable development. Given the significant work undertaken by these scholars, we would like to place these papers in the public domain in the interest of a rigorous debate on these issues. The roundtable has received support from the Strategic Programme Fund, British High Commission, which we gratefully acknowledge. Needless to say, the views expressed in the monograph are those of the author alone, and not of the Institute.

M. Govinda Rao
Director

Abstract

India is being currently pressurised by the northern industrialised countries to make commitment to the international community for restraining her CO_2 emission within an absolute upper bound time frame in the near future. The achievement of delinking of CO_2 emission and economic growth is a basic pre-requisite for making any such commitment as high economic growth is a necessary condition for the removal of India's income poverty and energy poverty, improvement of the quality of life and for ensuring human development of her people. This paper analyses the past pattern of economic growth of India, energy use and carbon emission and examines to what extent India has been able to restrain the growth of her carbon emission and what factors have been responsible to what extent for such changes in CO_2 emission. This analysis has been made for both the pre-economic reform and the post-economic reform period by using Decomposition Methods of Analysis. Taking clue from the results of such analysis, the paper further develops econometric models of future projection of energy related CO_2 emissions for the alternative scenarios of GDP growth, energy pricing and technology development. The models are used to see how far it would be possible to make India's economic growth low carbon in the time horizon up to 2031-32 and what policy approach would be appropriate to achieve that objective. It would be reassuring for all of us in the global community to see from all these models of decomposition and applied econometrics that it is possible for India to significantly delink growth and carbon intensity of GDP and lower the growth of absolute emission significantly vis-à-vis a frozen price and technology scenario by the choice of appropriate policies without making any compromise with the target of economic growth.

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Contents

List of Tables

I. Introduction

On the eve of the UN conference on climate change at Copenhagen, a debate that is currently attracting global attention is whether the fast developing countries like China and India should be made to commit or not to some target emission of greenhouse gases, particularly the CO_2 emission within a time frame in near future. It may be noted that India's share in the world total of CO_2 emission has been 4.8 percent and in the Greenhouse Gas (GHG) emission has been about 6 percent while her share in the past cumulative emission of GHGs between 1850 and 2002 has been only 2.2 percent. However, an accusing finger is being pointed to India along with China alleging that they are potentially going to be among the top polluters to be responsible for global warming in not distant future, due to their already large size of population and high rates of economic growth. The global media, politicians, social scientists and policymakers are engaged in this debate and a segment of this population is trying to justify some arm twisting of the developing world by way of posing an implicit threat of imposing tariff or non-tariff trade barriers in the event of their non commitment, irrespective of the developmental implication of such insistence. India has consistently taken the official position that every global citizen should have equal right and share of the eco-services rendered by the natural environment for the absorption of wastes like greenhouse gases. All members of the global family of the humans should have in fact equal entitlement to the fruits of prosperity derived from the use of this global public good (Government of India, 2009).

It should however be, first of all, noted that India is not in the same league as China in terms of emissions as well as the stage of development. While the per capita GNP of China has been 2.5 times that of India in terms of US $ and almost double that of India in terms of PPP $ in 2007, the shares of China in the total world CO_2 and GHG emissions have been the highest among all countries being respectively 19 percent and 18 percent in comparison with India's shares of 4.8 percent and 6 percent as already noted (*see, Table 1 and 2*). In terms of per capita emission China emits CO_2 3.3 times and total GHGs 2.5 times that of India. The poverty rates of India as per the national poverty line has been as high as 28.6 percent in 2004-05 whereas the corresponding estimates, for China has been 2.8 percent only for the same year (World Bank, 2009). It is thus unfair to bracket India with China in the context of any discussion regarding the time frame within which India or China may be expected to commit to the acceptance of any emission cap (Panagaria, 2009). Given the amount of substantively higher level of poverty and far lower emissions India would need more time than China to reach a stage of development when she can afford to make such commitment. The case of India in the context of such participation in the programme of control of climate change by way of the acceptance of the target CO_2 or GHG emission cap, should thus be separately and independently reviewed and assessed.

Table 1: Comparative Primary Energy Use across some Major Countries and Regions

Countries	E1 Population (million)	E2 Total primary energy use toe 2006 (mtoe)	E3 Per capita (PPP$) NI 2006	E4 Energy per capita Kg.	E5 Energy intensity of GDP (Kg/PPP$)	E6 Share of biomass in total primary energy (%)	E7 Share of fossil fuel (%)
India	1109.8	565.8	2460	510	0.21	28.3	69.0
China	1311.8	1878.7	4660	760	0.31	12.0	85.1
USA	299.4	2320.7	440.70	7768	0.18	3.4	85.7
High Income Countries	1030.7	5659.1	34933	5416	0.16	3.4	82.9
World	6538.1	11525.2	9209	1820	0.19	9.8	80.9

Source: World Bank (2009): World Development Indicators 2009.

Table 2: Comparative CO_2 Emission across some Major Countries and Regions

Countries	C1 Total CO_2 emission 2005 (mt)	C2 Total GHGs 2005 (mt)	C3 Share of CO_2 in world total (%)	C4 Share of CO_2 in total GHGs (%)	C5 Share of GHGs world total (%)	C6 CO_2 emission per capita 2005 (t)	C7 Carbon intensity of energy (t/t)	C8 Carbon intensity of GDP Kg/PPP$
India	1402.4	2424.92	4.79	57.83	6.02	1.3	2.6	0.6
China	5547.8	7229.96	18.96	76.73	17.96	4.3	3.2	1.0
USA	5776.4	7151.31	19.74	80.77	17.77	19.5	2.5	0.5
High Income countries	13099.7	16217.49	44.77	80.78	40.29	12.6	2.3	0.4
World	29257.0	40254.18	100.00	72.68	100.00	4.5	2.6	0.5

Source: World Bank (2009): World Development Indicators 2009.

The purpose of the paper is however not to dwell upon whether or not India should make commitment to the international community in respect of emission cap nor when should India commit if at all. This paper presumes that high growth is necessary for the removal of poverty, but also considers that the high growth should be at the same time environmentally sustainable. India should set her own target of emission reduction phased over time which would not interfere with the programme of the removal of income poverty. This paper analyses the past pattern of economic growth—its pace, structure as accompanied by energy related technical changes and examines to what extent India has been already able to lower the carbon intensity of growth. It also finds out whether economic reforms since 1991 in India made really any difference in the process.

On the basis of the findings of such analysis of the past behaviour of carbon emissions, the paper then projects the future paths of CO_2 emissions and assesses the potential of low carbon growth within the time horizon of 2031-32. It analyses the sensitivity of this path with respect to the pace of growth as well as finds out whether the government policy interventions of raising energy prices (e.g. imposing carbon tax) for energy conservation are more effective than tinkering with growth rate targets. It also brings out the importance of the supply side interventions through energy related technological changes at an accelerated rate. It also tries to identify the sectors and the energy resources which pose special challenges in carbon reduction and towards which the policies should be more specifically directed. The paper comments on what kind of space India would require to be provided for the inevitable rise in CO_2 emission to remove both income poverty and energy poverty, improve the quality of life and ensure human development of her people. It concludes by highlighting the policy implications of the analysis for carbon reduction while India is to move along a high growth trajectory.

II. The Historical Trend of Energy use and CO_2 Emissions

After a moderate growth experience of Indian economy at the trend rate of 4.4 percent during the 20 years of pre-economic reforms (i.e., 1971 to 1990) the Indian economy experienced an accelerated growth of an average of 6.0 percent per annum during the post-reform period 1991-2005. The Indian economy moved to a really high growth trajectory since 2003-04 experiencing an annual GDP growth in the range of 7.5 to 9.5 percent. Although the growth rate dropped to 6.7 percent last year 2008-09, it is likely to pick up soon because of the strength of the macro-economic fundamentals of the economy as newly attained. The use of the final end use commercial energy by the non-energy sector grew at the rate of 4.7 percent during the pre-reform period and 3.4 percent in the post reform period to support this development process. As the rate of growth of energy use declined in spite of acceleration of the GDP growth rate, there has been a decline of the GDP-elasticity of the final commercial energy use from 1.9 to 0.56 between the two periods. The growth rate of the total primary commercial energy supply correspondingly declined from 5.7 percent during 1971-1990 to 4.8 percent during 1991-2005. The growth of CO_2 emissions also as consequence decelerated from 6.5 percent per annum in the pre-reform period to 4.4 percent in the post reform period (*see, Table 3*). *Tables 4-7* provide the levels and fuel composition of the consumption of total final energy, primary energy, primary commercial energy and those of CO_2 emissions over the period 1971-2005. *Tables 3 and 7* further provide the changing GDP elasticities and the movement of total CO_2 emission per capita and CO_2 intensity of GDP over time. While the energy flow chart of India is given in *Chart 1*, the time paths of total primary energy, primary commercial energy, total final energy and CO_2 emissions are given in *Charts 2 to 5. Charts 2 to 4* further show the fuel wise break up of the respective energy totals. Chart 6 further shows the losses and efficiency of the electricity sector along with both the gross generation as well as final use of electricity. *Charts 7 and 8* show the sectoral distribution of the total (direct and indirect) use of primary energy in 2005 including and excluding non commercial energy respectively (*see,* Sengupta, 2009).

Table 3: Growth Rates and GDP-elasticities of Energy Use in India

Variable	Period	Growth rate(%)	GDP-elasticity
GDP at Factor Cost	1971-1990	4.4	-
	1991-2005	6.0	-
Real Price of Energy	1971-1990	2.2	-
	1991-2005	4.0	-
Real Price of Global Crude Oil	1971-1990	6.1	-
	1991-2005	5.1	-
CO_2	1971-1990	6.5	1.47
	1991-2005	4.4	0.75
Total Primary Energy	1971-1990	4.1	0.86
	1991-2005	2.8	0.52
Total Primary Commercial Energy	1971-1990	5.7	1.28
	1991-2005	4.8	0.79
Final Energy	1971-1990	4.7	1.09
	1991-2005	3.4	0.56
Gross Generation of Electricity	1971-1990	7.8	1.77
	1991-2005	5.7	0.98
Final Use of Electricity	1971-1990	7.5	1.71
	1991-2005	4.5	0.75

Source: Author's own estimation using IEA Data on Energy balances of Non-OECD countries different volumes.

Table 4: Final Energy Supply and Shares of Fuels

Unit %

Year	FNLEN (mtoe)	Coal	Oil	Gas	Electricity
1971	47.84	51.67	38.44	0.59	9.30
1975	56.56	52.88	36.17	0.97	9.97
1980	63.61	48.94	43.66	1.07	12.11
1985	87.59	40.66	43.77	2.71	13.56
1990	118.99	34.71	45.25	4.74	15.30
1995	146.92	25.70	50.48	5.72	18.10
2000	171.14	18.91	56.90	5.66	18.53
2005	199.05	18.96	53.38	7.01	20.65

Source: IEA: Energy Balances of Non-OECD Countries, Different Volumes.

FNLEN = Final Energy Supply.

Table 5: Primary Energy Supply and Electricity

Year-calendar	TPES (mtoe)	CMBRN (mtoe)	TPCES (mtoe)	FNLEN (mtoe)	ELG-Twh	FNLELC-Twh
1971	157.00	95.78	61.22	47.84	66.38	51.74
1975	208.52	132.21	76.36	56.56	85.93	65.58
1980	243.04	148.13	94.91	63.61	119.26	89.53
1985	292.28	162.33	129.95	87.59	188.48	138.14
1990	359.13	175.82	183.31	118.99	289.44	211.74
1995	430.05	188.65	241.40	146.92	417.62	309.19
2000	501.89	201.58	300.31	171.14	562.19	368.72
2005	537.31	158.12	379.19	199.05	699.04	477.91

Source: IEA: Energy Balances of Non-OECD Countries, Different Volumes.
TPES = Total Primary Energy Supply
CMBRN = Combustible Renewables and Wastes.
TPCES = Total Primary Commercial Energy Supply.
FNLEN = Final Energy Supply.
ELG = Electricity Generation (Gross).
FNLELC = Final Electrical Energy Supply.

Table 6: Primary Commercial Resources Supplies and Resource Mix

unit %

Year-calendar	TPCES (mtoe)	Coal	Oil	N.Gas	Nuclear Energy	Hydro	Non-Conv. Energy
1971	61.22	58.05	36.57	0.93	0.51	3.94	0.00
1975	76.36	62.65	31.40	1.24	0.77	3.97	0.00
1980	94.91	54.97	35.87	1.25	0.82	4.21	0.00
1985	129.95	58.66	33.94	3.16	0.86	3.48	0.00
1990	183.31	57.86	32.04	5.36	0.87	3.36	0.00
1995	241.40	57.45	30.73	6.74	0.86	2.58	0.02
2000	300.31	54.96	38.08	7.30	1.47	2.13	0.05
2005	379.19	54.85	33.91	7.61	1.19	2.27	0.14

Source: IEA: Energy Balances of Non-OECD Countries, Different Volumes.
TPCES = Total Primary Commercial Energy Supply.

Table 7: Trends of CO_2 Emission for India

Years	Sectoral Approach				Reference Approach		
	Total CO_2 emissions (in million tonnes)	**CO_2 emissions from coal** (in million tonnes)	**CO_2 emissions from oil** (in million tonnes)	**CO_2 emissions from gas** (in million tonnes)	**Total CO_2 emissions** (in million tonnes)	**CO_2 Emissions/GDP using purchasing power parities** (in kg CO2/ US$ using 2000 prices and purchasing power parities)	**CO_2 Emissions/ Population** (in tonnes CO2/capita)
1971	199.1	142.3	55.5	1.3	197.8	0.32	0.36
1975	240.2	175.8	62.3	2.1	237.7	0.34	0.39
1980	294.6	205.8	86.1	2.8	293.1	0.36	0.43
1985	417.6	291.1	117.7	8.8	426.2	0.39	0.55
1990	588.3	401.5	164.1	22.7	599.1	0.41	0.69
1995	784.9	522.6	222.1	40.1	801.7	0.42	0.84
2000	971.5	625.6	297.4	48.5	982.7	0.4	0.96
2001	980.7	641.1	291.3	48.4	999.6	0.38	0.95
2002	1011.2	657.8	301.5	51.8	1032.9	0.38	0.96
2003	1041.7	678.2	309.6	53.8	1066.1	0.36	0.98
2004	1102.8	734.2	314.4	54.2	1132.3	0.35	1.02
% Change 1990-2004	87.5	82.9	91.7	138.4	89	-13	47.5

Source: IEA (2006): CO_2 emissions from Fuel combustion 1971-2004, IEA, OECD, Paris.

It may be noted here that both the absolute level as well as the per capita CO_2 emission has increased over time for India, although the CO_2 intensity of GDP first rose over time till mid nineties, but then declined over time. While the GDP elasticity of CO_2 emission was 1.47 during the period 1971-1990, it significantly declined to 0.75 in the post reform period. With the development process, non commercial biomass fuel has been replaced by commercial fossil fuels which are much more efficient in providing end-use service and much cleaner, electricity particularly being the cleanest among all fuels for end-use. However, unlike biomass they are not carbon neutral. It is the declining share of the non commercial fuel i.e., combustible renewables and wastes – in the total primary energy from 61 percent in 1971 to 49 percent in 1990 and to 29 percent in 2005, and the rising share of electricity in the total final commercial energy from 9.3 percent in 1971 to 15.3 percent in 1990 and 20.6 percent in 2005 which can explain the intertemporal pattern of CO_2 emissions as experienced in India. As primary commercial energy has been as a consequence increasingly used after being converted into electricity, the share of primary fuels used indirectly through electricity rose from 28 percent in 1971 to 50 percent in 2006. As coal, though of inferior quality, has been relatively the most abundant fuel in India, the share of coal based power in the total power generation rose from 49 percent in 1971 to 69-70 percent in 2004-05. The share of carbon free power generation based on hydro-nuclear and other non fossil resources correspondingly declined from 44 percent in 1971 to 18 percent in 2005.

As the use of biomass as fuel for consumption is by and large carbon neutral due to carbon cycle and as the hydro, nuclear or wind resources are carbon free, the decline in the share of both of these types of energy resource use created upward pressure in CO_2 emission. It is therefore remarkable that in spite of such pressure and substitution of carbon free or carbon neutral fuel by fossil fuels, the CO_2 intensity of GDP could decline in the post economic reforms in India. It is the restructuring of the economy particularly industry and trade through market reform and the institutional and technology changes that could bring about the competitiveness in Indian industry and induce more efficient choice of technology, better allocation of resources and some improvement in energy efficiency and reduction in CO_2 emission intensity of GDP.

III. Role of Energy Related CO_2 Emissions in Global Warming

This paper mainly concentrates on the analysis of the behaviour of CO_2 emission from fossil fuel in ascertaining the behaviour of the carbon intensity of economic growth of India for getting insights into the relevant policy direction. The major greenhouse gases arising from human activities have been carbon dioxide CO_2, methane, nitric oxides and other greenhouse gases like chlorofluoro carbon (CFCs) Halons, etc. The share of CO_2 in this emission of total greenhouse gases in units of CO_2 equivalent as derived from the global warming potentials of the different gases, has been 73 percent for the world in 2005, but the same has been 58 percent for India, 77 percent for China and 81 percent for the USA. The respective shares of methane and nitric oxides in the total greenhouse gas emission has been on the other hand as high as 30 percent and 12 percent for India in the same year, while they have been 16.4 percent and 9.4 percent respectively at the global level. The share of the other remaining gases in the total greenhouse gas emissions has been quite small being 0.39 percent for India and 1.5 percent for the world. It is this relatively dominant share of CO_2 in the total global emission of greenhouse gases which has guided global discussion on the mitigation of greenhouse gases emissions to be focused on CO_2 emission mainly.

It is however, important to note in this context that while the main sources of CO_2 emission has been the burning of fossil fuels and land use change due to deforestation, sources of methane emissions has been livestock forming, rice farming, land use and wet land changes and land fill emissions from the wastes disposed. The nitric oxides also primarily arise from both fossil fuel burning as well as agricultural activities particularly from the use of fertilisers in agriculture. While the other greenhouse gases like CFCs arise mainly from industrial processes, like refrigeration etc. the shares of agriculture as sources of methane and nitric oxides emissions have been as high as 65 percent and 93 percent respectively in India in 2005. Since the agricultural growth and development is of critical importance for India for employment generation, poverty removal and food security, it is quite difficult and risky for India to follow any developmental strategy which would curb agricultural growth for abating methane or nitric oxide emissions. The policy approach for controlling the GHG emissions would therefore need to focus on CO_2 emission mitigation as well as on organic agriculture in the Indian condition.

The source of CO_2 emission has been again both burning of fossil fuel as well as land use changes. At the global level share of land use change and biomass burning has a share of about 9.1 percent of total the CO_2 emission. For India such data are unavailable. However, the major source of land use change contributing to CO_2 emission has been deforestation. This deforestation trend was however reversed in 1990's and the annual average rates of deforestation had been -0.6 percent during the period 1990 to 2000, while the same has been zero between 2000 and 2005. Although the deforestation process has been halted, the availability of per capita forest available in India has been only 0.06 hectare of forest land while the same has been 0.8 hectare as the world average (World Bank, 2009). Although India should have greater thrust on the conservation and development of forest in future to raise the area of forest coverage for many reasons beyond the reduction or absorption of CO_2 emission, the major scope of low carbon growth lies in the reduction of CO_2 emission from fossil fuel. We therefore review the energy relating trend of CO_2 emission and analyse its behaviour along with energy use, energy supply and fuel mix in India, and assess the potential of low carbon growth.

IV. Decomposition Analysis of CO_2 Emissions: Methodology

The environmental pressure that is created by CO_2 and any other green house gases depends upon the absolute stock of such gases in CO_2 equivalent unit. The warming effect of this stock would depend on the composition of the green house gases, their global warming potential as determined by their respective radiative forcings and the length of life time of their respective molecules. As the stock of such gases are only state variables and the flow of the emission per unit of time is a control flow variable, it is only through the reduction of emission to a certain level, it would be possible for the total stock of GHG's to attain a stationary state so that the climate can stabilise. The analysis of behaviour of the CO_2 emissions and that of their underlying determining factors are thus important in order to find out if we can delink the economic growth and the growth of CO_2 emissions. We therefore turn to the decomposition analysis of CO_2 emissions in India since 1971 for identifying the role of the immediately determining distinct factors of CO_2 emission. There has developed in fact a substantive literature on the decomposition of energy consumption and carbon di-oxide emissions for such purpose of identifying and assessing the relative importance of the crucial determining factors that might have influenced the changes in energy use and CO_2 emissions. These decompositions have mostly involved use of simple mathematical methods of decomposing the absolute change over time or the ratio yielding the growth factor for energy or CO_2. The absolute changes have been decomposed using simple algebraic techniques, following Larpeyres Index or Conventional Divisia Index method. [(*see*, Hankinson and Rhys (1983), Park (1992), Li *et.al*, (1990), Boyd *et. al*, (1988), Liaskas *et. al*, (2000)]. The ratio giving growth factor of energy consumption has also been decomposed using the alternatives of Laspeyres Index method, Conventional Divisia method, general parametric divisia index method and Refined Divisia index methods in the literature (*see*, Ang. (1994, 1999), Ang and Choi (1997), Choi and Ang (2003), Boyd *et. al*, (1988), Li *et. al*, (1990) for the details of these methods. If we take up the decomposition of CO_2 as arising from the use of energy in the industries or production economy, the absolute emissions can be represented as the product of the absolute level of GDP, the energy intensity of GDP and the CO_2 intensity of energy. The energy intensity of the overall GDP again is determined by the structural composition of GDP and the energy intensities of sectoral GDP would also vary from across the sectors. The CO_2 intensity of energy again varies with the fuel composition of energy which in turn can vary across sectors due to technological factors. The purpose of decomposition analysis is to work out the scale effect, structure effect, energy intensity effect and fuel mix effect on the over all changes in the CO_2 emissions.

We can in fact express the CO_2 as denoted by C as follows for the purpose of analysing the changes.

$$C = \mathrm{Y} * e * m$$

where Y is the total GDP, e is the energy intensity of the overall GDP in the *production economy*, m is the CO_2 intensity of energy in such economy. We however exclude the residential household's consumption of energy and the CO_2 emission out of this analysis.

Again $e = \sum_i e_i\, s_i$ where e_i is the energy intensity of GDP in sector i and s_i is the share of the ith sector in the total GDP.

$$m = \sum_i m_i\, e_i\, s_i \,/\, e$$

where m_j = the CO_2 intensity of energy used in the ith sector = $\sum_i m^j f_i^j$

where m_j is the CO_2 emission coefficient of the jth fuel which we will assume to be a constant and f_i^j is the share of the jth fuel in the energy use of the ith sector.

Thus $m = \sum_i e_i\, s_i \left(\sum_j m^j\ f_i^j \right) / e$ and

$$C = \mathrm{Y} * \sum_i e_i\, s_i \left(\sum_j m^j\ f_i^j \right)$$

we shall explain the absolute change in C or change in the ratio $\frac{C}{\mathrm{Y}}$ between 1971 and 1990 of the pre-reform period as well as in the post-reform period between 1991 and 2005. This comparative analysis will, first of all, give us some insight into the issue if economic reforms could contribute towards the end of rise in energy efficiency and reduction in CO_2 emission reduction and to what extent energy conservation and fuel substitution have contributed to the moderation of the upward pressure on CO_2 emission as created by economic growth.

In either of the decomposition of absolute change or of the ratio of growth factor over discrete time period the approach has been one of computing the effect of change in one of the factors while holding others fixed at some weighted level between their respective values at the initial and the terminal period. We shall consider the changes in Y to give scale effect, and those in $s_i,\ e_i\ and\ f_i^j{}'s$ to give the structural, energy intensity and fuel-mix effects respectively, the effect of change in each factor being considered under the ceteris paribus condition. Thus after the simple model of Park (1992) and Liaskas *et. al*, (2000), we decompose the absolute increase C, i.e., $\Delta C = C - Co$ as follows:

Total effect ΔC =

Output effect = $\Delta C_1 = \left(\text{Y}_T - \text{Y}_0\right)\left(\sum_i e_{io}\; s_{io}\left(\sum_j m^j\; f_{io}^{\,j}\right)\right)$ +

Structural effect = $\Delta C_2 = \text{Y}_0 \sum_i e_{io}\,(s_{iT} - s_{io})\left(\sum_j m^j\, f_{io}^{\,j}\right)$ +

Energy Intensity effect = $\Delta C_3 = \text{Y}_0 \sum_i (e_{iT} - e_{io})\, s_{io}\left(\sum_j m^j\, f_{io}^{\,j}\right)$ +

Fuel-mix effect = $\Delta C_4 = \text{Y}_0 \sum_i e_{io}\; s_{io} \sum_j m^j \left(f_i^{\,j} - f_{io}^{\,j}\right) +$

Residual effect = R (D1)

Here in the estimation of each effect we assume the other factors to assume the base year value as in the Laspeyre's indexing method. We shall use this method to decompose the absolute changes in CO_2 emissions over the period 1971-1990 and 1999-2005. The values of the other factors in the formula can alternatively be taken as the unweighted mean value of the initial and the terminal value as in Bannet's indexing formula (*see*, Choi and Ang. 2003).

If $Z = \Sigma x_i y_i$, and $\Delta Z = Z_T - Z_0$ is to be decomposed to assess the effects of structure as indicated by say y_i's, and technology as by x_i's, we can write

$\Delta Z_T = Z - Z_0 = \sum_i (x_{iT} - x_{io})\; w_{xi}^* + \sum_i (y_{iT} - y_{io})\; w_{yi}^* + R$ (D2)

where as per Laspeyres method, $w_{yi}^* = y_{io}, w_{xi}^* = x_{io}$

As per Bennet's index, we can alternatively get, $w_{xi}^* = \dfrac{y_{iT} + y_{io}}{2}$ and

$$w_{xi}^* = \frac{x_{io} + x_{iT}}{2}$$

We present the empirical results for the changes in CO_2 emission in the pre-reform and post-reform period using both these methods in the following section.

As growth may be considered as an imperative for the development of well-being of the people, it is really the control of *CO_2 intensity* of GDP which is of major policy concern particularly in the developing countries. For decomposing the changes in the CO_2 intensity of GDP over discrete time we shall for this paper use the ratio method for explaining the changes over two discrete time periods using alternatively Conventional Divisia Method as well as Refined Divisia Method.

Let $c = \dfrac{C}{\text{Y}}$ be the carbon-dioxide intensity of over all GDP.

c can be expressed as $\sum_i e_i\, s_i\, m_i$, where e_i, s_i *and* m_i are as already explained. m_i being $\sum_j m^j\, f_i^{\,j}$ (the CO_2 intensity of fuel composition in the ith sector). It can be easily shown that

$$\frac{1}{c}\,\frac{dc}{dt} = \frac{d}{dt}(\log c(t))$$

$$= \sum_i \left[\frac{d \log s_i}{dt}\omega_i + \frac{d \log e_i}{dt}.\ \omega_i + \frac{d \log m_i}{dt}.\ \omega_i \right]$$

where ω_i is the share of the ith sector in total CO_2 emission arising, i.e. C_i / C

Thus $$c(t) = \exp\left(\sum_i \frac{d \log s_i}{dt}.\omega_i \right) * \exp.\left(\sum_i \frac{d \log e_i}{dt}\ .\ \omega_i \right)$$

$$* \exp.\left(\sum_i^{d \log} \frac{m_i}{dt} * \omega_i \right)$$

Now for the analysis of change in carbon intensity of GDP over discrete time by ratio method we may represent C_T/Co as follows:

$$\frac{C_T}{C_0} = \exp \sum_i (\log s_{iT} - \log s_{io})\,\overline{\omega}_i\ *$$
$$\exp \sum_i (\log e_{iT} - \log e_{io})\,\overline{\omega}_i\ *$$
$$\exp \sum_i (\log m_{iT} - \log m_{io})\,\overline{\omega}_i\ *$$
$$R \ldots\ldots\ldots \qquad \text{(D3)}$$

The first of the product expression giving the structural effect, the second one the energy intensity effect, the third one the fuel-mix effect and the fourth one the residual effect of change when expressed in multiplicative growth factor form. The weight factor $\overline{\omega}_i$ as appearing in all the terms represents the share of the ith sector in the total CO_2 emission arising, i.e., $\omega_i = \dfrac{e_i\, s_i m_i}{\sum_i e_i s_i m_i}$,

It may be noted that

$m_{iT} = \sum_j m^j\, f_{iT}^{\,j}$ *and* $m_{io} = \sum_j m^j\, f_{io}^{\,j}$. where m^j is constant.

We shall take $\overline{\omega}_i$ to be alternatively, values following the Conventional Divisia method and the formula of the Refined Divisia method.

As per Conventional Divisia Method

$$\overline{w_i} = \frac{w_{io} + w_{iT}}{2}$$

As per Refined Divisia Method, $w_i = \frac{L_i(w_{io}, w_{iT})}{\sum_i L_i(w_{io}, w_{iT})}$

where $L(u_T, u_0)$, u being any variables is the logarithmic mean of u_T and u_0, i.e.

$$L(u_T, u_0) = \frac{u_T - u_0}{\log(u_T) - \log(u_0)} \; where \; u_0 \neq u_T$$

u = when $u_0 = u_T = u$

o = when $u_0 = u_T = o$

The relative merit of Refined Divisia method over the conventional divisia one is that decomposition is being made as per the former method for separating the effects of the factors so that the residual term ideally vanishes and the decomposition is complete.

V. Results of Decomposition Analysis for India

We present first the results of decomposition analysis explaining the absolute increase in CO_2 emission by using D (1) with Laspeyre's indexing formula and D2 with Bennet's weighting index. We shall then present the results of the decomposition of CO_2 intensity using the Ratio method of Conventional Divisia and the Refined Divisia. The results are presented and analysed for both the pre-reform and post-reform period.

We may first of all note here that the total quantum of changes in terms of total percentage increase over the pre-reform and post-reform periods and correspondingly the annual average growth rates of the fundamental variables involved in the analysis – i.e., GDP, Energy consumption, Carbon Dioxide emissions, energy intensity of GDP, CO_2 intensity of energy and that of GDP as given in *Tables 8 to 10*. It is important to note that while GDP increased at an annual average rate of 4.40 percent in the pre-economic reform year on a point to point basis, the growth was accelerated to 6.39 percent in the post reform period considered. The annual growth of primary commercial energy used in the non-energy sector other than residential households of the economy directly as well as indirectly through electric power, however, declined from 5.47 percent to 4.09 percent between the two periods. The annual growth of CO_2 emission also sharply declined from the high rate of 5.88 percent per annum to 3.86 percent between the two periods. The energy intensity of GDP increased in the pre-reform period by 2.27 percent per annum while it declined at the rate of 2.16 percent per annum in the post reform period. Similarly, the carbon intensity of energy grew at the rate of 0.39 percent per annum in the pre-reform period while it declined at a moderate rate of 0.21 percent per annum in the post-reform period. The annual average growth of the resultant CO_2 intensity of GDP for the producing economy (excluding residential sector but including all personal transport) was at the rate of 0.63 percent per annum in the pre-reform period. The same turned out to be negative – i.e., a decline at an annual rate of 3.52 percent per annum during the post economic reform period. *Tables 11 to 16*. Further give the sectoral details about the shares in GDP, primary commercial energy use and CO_2 emissions and their respective intensities i.e., primary commercial energy intensity of GDP, and the CO_2 intensity of energy and the CO_2 intensity of GDP in the years of comparison for the change in CO_2 i.e., 1971, 1990 and 2005.

Table 8: Annual Average Growth Rate of GDP, Energy, CO_2 Emission and of related Intensities in the Production Economy (i.e., except Residential Sector) in the Pre-reform and Post-reform Periods (%)

Period	GDP growth rate	Primary commercial energy	Energy intensity of GDP	CO_2 emission	CO_2 intensity of energy	CO_2 intensity of GDP
1971-1990	4.40	5.47	0.63	5.88	0.394	1.42
1990-2005	6.39	4.09	-3.52	3.87	-0.214	-2.37

Source: Author's own estimation using NAS data for CSO, Government of India and IEA data on Energy Balances of Non-OECD countries of different volumes (1971-2005) and CO_2 emissions from fuel combustion 1971-2004 in IEA 2006 edition.

Table 9: Annual Average Growth Rates of Private Final Consumption Expenditure (PFCE), Energy, CO_2 Emission and of Related Intensities of the Residential Sector

Period	PFCE growth rate	Primary commercial energy	Energy intensity of PFCE	CO_2 emission	CO_2 intensity of energy	CO_2 intensity of PFCE
1971-1990	3.83	6.19	2.27	6.62	0.398	2.68
1990-2005	4.77	7.19	2.30	7.27	0.073	2.38

Source: Author's own estimation using NAS data for CSO, Government of India and IEA data on Energy Balances of Non-OECD countries of different volumes (1971-2005) and CO_2 emissions from fuel combustion 1971-2004 in IEA 2006 edition.

Table 10: Annual Average Overall growth Rate of Energy, CO_2 Emission and their Intensities with Respect to GDP (%)

Period	Primary commercial energy	Energy intensity of GDP	CO_2 emission	CO_2 intensity of overall energy	CO_2 intensity of overall GDP
1971-1990	5.55	1.10	5.96	0.389	1.5
1990-2005	4.56	-1.72	4.36	-0.191	-1.91

Source: Author's own estimation using NAS data for CSO, Government of India and IEA data on Energy Balances of Non-OECD countries of different volumes (1971-2005) and CO_2 emissions from fuel combustion 1971-2004 in IEA 2006 edition.

Table 11: Sectoral Share of GDP and Share of PFCE in GDP (unit %).

Year	Industry inc. oth. Energy	Agriculture	Transport	Services (except transport)	PFCE	Total
1971	20.73	44.67	4.11	30.47	86.28	100.00
1990	23.24	34.04	5.46	37.24	77.84	100.00
2006	24.84	20.47	6.42	48.25	60.92	100.00

Source: Author's own estimation using NAS data of the CSO, Government of India.

Table 12: Sectoral Share of Primary Energy use (Direct and Indirect) (unit %)

Year	Industry inc. oth. Energy	Agriculture	Transport	Services (except transport)	Residential	Total
1971	58.29	4.02	23.73	2.84	11.12	100.00
1990	59.03	8.63	15.09	4.77	12.48	100.00
2006	48.80	12.23	11.43	8.96	18.57	100.00

Source: Author's own estimation using IEA data on Energy Balances of Non-OECD countries of different volumes (1971-2005).

Table 13: Sectoral Share of CO_2 emissions (Direct and Indirect) (unit %).

Year	Industry inc. oth. energy	Agriculture	Transport	Services (except transport)	Residential	Total
1971	59.11	3.20	25.08	2.22	10.39	100.00
1990	61.29	8.77	13.53	4.72	11.68	100.00
2006	50.28	12.52	9.33	9.73	18.14	100.00

Source: Author's own estimation using IEA data on Energy Balances of Non-OECD countries of different volumes (1971-2005) and CO_2 emissions from fuel combustion 1971-2004 in IEA 2006 edition.

Table 14: Primary Energy Intensity of Sectoral GDP. Kg/Rs.

Year	Industry	Transport	Agriculture	Other services	Residential*	Overall
1971	0.035	0.078	0.001	0.001	0.002	0.014
1990	0.038	0.046	0.008	0.002	0.003	0.017
2005	0.028	0.024	0.008	0.003	0.011	0.021

*For Residential Sector the intensity is defined w.r.t. private final consumption expenditure

Source: Author's own estimation using NAS data for CSO, Government of India and IEA data on Energy Balances of Non-OECD countries of different volumes (1971-2005) and CO_2 emissions from fuel combustion 1971-2004 in IEA 2006 edition.

Table 15: Sectoral CO_2 Intensities of Energy (t/mtoe).

Year	Industry	Other Energy Ind.	Agriculture	Transport	Other Services	Residential Sector	Overall
1971	3.03	3.11	2.38	3.16	2.34	2.80	2.99
1990	3.38	3.04	3.28	2.89	3.19	3.02	3.18
2006	2.76	3.03	3.20	2.55	3.38	1.08	2.06

Source: Author's own estimation using IEA data on Energy Balances of Non-OECD countries of different volumes (1971-2005) and CO_2 emissions from fuel combustion 1971-2004 in IEA 2006 edition.

Table 16: CO_2 Intensity of Sectoral GDP kg/Rs.

Year	Industry	Transport	Agriculture	Other services	Residential*	Overall
1971	0.107	0.247	0.003	0.003	0.036	0.041
1990	0.127	0.133	0.015	0.007	0.048	0.048
2005	0.079	0.060	0.026	0.009	0.034	0.042

*For Residential Sector the intensity is defined with respect to Private Final Consumption Expenditure.

Source: Author's own estimation using NAS data for CSO, Government of India and IEA data on Energy Balances of Non-OECD countries of different volumes (1971-2005) and CO_2 emissions from fuel combustion 1971-2004 in IEA 2006 edition.

It is important to notice in this connection that while all the sectors experienced growth of energy as well as carbon intensity of their respective sectoral GDP except for transportation in the pre-reform period, both the total primary consumption of energy and the CO_2 intensities declined in the post-reform period at varying rates for all the production sectors excepting agriculture and non-transport commercial service sector. The latter sector now in fact constitutes a large segment of the Indian economy having a share of 48 percent of GDP. The CO_2 intensity of primary commercial energy used directly or indirectly through electric power has been also declining at a very moderate rate in all the sectors excepting for the non-transport services in the same post-reform period. While the growth of energy and carbon intensities of agriculture is understandable due to the role of diminishing return on investment on fixed land, the growing energy as well as carbon intensity of the service sector, inspite of its level being quite low, is indicative of the changing product mix and technology of the sector in favour of electric power and modern energy usage and would also be a matter of policy concern in the long run. The decomposition analysis of the absolute change of CO_2 into the effects of changes in scale, structural, energy intensity, fuel mix and residual factor in terms of absolute amounts as well as in terms of percentage growth over the base year total of CO_2 emission are given in *Tables 17-18 (see, Chart 9).*

Table 17: Results of Decomposition Analysis of Carbon Dioxide Emissions (Absolute difference), using Laspeyre's Index.

Period	Output effect	Structural effect	Energy int. effect	Fuel mix effect	Residual	Total change
Overall % increase in the terminal year over the base year CO_2 emission.						
1971-1990	125.5	16.89	6.52	3.42	43.71	196.12
1990-2006	164.54	4.80	-27.16	-1.20	-57.49	83.50
Annual average % increase over the base year CO_2 emission.						
1971-1990	4.37	0.82	0.33	0.18	1.93	5.88
1990-2006	5.25	0.25	-1.65	-0.063	-4.40	3.25

Source: Author's own estimation.

Table 18: Decomposition Analysis of CO_2 Emission (Absolute Difference) using Bennet Index.

Period	Output effect	Structural effect	Energy int. effect	Fuel mix effect	Residual	Total change
Overall % increase the terminal year over the base year value of CO_2 emission						
1971-1990	205.80	21.50	12.48	11.64	-55.30	196.12
1990-2006	140.07	0.79	-57.38	-1.13	1.14	83.50
Annual average % increase over the base year value CO_2 emission.						
1971-1990	6.06	1.03	0.62	0.58	-4.15	5.88
1990-2006	4.72	0.04	-4.30	-0.06	0.06	3.25

Source: Author's own estimation.

Using Laspeyre's method of indexing change in CO_2 emission we decompose the total rise of CO_2 at the rate of 5.88 percent per annum during the pre-reform period and obtain the effects of changes in scale of GDP, structure, primary energy intensity and fuel mix to be the growth of CO_2 emission at the annual average rates of 4.37 percent, 0.82 percent, 0.33 percent and 0.18 percent respectively over the base year total emission. The residual interactive effects of different factors could contribute growth of additional 1.92 percent per annum. This scenario substantively changed in the post reform period (1990-2006) when the annual average growth of CO_2 dropped to 3.24 percent. Although the contribution of growth of the scale of GDP or the economy caused the CO_2 emission to grow at the rate 5.25 percent per annum over the base year (1990) emission. The structural effect showed a growth of CO_2 emission at a decelerated rate 0.25 percent per annum as compared to the experience of growth at 0.82 percent per annum in the preceding period. The energy intensity effect, the fuel mix effect and the residual effect contributed on the other hand to the decline of CO_2 emission at annual average rates of 1.65 percent, 0.06 percent and 4.4 percent respectively. The use of Bennet's formula for indexing change over discrete time as used here also give similar results. As per this latter the impact of scale on CO_2 emission in the post reform period is found to be in the range of annual growth of 4.72 percent and that of structural effect in the range of 0.042 percent per annum. This alternative weighting method following Bennet's formula shows the energy conservation effect to contribute towards the decline of such emission over its base year value at an annual average rate in the range of 4.39 percent per annum as compared to the decline at the annual average rate of 1.65 percent as per Laspeyre's formula. The effect of fuel mix change caused on the other hand an annual average decline of CO_2 emission at the rate of 0.06 percent during the same post reform period (1990-2006) which is comparable to the result of Laspeyre's method. The over all pattern of changes thus bring out clearly that the structural adjustment and institutional reforms of India could bring about some rise in operational efficiency resulting in the conservation of commercial energy use and lower CO_2 intensity of energy which could in turn moderate the effects of upward pressure of scale and structure on CO_2 emission. *Table 18* further shows that while the impact of growth of scale of the economy is the dominant factor in terms of percentage of total change explained, energy intensity effect is the dominant moderating factor for reducing the contribution to CO_2 particularly in the post reform period.

We have also used the Conventional and the Refined Divisia (ratio) method to decompose the total change of 1.42 percent annual growth of CO_2 intensity of GDP in the pre-reform period and 2 percent annual average decline in the post reform period. The decomposition analysis shows that all the factors of change in energy intensity, structural change and fuel mix change contributed to the rise in CO_2 emission intensity of GDP both as the per Conventional Divisia and the Refined Divisia Method (*see, Tables 19 and 20 and see Chart 10*). In the post reform period, energy intensity and fuel mix change contributed to the decline in CO_2 intensity of GDP at annual average rates of 1.90 percent and 0.057 percent per annum respectively as per Conventional Divisia method and at the respective rates of 2.27 percent and 0.06 percent per annum as per the Refined Divisia method. The structural effects on the other hand caused a rise of CO_2 emission intensity at an annual average rate of 0.12 percent per annum for the post economic reform period as per the Conventional Divisia formula and at the rate of 0.145 percent as per the Refined Divisia formula. In any case the energy intensity change has been the primary factor in driving the changes in the CO_2 intensity of GDP in India. As the CO_2 intensity of energy is primarily driven by the energy resource endowment and the supply situation, minimal impact of the fuel mix change on the CO_2 intensity of GDP is understandable for an energy importing country like India whose dominant energy resource has been coal with high CO_2 intensity per unit of energy. *Table 19 and 20* accordingly show that most of the changes of CO_2 intensity movement in the pre-reform and post reform period is explained mostly in terms of changes in the energy intensity or energy conservation and a relatively minor part in term of changes in the CO_2 intensity of the fuels.

Table 19: CO_2 Intensity Decomposition Analysis using Conventional Divisia (Ratio) Method of Growth for the Determining Factors

Period	Energy intensity	Structural Effect	Fuel mix effect	Residual	Co2 Int. Ratio Cn/Co
Effects as overall Growth Factor over the base year for the entire period.					
1971-1990	1.06492	1.13683	1.05277	1.0269	1.30881
1990-2006	0.6947	1.02366	0.99076	0.9666	0.68103
Effects as annual % increase over the base year value					
1971-1990	0.33	0.68	0.27	0.14	1.43
1990-2006	-1.90	0.12	-0.05	-0.18	-2.00

Source: Author's own estimation.

Table 20: Decomposition Analysis of Growth of CO_2 emission Intensity by Refined Divisia Method

Period	Energy intensity	Structural effect	Fuel mix effect	Residual	CO2 Int. Ratio Cn/Co
Effects as overall growth factor over the base year					
1971-1990	1.061	1.138	1.052	1.029	1.307
1990-2006	0.692	1.023	0.99	0.97	0.681
Effects Annual Average percentage growth over the base year					
1971-1990	0.313	0.683	0.269	0.149	1.42
1990-2006	-2.27	0.145	-0.06	-0.188	-2.37

Source: Author's own estimation.

In the above decomposition analysis we did not include the CO_2 arising from the direct and indirect use of fossil fuel by the residential households as they do not fit in the structure of the economy as a producing sector, but is a major user of GDP for consumption. While the private final consumption expenditure amounted to 86.29 percent GDP in 1971, its share declined to 77.84 percent in 1990 and 60.92 percent in 2006. The share of the residential sector in the total primary energy use directly or indirectly through electricity increased from 11.12 percent in 1971 to 12.48 percent in 1990 and 18.57 percent in 2006. The share of this sector in CO_2 emission correspondingly increased from 10.39 percent in 1971 to 11.68 percent in 1990 and 18.14 percent in 2006. The total private final consumption expenditure grew at the rate of 3.83 percent per annum in the period 1971 to 1990, the direct and indirect primary energy through electricity used by the residential sector and the corresponding CO_2 emissions grew at the annual average rate of 6.19 percent and 6.62 percent respectively. In the post reform period of 1990 to 2006 the growth of PFCE accelerated to 4.77 percent per annum, and correspondingly the primary commercial energy used by the sector and the CO_2 emission imputable to such energy use grew at the accelerated rates of 7.19 percent and 7.27 percent per annum respectively. This implied annual average growth of carbon intensity of PFCE to be 2.68 percent in the pre-reform period, and 2.38 percent in the post-reform period. This is explained by the growth of primary commercial energy intensity (including the share for the electric power consumed) of PFCE of the sector at an annual average rate of 2.28 percent in the pre-reform period and its acceleration to 2.3 percent in the post reform period on the one hand, and by the annual average growth of the carbon intensity of energy in the residential sector at 0.398 percent in the pre-reform period and at 0.073 percent rate in the post reform.

The above observations regarding the behaviour of the residential sector is nothing surprising in view of the large dependence of the Indian households on the unclean unconverted biomass fuel because of the energy poverty and the income poverty prevailing in the economy (Sengupta, 2009). With the growth of private expenditure by the households it is expected that the commercial energy intensity of PFCE would grow as people would like to substitute the biomass energy by modern clean petroleum fuel for cooking and consume more of electricity substituting kerosene for lighting. It is the supply side constraints which restrain the households from being able to consume cleaner fuel although that would have led to higher commercial energy intensity and therefore higher carbon intensity of PFCE. With high economic growth of India, the energy planner must provide adequate space for energy consumption and carbon emission for the Indian residential sector.

VI. Econometric Analysis of Behaviour of Energy Requirement and Methodology of Projection of Primary Energy as well as CO_2 Emission

The decomposition analysis of the preceding section analyses the CO_2 arising from the combustion of fuels in the integrated process of energy conversion in the electricity and petroleum refining sector as well as in the end use of energy in the non-energy sectors. We have allocated the use of primary resources used at the stage of energy conversion or refining among the end use sectors in proportion to their respective uses in the final energy form – petroleum products and electricity. The behaviour of primary energy intensity of GDP or final expenditure as analysed in that section thus captured the efficiency or inefficiency both at the end use demand side as well as the supply side of commercial energy. While the decomposition analysis enables us to identify the factors and quantify their role in the changes in CO_2 emissions, it does not yield any result on the sensitivity of CO_2 emission for variations in the policy variables like carbon taxes or choice of pace of development or of any energy policy initiatives at the technology or supply sides. For the purposes of environmental control and policy formulation it is important to ascertain the following:

- the behaviouristic functions of the final energy use of the end use sectors giving the elasticity of energy requirement and that of CO_2 emissions, with respect to the concerned macro economic variables;
- the behaviour of the efficiency in the supply side of the energy industry; and
- the projections of the final end use of energy and those of the derived primary energy requirement and the corresponding CO_2 emissions for the alternative scenarios of growth of GDP, energy prices and assumptions of technological changes cum behavioural characteristics of the final end use sectors.

We would now present the results as carried out by analysing the data on energy consumption and primary energy resource supply during the period 1971 to 2005. We then finally project future scenarios of final end use energy demand and primary energy supply with fuel wise break up to match such demand and the corresponding CO_2 emissions. These projections will be given over a time horizon upto 2031-32, that is the end of India's Fifteenth Five Year Plan, starting from the base of 2005 for the alternative behavioristic and technological assumptions and macroeconomic policy targets.

Final commercial energy in the forms of coal, oil, natural gas and electricity is consumed widely almost everywhere in the economy. It is required as an essential service and universal intermediate input in the economy. The households also need it as an essential commodity for cooking, lighting, water heating, space-heating. At the aggregate economy level, the overall total final energy demand in oil equivalent unit is likely to be a function of the GDP and the real price index for overall energy sold in the final form expressed as an index number (overall wholesale energy price index deflated by the GDP deflator). Similarly the sectoral final energy demand in oil equivalent unit is likely to depend on the sectoral GDP and the real price of energy as faced by the concerned sector. As the fuel composition of energy differs from sector to sector, the weighted average energy price of fuels as faced by a sector would vary across sectors. We set up single equation double log linear regression models to estimate the GDP and price elasticities of the overall as well as sectoral final energy demand. After using a first order autoregressive scheme whenever any autocorrelation is detected and estimating the White's Heteroskedasticity Autocorrelation – consistent standard errors and covariance, we obtain the estimated equations as given in *Table 21*. We have not, however, been able to test for the stationarity of the time series data because of the data limitation. However, it will be important to estimate the equations taking care of any non-stationarity problem, if present, by choosing appropriate model of forecast. However, the regression equations as estimated with these limitations have been used for prediction in the light of the significance of the coefficients, Adj R^2, etc. It is only the residential sector and the sector of other services that the real price variables were of no significance in these estimated models. The models for the sectors of transport and other services had, however, to be run with the first order autoregressive scheme to eliminate the autocorrelation problem in the estimation of coefficients.

Table 21: Relationship of Final Energy Demand – Income and Real Price

Sr. No.	Variables	Coefft.	P-value	No. of Obs.	Adj. R^2	DW statistics
M1	Dep.	-	-	22	0.972	1.831
	LOG (TOTENDD)					
	Indep.	3.155	0			
	LOG (TOTGDP)	0.849	0			
	LOG (ALLENPR)	-0.719	0			
M2	Dep.	-	-	23	0.857	1.388
	LOG (INDENDD)					
	Indep.					
	C	8.091	0			
	LOG (INDGDP)	0.654	0			
	LOG (INDENPR)	-1.143	0			
M3	Dep.	-	-	22	0.926	1.594
	LOG (AGRENDD)					
	Indep.		-			
	C	-24.225	0			
	LOG (AGRGDP)	2.863	0			
	LOG (AGRENPR)	-0.832	0.0004			

Table 21: Relationship of Final Energy Demand – Income and Real Price (contd.)

Sr. No.	Variables	Coefft.	P-value	No. of Obs.	Adj. R^2	DW statistics
M4	Dep. LOG (TRANSENDD) Indep. C LOG (TRANSGDP) LOG (TRANSENPR) AR(1)	- 5.059 0.733 -0.641 0.579	- - 0 0 0.0002 0.1135	23	0.932	1.898
M5	Dep. LOG (OTHSVS) Indep. C LOG (OTHSVSGDP) AR(1)	- -12.708 1.568 0.716	- - 0.0006 0 0.0002	20	0.946	1.954
M6	Dep. LOG (RESENDD) Indep. C LOG (PFCE)	- -10.377 1.468	- - 0 0	28	0.976	0.897

Source: Author's own estimation.

TOTENDD = Total Final Energy Demand of the Macro economy.
TOTGDP = Total GDP
INDGDP = GDP of Industrial Sector
AGRGDP = Agricultural GDP
TRANSGDP = Transport Sector's GDP
OTHSVS = Other Services Sector's GDP
PFCE = Private Final Consumption Expenditure of the economy
ALLENPR = Overall Real Energy Price Index
INDENPR = Real Energy Price faced by Industrial Sector
AGRENPR = Real Energy Price Index for Agriculture
TRANSENPR = Real Energy Price Index for Transport Sector.

Table 22: Constant Term and Partial Elasticities Coefficients of the Double Log Linear Regression models for Final Energy Demand

Sr. No.	Model	Constant	Partial GDP-Elasticity or PFCE elasticity	Partial Real Price Elasticity
1.	Overall	3.155	0.849	-0.719
2.	Industry	8.091	0.654	-1.143
3.	Agriculture	-24.225	2.863	-0.832
4.	Transport	5.059	0.733	-0.641
5.	Other Service	-12.708	1.568	-
6.	Residential	-10.377	1.467	-

Source: Author's own estimation.

Using the results of the regression models M1 to M6 of *Tables 21* and 22 the projections of final demand for the over all economy and the different sectors showed that the overall final end use energy-intensity of GDP to be growing at higher rate or declining at a slower rate during the period 2005-31 than the historical experience of rate of change of such intensity during the post-reform period (*see, Table 23*). This is explained by the fact that the regression models do not accommodate separately any role of technical change in the energy using sector to influence the demand of energy in the final end use sectors. However, we stick to the income-price model of final energy demand projections for the over all macro economy, industry and transport demand projection which show declining trend of energy intensity of aggregate or sectoral GDP, while we adopt the following model of energy-intensity trend based future demand projection for agriculture, other services and residential sector.

Model-M7: $y = a(o)\ x(t)\ g^t$ where y is the concerned sectoral final energy demand, a(o) is the sectoral energy intensity of GDP at the base year (o) i.e., 2005, x(t) the concerned sectoral GDP or private final consumption expenditure in year t, and g is the trend average annual growth factor of energy intensity as experienced during the period 1990-2005 for the concerned sector. This would mean the model assumes the following values of a(o) and g for agriculture, services other than transport, and the residential sector as given in *Table 24*.

Table 23: Comparative Trend Growth Rate of Energy-Intensity of Sectoral or Overall GDP.

Sectors	Trend growth rate of final energy-intensity of GDP (Or PFCE) during 2005-2031 (in %) based on Income Price Regression Models of Projections	Trend Growth rate of final energy intensity of GDP (or PFCE) as experienced during 1990 to 2005 (in %)
Overall Economy	-0.912	-3.523
Industry	-2.413	-5.717
Agriculture	6.318	1.255
Transport	-1.744	-4.592
Other Service	3.461	0.394
Residential Sector	2.478	2.270

Source: Author’s own estimation.

Table 24: Values of Parameters of the Projection Model M7.

		a(o)	g
M.3a	Agriculture	0.0263	1.0125
M.5a	Other Services	0.0105	1.0033
M.6a	Residential	0.0195	1.0227

Source: Author’s own estimation.

The energy intensity of the concerned sectoral GDP is expected to rise according to either of the models due to the laws of diminishing return in agriculture, or due to the proliferation of energy using or particularly electricity using newly developed service activities (e.g., information technology or computer aided services, etc). The energy intensity of the private final consumption expenditure is also expected to rise over time due to the penetration of modern clean fuel and electricity into the households with rise in income.

We develop a reference scenario of final energy demand projection at an over all macro economy level for any given growth rate using model 1 of *Table 21*. We also take a sectoral approach of demand projection and define a second scenario which projects the sectoral final energy demand using the sectoral models M2, M3(a), M4, M5(a) and M6(a) and derive the aggregate final energy demand projection by summing them over sectors.

We define a third scenario of final energy demand projection for any given growth rate based on economic growth and technical change. It may be noted that the penetration of electricity with development in the end use sector has two kinds of effects on final energy demand. First, it raises the use of modern energy services whenever electricity is available. Second, in view of the higher efficiency of electricity than fossil fuel or others energy resources in direct final use such penetration of electricity is likely to reduce the demand for final energy in oil equivalent unit. We therefore set up a model of regression to estimate the requirement of sectoral or overall economy's final energy demand with sectoral or total GDP and the share of electricity in the total final energy use as independent explanatory variables, all variables being taken in logarithmic form. Using the data on the share of electricity in the final energy use and those of GDP we could however obtain reliable estimates of regression equation for industry, transport and other services. (*see, Table 25* for estimated equation results). As all the models when run with OLS had autocorrelation problem, we could not obtain any convergent solution for the over all macro economy as well as for the residential sectors when any AR(1) scheme was tried to eliminate the autocorrelation problem. For agriculture the estimated relation with PRAIS-Winsten AR(1) scheme or Cochrane Orcutt AR(1) scheme could not give all the relevant co-efficient values to be significant. Thus we define a third scenario with sectoral approach for final energy demand projection with the following models 2(a), 4(a) and 5(b) for industry, transport and other services respectively while we retain the use of model 3(a) and 6(a) for agriculture and residential sector.

Table 25: Relationship of Final Energy Demand with Electricity Share and GDP

Sr. No.	Variables	Coefft.	P-value	No. of Obs.	Adj. R^2	DW Statistics
M2(a)	Dep. variable					
	LOG (INDENDD)	-	-	26	0.6711	2.008
	Run with Cochrane Orcutt AR(1) Regression		AR(1)			
	Indep. Variables					
	C	3.908	0.018			
	LOG (INDGDP)	0.739	0			
	LOG (Shelecind)	-0.897	0			
M4(a)	Dep.					
	LOG (TRANSENDD)	-	-	31	0.9972	1.608
	Run with Prais-Winsten Regression		AR(1)			
	Indep. variables					
	C	2.346	0			
	LOG (TRANSGDP)	0.726	0			
	LOG (Shelectrans)	-0.757	0.013			
M5(b)	Dep.					
	LOG (OTHSVSENDD)	-	-	20	0.953	1.884
	Run with Cochrane Orcutt Regression		AR(1)			
	Indep. variables					
	C	-2.922	0			
	LOG (OTHSVSGDP)	1.115	0			
	LOG (Shelecothsvs)	-0.8775	0.027			

Shelecind = Share of electricity in final energy use by industry
Shelectrans = Share of electricity in final energy use by transport sector
Shelecothsvs = Share of other services in final energy use by other services sector
INDENDD, TRANSENDD, OTHSVSENDD, INDGDP, TRANSGDP, OTHSVSGDP as already expanded at the bottom of *Table 21.*
Source: Author's own estimation.

It is important to notice that as the share of electricity in the total final energy goes up, the total demand for final energy will go down as expected because of the significantly higher efficiency of electricity in the final end use than of other fuels. In these models certain normative target of technical change in the form of annual rise in the share of electricity in the total final energy consumption is assumed for projection. Finally, we derive the aggregate final energy requirement of the economy by aggregation over the sectors in this sectoral approach. This scenario is driven by growth and technical change and takes no account of energy price changes. We have thus finally made projections of the final energy requirement for the following scenarios:

Sc1A: Macro-economic reference approach: Macro level projection using the model of aggregate income and real energy prices M1, GDP growth of 8 percent per annum, real energy price held constant at 2005 level.

Sc1B: Sectoral Approach, using the income – price based regression model M2 and M4 for Industry and Transport and the growth cum technical change based models M3(a), M5(a) and M6(a) for agriculture, other services and residential sector, GDP growth of 8 percent and real energy price held constant at 2005 level.

Sc1C: Sectoral Approach: Growth and technical change based projection using models M2(a), M3(a), M4(a), M5(b) and M6(a) for industry, agriculture, transport, other services and residential sector respectively, GDP growth of 8 percent and real price of energy held constant at 2005 level.

Sc2A: The same as 1A except that all the real energy prices rising at an annual compound rate of 3 percent per annum.

Sc2B: The same as 1B except that the real energy prices rising at an annual compound rate of 3 percent per annum.

Sc3A: The same as 1A accept that the GDP growth rate is 6 percent per annum.

Sc3B: The same as 1B except that the GDP growth rate is 6 percent per annum.

Sc3C: The same as 1C except that the GDP growth rate is 6 percent per annum.

The projections for the above scenarios would thus require information about sectoral composition of GDP for all the sectoral approach scenarios, real energy prices as faced by the aggregate economy and individual sectors, and the information about the energy intensities and the share of electricity in final energy demand in the different sectors in the future. We need also the shares of individual fuels in the total final energy other than electricity to have the complete fuel wise break up of final energy demand projection which we would need for the projection of primary energy and particularly CO_2 emission. We present these assumptions and parameters in *Table 26*. (*see, Charts 11 to 14*).

Table 26: GDP Elasticities of Sectoral Growth, Energy Intensity and Shares of Fuels in the final Energy for the Future

Items	Overall economy	Industry	Agriculture	Transport	Other services	Residential
Secroral GDP elasticity w.r.t. Aggregate GDP	1	1.07	0.56	1.17	Residual absolute amount to match with the total GDP	0.80
Real Energy price index faced by a sector (1999-2000=100)	168.98	164.94	155.35	184.40	118.96	192.77
Energy intensity of GDP in 2005 (kg/Rs.)			0.0263		0.0105	0.0195
Assumed growth factor of energy intensity during 2005 to 2031			1.0125		1.0033	1.0227
Target energy intensity of GDP in 2031 (kg/Rs.)			0.03640		0.01142	0.035
Share of electricity in total Final Energy in 2005 (%)	23.78	24.36	57.74	2.3	40.84	26.09
Linear Growth rate (Annual) of share of electricity in final energy	0.624	0.735	0.9	0.054	1.275	0.689
Share of electricity in total final energy in 2031	40.00	43.46	81.13	3.71	75.27	44.0
Shares of fossil fuels in non-electrical final energy (%)						
(a) Coal	31	54	0	0	93	10
(b) Oil	63	35	98	98	7	87
(c) Gas	6	11	2	2	0	3

Source: Author's own estimation.

In order to derive the CO_2 emission from the final energy demand we have to derive the projection of gross electrical energy requirement of the economy, the direct primary energy requirement for meeting the final energy demand as well as the indirect requirement of primary fuels required for the generation of power and production activities in the other energy industries. In these derivations of the fuel requirement for power and other energy industries we have assumed higher efficiency norms in respect of auxiliary loses, T&D losses and conversion losses with a target linear time phasing of these improvement over the time horizon from 2005-2031. In respect of fuel mix of generation of electricity we have built in rise in the share of carbon free energy resources and relatively cleaner fossil fuel like natural gas and reduced the share of coal and oil with linear rule of time phasing of such changes in fuel shares. For the energy industry other than electricity we have also allowed for the requirement of coal, oil and gas as per the norms decided on the basis of analysis of the data of the detailed energy balances of India. Finally, we have assumed CO_2 coefficients of the individual fuels as published by International Energy Agency (IEA) in its Energy Balances of Non-OECD countries, different volumes and CO_2 emissions from fuel combustion 1971-2004 in 2006 edition. All these norms regarding the energy industry's efficiency and fuel mix are given in *Table 27*.

Table 27: Normative Assumptions about Efficiency of Power Sector and other Energy Industry

SN	Items	Overall	Coal	Oil	N Gas	Others
1.	Auxiliary Loses as % of gross Generation 2005 2031	 6.8 5.0				
2.	T & D Losses as % of gross generation 2005 2031	 25.8 15.0				
3.	Auxiliary cum T&D Losses as a % of gross Generation (a) 2005 (b) 2031 (c) Increase per year	 32.6 20.0 -0.485				
4.	Generation mix of gross generation (%) (a) 2005 (b) 2031 (c) Increase per year in share (linear rule)		 69.5 61.0 -0.327	 4.5 2.0 -0.096	 9 15 0.2308	 17 22 0.1923
5.	Conversion Efficiency (%) (a) 2005 (b) 2031 (c) Increase in efficiency per year (linear rule)		27.0 35.0 0.3077	32.0 38.0 0.2308	42.0 45.0 0.1154	67.0 70.0 0.1154
6.	Fuel Requirement of other energy industries as % of total direct and indirect fuel requirement of the non energy sector		6	12	1	0
7.	CO_2 emission factor (tome to tonne)		3.75	2.47	2.31	0

Source: Author's own estimation.

VII. Projections of Future Energy use and CO_2 Emissions

The results of our analysis in respect of projections of the requirements of final energy, primary energy, gross electricity generation and CO_2 emissions for the 8 scenarios Sc1A to Sc3C, based on the alternatives of GDP growth rate, rise in real energy prices and on the choice of the determinants of energy demands, are presented in *Tables 28 to 31*. (*see, Charts 15,16, 19 and 20*). The results as presented in the tables show that the scenario Sc1A as given by the macro econometric model provides the CO_2 emissions to be lying between the two paths given by the sectoral approach scenarios Sc1A and Sc1C with real prices of energy held constant but with different assumptions regarding sectoral demand behaviour. The macro approach scenario 1A and one of the sectoral approach scenarios Sc1B assume the overall or sectoral GDP and the real prices of energy to drive the demand, except in the cases of agricultural and residential sectors and in the sector of service other than transport. The energy demand of industry as well as transport are driven by the production or income arising in the sector and the real energy prices. The scenario Sc1C with sectoral approach assumed demand to be decided by the growth and the technological factors like energy intensity of sectoral GDP or share of electricity in the total energy. Such scenario assumes no price sensitivity of demand depending on the sectoral characteristics and specificities. Both 6 percent and 8 percent GDP growth scenarios consist of sets of 3 solutions one for macro, and two for sectoral approaches. While for 6 percent we have not considered any price change, the 8 percent growth scenarios have been run with real price change at the rate of 3 percent per annum compounded every year which describe scenarios Sc2A and Sc2B. It is interesting to observe that the scenarios 2A and 2B with 8 percent growth and 3 percent annual compound rate of real price increase would not only give emissions substantively lower than the one with 8 percent growth and no price changes but the macro reference scenario Sc2A would also give emissions to be lower than the corresponding macro reference scenario Sc3A as well as the technology-cum-growth scenario Sc3C of 6 percent growth with no price change. Such price increase can also keep the absolute level of emissions with 8 percent growth with sectoral approach within approximately 15 percent range above the emissions of the counterpart sectoral scenario Sc3B of 6 percent growth with no price change. If however energy prices are not raised or lowered, it is the technology driven demand situation which would give the lowest emissions (*see, Table 31*).

Table 28: Projection of Final Energy, 2005-2031

Year	8% GDP Growth and no energy real price change			8% GDP Growth 3% annual rise in real energy prices		6% GDP Growth and no change in real energy prices		
	Sc 1A	**Sc 1B**	**Sc 1C**	**Sc 2A**	**Sc 2B**	**Sc 3A**	**Sc 3B**	**Sc 3C**
Final Energy mtoe 2005	171	171	171	171	171	171	171	171
2011	244	243	244	215	244	236	236	237
2021	468	478	438	334	438	387	400	365
2031	900	951	823	518	823	635	687	589
Future annual growth rate of Final Energy 2005-31(%)	6.72	6.94	6.11	4.45	5.8	5.13	5.49	4.63
GDP elasticity	0.84	0.87	0.96	0.56	0.73	0.84	0.9	0.76

Source: Author's own estimation.

Table 29: Projection of Electricity Generation Requirement mtoe
Generation Gross Electricity at Plant

Scenarios	Sc1A	Sc1B	Sc1C	Sc 2A	Sc 2B	Sc3A	Sc3B	Sc3C
2005	61	61	61	61	61	61	61	61
2011	95	95	98	84	89	93	93	95
2021	210	217	207	150	185	174	182	172
2031	450	486	440	259	399	317	352	315
Electricity generation per capita 2031 kwh	3587	3873	3505	2065	3181	2530	2805	2507
Future annual growth rate(%)	8.11	8.47	7.74	5.84	7.66	6.53	7	6.25
GDP elasticity	1.02	1.06	0.97	0.73	0.96	1.07	1.15	1.02

Source: Author's own estimation

Table 30: Projection of Primary Energy 2005-31 (mtoe)

Year	8% GDP Growth no energy real price change			8% GDP Growth 3% annual rise per annum rise in real energy prices		6% GDP Growth no change in real energy prices		
	SC 1A	**SC 1B**	**SC 1C**	**Sc 2A**	**Sc 2B**	**SC 3A**	**SC 3B**	**SC 3C**
2005	348	348	348	348	348	348	348	348
2011	495	495	502	436	471	479	480	484
2021	938	963	898	668	837	776	808	743
2031	1759	1879	1659	1012	1553	1240	1358	1177
Future growth rate primary Energy 2005-31(%)	6.53	6.83	6.05	4.29	5.96	4.97	5.38	4.56
GDP elasticity	0.82	0.857	0.759	0.54	0.75	0.81	0.88	0.75

Source: Author's own estimation

Table 31: Projection of CO_2 Emissions mt.

CO_2 Emission mt.	SC1A	Sc1B	Sc1C	Sc 2A	Sc 2B	Sc3A	Sc3B	Sc3C
2005	1084	1083	1083	1083	1083	1083	1083	1083
2011	1532	1523	1552	1349	1452	1484	1479	1498
2021	2860	2910	2726	2036	2532	2364	2442	2257
2031	5258	5553	4920	3027	4597	3709	4016	3493
Future growth rate of CO_2	6.36	6.62	5.84	4.12	5.76	4.8	5.18	4.36
GDP elasticity	0.797	0.831	0.733	0.52	0.72	0.785	0.85	0.71

Source: Author's own estimation

It is, however, confusing to say demand is technology and growth driven, but not driven by the growth of income and dynamics of prices. What is meant here is that if it is a situation of imperfect market or state guided economy with prices and demand following the availability of new technologies and appropriate entrepreneurship and not the other way round, then it is the projected technical changes that would induce entrepreneurs to demand technology and energy accordingly. This inducement would arise because of the potential gain from the substantive dynamic externalities that such technological initiatives may often generate in the long run. The technology driven scenarios 1C and 3C have mostly assumed either the energy intensity of sectoral GDP to follow the historical trend of movement of energy intensity as experienced in the post reform period or the realistic target regarding penetration of electricity in the end-use sectors of energy in the form of rising share of electricity in the total final energy. We see that even with quite modest assumptions, it provides the projection of primary energy and CO_2 emissions to be lower than other scenarios for similar growth rate, but no energy price change situation (*see, Tables 28 to 31*).

The immediate major policy conclusion that follows is that an effective policy for low carbon growth is the rationalisation of energy prices in the form of not just imposing once for all an imposition of carbon tax, but of regularly revising such tax, or royalty/tariffs in a manner that the real price of energy as faced by all the sectors rise at a moderate rate of 3 percent per annum. Such rising energy price would be quite justifiable to reflect the increasing scarcity of fossil fuel energy resources which an energy importing country like India would be most of the time facing. One should note that real energy prices increased at an annual average of 9.14 percent for the overall economy and all the individual sectors had to face real price increase in the range of 2.94 percent to 11.56 percent per annum during the period from 1999/2000 to 2005/06. The real price of oil has risen at an even faster rate after 2005. We are not, however, emphasising here any particular number or magnitude for the annual rate of energy price rise, but would like to focus on the choice of the policy variable and the direction of its movement. Pricing as a policy variable is more effective than reducing growth rate in reducing emissions over the long run time horizon than any policy of compromising with the pace of development.

It may be further noted that in some of the scenarios the projections are partly or entirely driven by technological factors which depend really on the supply side initiatives of technology in the non energy sector. It is important that the state policy either directs investments in new R&D activities in the field of energy technology or provides initial support or fiscal or other incentives to see that the energy conserving technologies are in place and energy intensities and CO_2 intensities can decline over time.

It may be noted that the projections of final energy, primary energy and gross electricity generation compare similarly across scenarios as the CO_2 emission projections (*see, Tables 28 to 31* and *see Charts 15, 16, 19 and 20*). This is not surprising as the CO_2 emissions were derived from the former in a sequence. The projection of fuel mix of power generation is shown in *Charts 17A to 17D*. It is also important to notice that all the future GDP-elasticities of final energy, primary energy and CO_2 emissions for various scenarios are less than unity implying declining energy-intensity or CO_2 emission intensity of GDP in future. The exception has been in the cases of generation requirement of electricity where the elasticity has exceeded 1 marginally in a few scenarios. This is not surprising particularly in view of the increasing use of electricity with the removal of energy poverty for lighting particularly of the rural households with economic growth, the higher electrical energy need for irrigation and other activities of agriculture, and the product composition of the service sector being increasingly knowledge and more electricity intensive as compared to traditional services. It may be noted in this connection how the share of electrical plants in the total CO_2 emission in India increased from 22.32 percent in 1971 to 39.36 percent in 1990 and 58.61 percent in 2006. In future, the share of fossil fuel to be used in power sector, particularly coal and gas, will rise and be around 86-87 percent in 2031 as per the base case scenario of 8 percent growth and no energy price rise. The share of power sector in the total primary energy will in fact rise from 59 percent in 2006 to somewhere in the range of 67 to 69 percent in 2031. This warrants that the focus of fuel policy should be on the power sector for reducing CO_2 emissions (*see, Table 34* and *see also Chart 18*). The importance of nuclear fuels and that of emerging carbon free technology can easily be appreciated looking at such numbers, although India is yet to make any significant progress in such directions. In any case, it is important to maximise the share of carbon free technologies in power generation subject to the conditions of economic viability after taking account of social and environmental cost-benefits into account.

Coming to the sectoral projections *Table 32* provides the sectoral percentage share of final energy demand which is the fundamental determinant of the pattern of primary energy use as well as CO_2 emissions. The growth rates of sectoral energy requirements over the planning horizon 2005-31, GDP elasticities and final energy intensities of the sectoral GDP in the terminal year are given in *Table 32* for scenarios Sc1B and Sc1C. It shows the GDP elasticity of such sectoral requirement to be greater than unity in agriculture, services other than transport and residential sector. As already discussed, objectives of inclusive growth and poverty removal, food security, and development of agro-based industries in India would require the growth of agricultural productivity and agrarian income. This would imply higher energy requirement for irrigation and other agrarian processes per unit of land as well as per unit of agricultural output as agriculture is the domain of operation of the law of diminishing returns making production costlier at the intensive margin of cultivation. The elasticity of energy demand for agriculture as determined by income and prices yields, in fact, very high growth rate and GDP elasticity of energy than what *Table 32* shows. We assumed for the projection for agriculture as given *Table 32* the energy intensity of agricultural income to grow much more modest lower rate. The basis of such assumption had been that the emergence of some supply side initiatives for raising agrarian productivity in the form of technical changes would ensure the energy intensity of agricultural value added to grow at a lower rate at which such intensity grew in the post economic reform period in

India. However, there would be further scope of moderating growth of energy intensity of agriculture if the political economy of India is amenable to annual rise in real energy price as faced by agriculture, if the policymaker can take advantage of the price elasticity value (-) 0.832 as revealed by the data through our econometric model.

The requirement of final energy for the sector of services other than transport is also projected to grow at a rate higher than GDP with elasticity 1.043 in future. The past data on the sector do not show any significant response to price movement and the consumption of final energy by the sector is driven by GDP with mildly growing energy intensity. This sector had a share in GDP of 37 percent in 1990 and the share rose to 47.52 percent in 2005 and is projected to have a share 51.3 percent in 2031 implying a more than 60 percent share of all the services together including transport in that year (*see, Table 33*). This other service sector which includes information technology among others has been the engine of India's post-reform economic growth since 1991 and has experienced proliferation of various new service activities and products which are both knowledge and an more energy (power) intensive than the traditional ones describing the other components of products or activities of the sector. While the level of energy intensity of the sector would be quite low as compared to other sectors like industry or transport, the momentum effect of this proliferation and growth would push upwards the energy intensity and result in relatively high energy elasticity.

Table 32: Sectoral Share in Final Energy Demand, Growth rate of Final Energy Consumption and Energy Intensity of GDP for Sc 1B and Sc 3B (Growth Rate Sensitivity)

Item	Year	Industry	Transport	Agriculture	Other Services	Residential Sector	Aggregate
SC1B Sectoral Share in Final Energy(%)	2005	43.6	21.69	7.86	7.6	19.29	100
	2031	27.5	22.12	5.95	11.93	32.5	100
Growth rate final energy consumption 2005-31(%)	2005-31	5.49	6.81	5.69	8.69	8.78	6.95
Sectoral GDP or PFCE elasticity	2005-31	0.64	0.73	1.29	1.043	1.38	0.87
Final Energy Intensity of GDP(gm/Rs)	2005	10.7	21.8	2.6	1.0	2.0	6.5
Sectoral GDP elasticity	2005-31	0.043	0.118	0.036	0.011	0.035	0.049
SC 3B Sectoral Share (%)	2031	28.57	21.54	6.55	10.94	32.40	100
Growth Rate (%)	2005-31	4.12	5.23	4.67	6.80	7.28	5.49
GDP elasticity		0.62	0.73	1.38	1.055	1.49	0.90
Energy Intensity of GDP (gm/Rs)	2031	5.0	13.0	3.6	1.1	3.5	5.3

Source: Author's own estimation

Table 33: Projected Sectoral Shares of GDP and Share of PFCE in GDP as per 8% GDP Growth Rate (%) (Sc1B)

Year	Industry	Transport	Agriculture	Other Services	PFCE	Total
2005	26.42	6.51	19.56	47.52	64.68	100
2011	28.28	7.07	15.79	48.86	61.99	100
2021	29.84	8.06	11.25	50.85	53.15	100
2031	31.49	9.19	8.02	51.30	45.57	100
Future growth rate (%)	8.58	9.39	4.38	8.33	6.37	8.0
GDP elasticity income	1.077	1.178	0.55	1.045	0.80	1.0

Source: Author's own estimation.

Finally, the residential sector of India is projected to have relatively high private final consumption expenditure (PFCE) elasticity of the final commercial energy consumption by the residential households. The Indian household sector is starved of both power for lighting and cleaner hydrocarbon fuels (like LPG or Kerosene) for cooking. With the growth in the per capita income and expenditure this sector is likely to spend more on cleaner commercial energy which is a necessity and far more efficient than biomass resources which need badly to be replaced by cleaner fuels. The energy consumption of this sector has not in fact shown any significant responsiveness to price variation as per our econometric analysis. The projection of energy requirement of this sector as based on the growth of energy intensity of expenditure since the introduction of reforms, however, makes it more moderate than any projection based on expenditure elasticity of final energy consumed by the households. The final commercial energy intensity of such expenditure by the residential households is again projected to be the second lowest one in 2031, but it would be experiencing rise over time. This is an expected inevitable consequence of the poverty removal and growth and of the improvement of quality of life that such changes will bring about.

Thus the results of our analysis of data and models of future projection shows that the industry and the transport which account for almost two third of the share of final commercial energy use have high energy intensity and would be experiencing significant energy conservation, low GDP elasticity and decline in their respective energy intensities. This will have a great moderating effect on the rise of CO_2 emission induced by GDP growth. While technical changes in industry and transport would intend to pull down emission, the rising tendency of energy intensity of agriculture, other services and residential sectors as explained above would tend to push the CO_2 emissions upwards. The net effect of the opposing elasticity effects would cause the overall energy intensity and emission intensity of GDP to decline moderating the upward growth effect of emission. Although we have not given any table of sectoral distribution of total primary energy use (direct and indirect together) or CO_2 emissions there from *Tables 12* and *13* show the historical trend of changes in such sectoral distributions in the pre-economic reform and post economic reform periods referring to the specific years of 1971, 1990 and 2005. *Table16* also shows the changes in CO_2 intensity of sectoral GDP during 1971 to 2005.

Before we end this section, we should note that as in the past the major resource of our primary energy, electricity generation and source of CO_2 emission will remain to be coal. Its share will increase for primary energy, while for CO_2 emission it will remain almost unchanged for 8 percent GDP growth scenarios (*see, Tables 35* and *36. see also Charts 21A to 21D, 22A to 22D*). So far as the oil and gas is concerned, the share of the former in both primary energy supply and CO_2 emission is expected to decline, while that of gas to rise. As the fuel mix of an economy is by and large inflexible being decided by the natural resource endowments, it is nothing surprising that we find the domination of coal to continue over our planning horizon. As 82 to 87 percent of coal is supposed to be used in the electricity sector in the future (*see, Table 34*) and as fuel substitution is quite possible in the electricity sector, a major policy thrust for making growth low carbon should be on raising the share of nuclear fuel, hydro resource and other carbon free resources like wind, solar energy, etc. in the generation of power. The ways need to be found out to utilise effectively India's thorium reserve for use as blanket cover in nuclear reactor operating with uranium 235 as fuel to generate uranium 233 isotopes which may become an important fuel resource for the next cycle or phase of power generation. This is one of the most important ways of making growth low carbon at competitive cost for power supply. The development of bio-liquids as substitutes of oil in transport is also to provide oil security on the one hand and substituting oil with carbon neutral bio-liquids on the other. As the net carbon emission from bio-liquids after adjusting for recycling of carbon through photosynthesis, is quite low, if not nil, the development of such fuels can also contribute to low carbon growth of the Indian economy.

Table 34: Projected Shares of use of Primary Fuels through Electricity (%)

Year	Coal	Oil	Gas	Others	Overall
2005	79.32	9.61	62.14	100	59.98
2031					
SC 1A	82.41	6.51	82.24	100	67.06
SC 1B	87.29	5.83	86.29	100	67.86
SC 1C	87.43	6.41	86.28	100	69.49

Source: Author's own estimation.

Table 35: Projected Shares of Primary Fuels in Total Primary Commercial Energy(%)

Year	Coal	Oil	Gas	Others	Total
2005	59.81	29.19	6.58	4.41	100
2031					
SC 1A	57.37	23.18	11.41	8.04	100
SC 1B	54.72	26.16	10.99	8.13	100
SC 1C	56.01	24.38	11.27	8.33	100

Source: Author's own estimation**.**

Table 36: Projected Shares of Primary Fuels in Total CO_2 Emission (%).

Year	Coal	Oil	Gas	Others	Total
2005	72.01	23.11	4.88	0	100
2031					
SC 1A	72.03	19.14	8.83	0	100
SC 1B	69.54	21.86	8.60	0	100
SC 1C	70.91	20.30	8.79	0	100

Source: Author's own estimation.

VIII. Comparison of Results with Other Studies of Energy Demand Projection

Although I have not as yet referred to the literature of energy demand projections and their CO_2 emission implications, there has been substantive work done on the analysis of sustainability of the environment-energy-economy interaction in the Indian context, using both top down and bottom up approach of mathematical modeling for the different sectoral and end use levels of the economy. Such models have been adopted for the country level policy analysis for India. There have given projections of energy and CO_2 emissions as well as on the specific impact of various illustrative policy initiatives for mitigation [(*see*, Garg *et. al*. (2001), Kainamu *et..al*, (2003), Pandey and Shukla (2003), Shalizi (2007), Ghosh *et..al*, (2002)].

There has also been a very useful study by the Integrated Energy Policy Committee (IEPC) of the Planning Commission (PC) using an integrated linear programming optimisation model and generating different policy scenarios for not only CO_2 emission reduction but for the sustainability of India's energy system in more comprehensive sense of the term (*see,* Planning Commission, 2006). We compare below the estimates of primary commercial energy requirement of this paper with those of the Planning Commission 2006 as the latter has given projection for 8 percent growth rate and seems to have projected requirements assuming constant prices. We therefore compare the IEPC's projection with our scenarios Sc1A, Sc1B and Sc1C (*see, Table 39*).

It is important to note that the results of the present study project marginally higher level of energy requirement than for the IEPC Report scenarios except for the scenarios involving the simultaneous use of all the measures for sustainable energy development. Our projection also predict the share of coal and gas to be higher than the IEPC projections. The present study of this paper has not however worked out the implications of the projections in respect of non-commercial energy. Inspite of the differences in the projections of the two studies it is important to note that they are not widely apart and the inter-scenario comparison of results of both the studies establishes reasonable degree of their robustness. Besides, it is also reassuring to note that the results of the two studies adopting highly disparate methodology provide by and large comparable.

Table 37: Projection of Per-capita CO_2 Emission and Emission intensity of GDP (Sc1A)

Year	Pri. Energy (mtoe)	Emissions mt.	Population million	Pri. Energy per cap.	Per capita emissions (t)	GDP Rs billion	Pr. Energy Intensity kg/Rs.	Emission int. of GDP (Kg/Rs)
2005	348	1084	1096	0.317	0.989	26128.47	0.013	0.041
2011	495	1532	1193	0.415	1.284	41586.09	0.012	0.037
2021	938	2860	1340	0.700	2.135	89781.25	0.010	0.032
2031	1759	5259	1462	1.205	3.605	193830.98	0.009	0.027

Source: Author's own estimation.

Table38: Projections of Carbon and Energy Intensities and Per Capita uses

		Sc1A	Sc1B	Sc1C	Sc2A	Sc2B	Sc3A	Sc3B	Sc3C
CO2 Intensity of GDP gms/Rs	2005	41	41	41	41	41	41	41	41
	2021	32	32	30	23	28	33	34	31
	2031	27	29	25.4	16	24	29	31	27
% Drop over the base year 2005	2021	-21.95	-21.95	-26.83	-43.9	-31.71	-19.51	-17.07	-24.39
	2031	-34.15	-29.27	-38.05	-60.98	-41.46	-29.27	-24.39	-34.15
Primary Energy Intensity gms/Rs	2005	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3
	2021	10.5	10.7	10	7.4	9.3	10.8	11.3	10.4
	2031	9.1	9.7	8.6	5.2	8	9.7	10.6	9.2
% Drop over the base year 2005	2021	-21.05	-19.55	-24.81	-44.36	-30.08	-18.8	-15.04	-21.8
	2031	-31.58	-27.07	-35.34	-60.9	-39.85	-27.07	-20.3	-30.83
Per capita CO2 emission tonnes	2005	0.989	0.989	0.989	0.989	0.989	0.989	0.989	0.989
	2021	2.135	2.172	2.035	1.52	1.89	1.765	1.823	1.685
	2031	3.605	3.806	3.372	2.075	3.151	2.543	2.753	2.395
% rise of per capita Co2 emission over the base year 2005	2021	115.87	119.62	105.76	53.69	91.1	78.46	84.33	70.37
	2031	264.51	284.83	240.95	109.81	218.6	157.13	178.36	142.16
Per capita Primary Energy use tonnes	2005	0.317	0.317	0.317	0.317	0.317	0.317	0.317	0.317
	2021	0.7	0.719	0.671	0.499	0.625	0.579	0.603	0.555
	2031	1.205	1.288	1.137	0.694	1.065	0.85	0.931	0.807
% rise of per capita energy use over the base year 2005	2021	120.82	126.81	111.67	57.41	97.16	82.65	90.22	75.08
	2031	280.13	306.31	258.68	118.93	235.96	168.14	193.69	154.57

Source: Author's own estimation.

Table 39: Comparative Projections of Primary Energy Requirements for the 8% GDP Growth: Present Study and Planning Commission

Scenarios Present Study 8% growth	Primary Energy mtoe 2031-32	Share Coal %	Share Oil %	Share Gas %	Share Others %	Non commercial %
Sc1A Sc1B Sc1C	1759 1879 1658	57.37 54.72 56.01	23.18 26.16 24.38	11.41 10.99 11.27	8.04 8.13 8.33	N/A
IEPC Report, Planning Commission						
Coal Dominant scenario	1702	54.1	25.7	5.5	4.8	9.8
Maximum use of Hydro, Nuclear & Gas potential scenario	1652	45.5	26.4	10.7	7.3	10.1
Simultaneous use of all strategies for sustainable Energy Development	1351	41.1	22.8	9.8	14.2	12.0

Source: Author's own estimation and Planning Commission (2006): Integrated Energy Policy Committee Report.

IX. Conclusion

The policymakers for climate stabilisation are anxious to find ways for delinking carbon emission and economic growth. This would require the absolute level of CO_2 emission to be cut down by the major players (i.e., the developed countries) and the growth of CO_2 emission to be decelerated for the developing countries for the absolute global emission of CO_2 to stabilise at a certain level. As high economic growth is a necessary condition for the removal of income poverty, hunger, energy poverty, malnutrition, disease, and illiteracy, the first step towards making growth low carbon is to make the primary energy and CO_2 intensity of GDP to decline. India has been experiencing decline in macro level energy intensity and CO_2 emission intensity of GDP since the introduction of economic reforms in 1991. It has sometimes been argued that the decline in energy intensity as experienced has been more an expression of compression of energy use due to energy rationing in a situation of chronic energy deficiency – particularly of electric power in India – than that of rise of energy efficiency. This argument is not tenable in view of the persistent increase in efficiency of power use and that of use of primary energy resource use over time, in spite of substantive creation of captive power generation capacity which is of lower efficiency of supply than the grid power. Our decomposition analysis of CO_2 growth has in fact been quite revealing in this respect.

As per the projections of the base case scenario Sc1A, the primary energy intensity of GDP is supposed to go down from 0.013 kg/Rs in 2005 to 0.010 kg/Rs in 2021 and 0.009 kg/Rs in 2031while the per capita primary energy use will rise from 0.317 tonne in 2005 to 0.7 tonne in 2021 and 1.205 tonne in 2031. The CO2 emission intensity of GDP correspondingly is projected to decline from 0.0415 kg/Rs in 2005 to 0.032 kg/Rs in 2021 and 0.0271 kg/Rs in 2031, while the per capita emission will be rising from 0.989 tonne per annum in 2005 to 2.135 tonne in 2021 and 3.605 tonne in 2031. (*see, Table 37*). We have also given comparative CO2 intensity and primary commercial energy intensity of GDP and per capita CO2 emissions and energy uses for all the scenarios in *Table 38*. (*see also, Charts 23 to 26*). Thus the drop in CO2 intensity of GDP between 2005 and 2021 is projected to be around 22 percent and that between 2005 and 2031 around 35 percent as per the base case scenario Sc1A. India's per capita emission as per the projection of this scenario would be 18.4 percent of the per capita emission of USA in 2005 which has been 19.5 tonne and 20 percent lower than the world average per capita emission which stood at 4.5 tonne in the same year. Although we have not considered the cost of achievement of decline of such carbon intensity, we implicitly assume that for the GDP growth rates of 8 percent and 6 percent the economy will be able generate and mobilise the requisite financial resources for investment for the purpose and be competitive in energy supply with low carbon intensity. India has thus already started moving towards a low carbon growth trajectory, although there exists substantive scope for further accelerating the pace of carbon reduction. These would lie in the following areas for which pro-active departure from the business as usual trend of conservation of energy is required.

- Energy conservation for irrigation for agriculture, service sector and the household sector should be of high priority in the energy policy agenda for influencing the demand side of the market.
- Rationalisation of energy prices and using pricing as a tool for conservation and not take any recourse to the deceleration of growth rate for making economy low carbon.
- Technological initiatives are important on the supply side of technologies for energy conservation in the non energy sector and carbon free technologies for power generation or carbon neutral renewable bio-liquid fuels for transportation.
- Development of entrepreneurship for proactive initiatives in the supply of the new technologies is an imperative. Fast deployment of new technologies is a critical requirement for reducing its cost and making it competitive.
- Government needs to innovate appropriate fiscal-monetary and other policies for the realisation of the points made in (2), (3) and (4) above. The policies should target the development of appropriate market conditions for the purpose.

While the Indian economy would be striving to do better for achieving low carbon growth than as predicted in this paper, it is clear that India will not be in a position to make any commitment to the international community for a cap on the *absolute level* of carbon emission. India should however set her own plan target and make internal national level commitment for emission reduction within time frame of 5 to 10 years. Whenever India is to participate in any debate and discussion on her requirement of carbon space and rationale of non-commitment, she should make a hard bargain with the rest of the world for the legitimate share in the rights to emission, for using the capacity of global environment as sink for carbon emission. It is for removing income poverty, employment generation in the growth sector of services and eliminating energy poverty which affects Indian women and children's health and education, that such space for carbon emission is required. India's argument for carbon emission rights and space is not for the adoption of the western style of life for her people, but for the removal of the disparities in the pattern of energy consumption among her own people. The removal of such disparities and poverty is imperative for providing justice to the Indian common people and for ensuring a better quality of life and higher level of human development for them.

References

Ang B. W., 1994. "Decomposition of industrial energy consumption: the energy approach", *Energy Economics*, 16.

-----------, 1999. "Decomposition Method in Energy Demand and Environmental Analysis" in (*eds*.) van den Bergh, C J M Jeroen, *Handbook of Environmental and Resource Economics*. UK: Edward Elgar.

Ang B. W. and K. H. Choi, 1997. "Decomposition of aggregate energy and gas emission intensities for industry: a Refined Divisia index method", *Energy Journal*, 18(3).

Boyd G. A., D. A. Hanson and T Sterner, 1988. "Decomposition of changes in energy intensity – a comparison of the Divisia index and other methods", *Energy Economics*, 10.

Choi Ki-Hong and B. W. Ang, 2003. "Decomposition of aggregate energy intensity changes in two measures: ratio and difference", *Energy Economics*, 25.

Garg Amit, D Ghosh and P R Shukla, 2001. "Integrated Modelling System: Energy and Environment Policies", *Opsearch*, February 2001.

Ghosh D, P R Shukla, A Garg and P Venkata Ramana, 2002. "Renewable Energy Technologies for Indian Power Sector: Mitigation Potential and Operational Strategy", *Renewable and Sustainable Energy Reviews Journal*, 6(6).

Government of India, "The Road to Copenhagen: India's Position on Climate Change Issues", Ministry of External Affairs: Public Diplomacy Division, New Delhi, February 27, 2009.

Hankinson G. A and J. M. W. Rhys, 1983. "Electricity consumption, electricity intensity and industrial structure", *Energy Economics*, 5.

International Energy Agency, *Energy Balances of Non-OECD Countries 1971-87, 1985-1989, 1999-2000, 2002-2003, 2004-2005.* Paris: OECD/IEA.

--------------------, 2006. CO_2 Emissions from Fuel Combustion 1971-2004. Paris: OECD/IEA.

(*Eds*.) Kainuma M., Y. Matsuoka, and T. Morita, 2003, *Climate Policy Assessment: Asia-Pacific Integrated Modelling*. Tokyo: Springer Verlag.

Li J. W., R. M. Shreshtra and W. K. Foell, 1990. "Structural change and energy use: the case study of the manufacturing sector in Taiwan", *Energy Economics*, 12.

Liaskas K., G. M. Mavrotas, Mandaraka and D. Diakoulaki, 2000. "Decomposition of Industrial CO_2 Emissions: The case of European Union", *Energy Economics*, 22.

Panagariya Arvind, 2009. "Climate Change and India Implications and Policy Options", Paper presented at the Sixth India Policy Forum Conference in New Delhi, July 14–15.

Park S. H., 1992. "Decomposition of industrial energy consumption: an alternative method", *Energy Economics*, 14.

Pandey R and P. R. Shukla, 2003. "Methodology for exploring co-benefits of CO_2 and SO_2 mitigation policies in India using AIM/ end use model" in (*eds*.) Kainuma M., Y.Matsuoka, and T. Morita, *Climate Policy Assessment : Asia-Pacific Integrated Modeling.* Tokyo: Springer Verlag.

Planning Commission, Government of India, 2006. Integrated Energy Policy: Report of the Expert Committee, New Delhi

Sengupta Ramprasad, 2007. High Economic Growth, Equity and Sustainable Energy Development of India, Discussion Papers Series No. 213, Research Institute for Economics and Business Administration, Kobe University, Kobe, Japan.

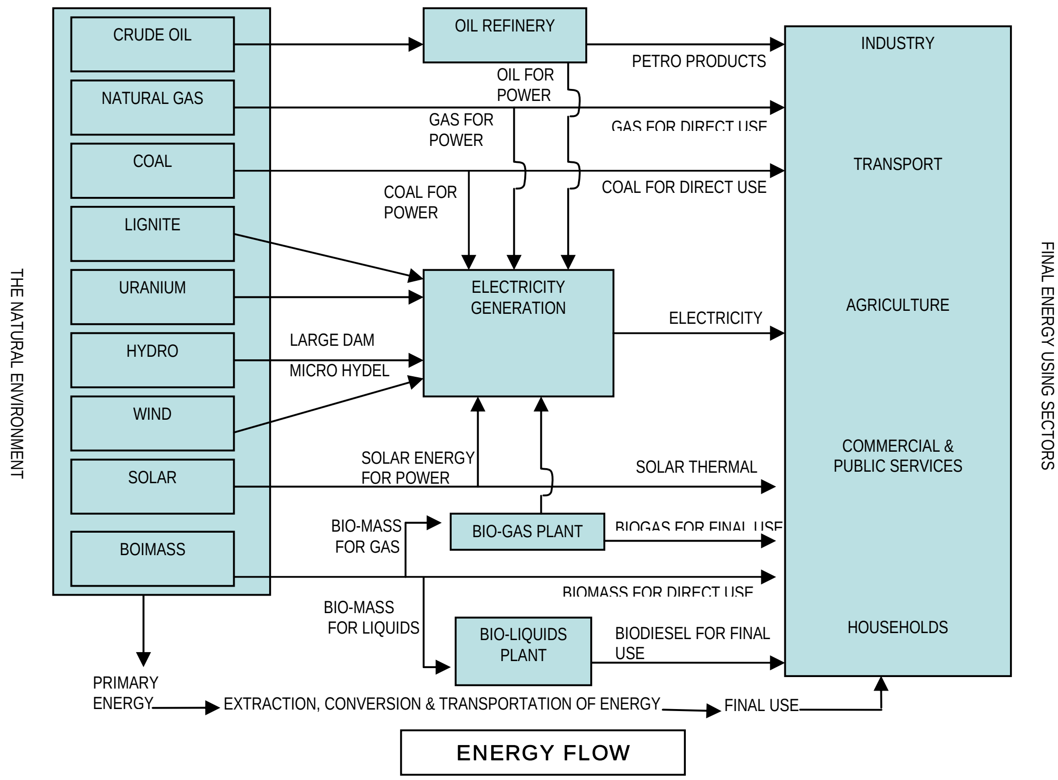
---------------, 2009 "Energy, Equity and Inclusive Economic Growth of India", Dr. S.N. Sen Memorial Lecture 2009, *Arthabeekshan,* 17(4); March 2009. (Journal of the Bengal Economic Association), Kolkata.

Shalizi Z, 2007. Energy and Emissions: Local and Global effects of the Rise of China and India*,* World Bank Policy Research Working Paper 4209.

World Bank, 2009. *World Development Indicators 2009.* Washington DC: World Bank.

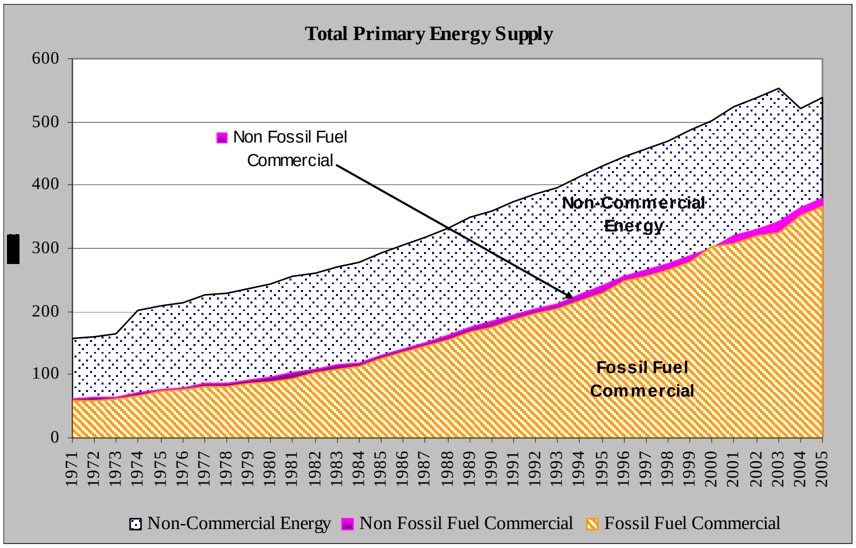
CHARTS

Chart 1: Energy Flow Chart



Source: Author

Chart 2



Source: Based on IEA Data on Energy balances of Non-OECD countries, different volumes.

Chart 3

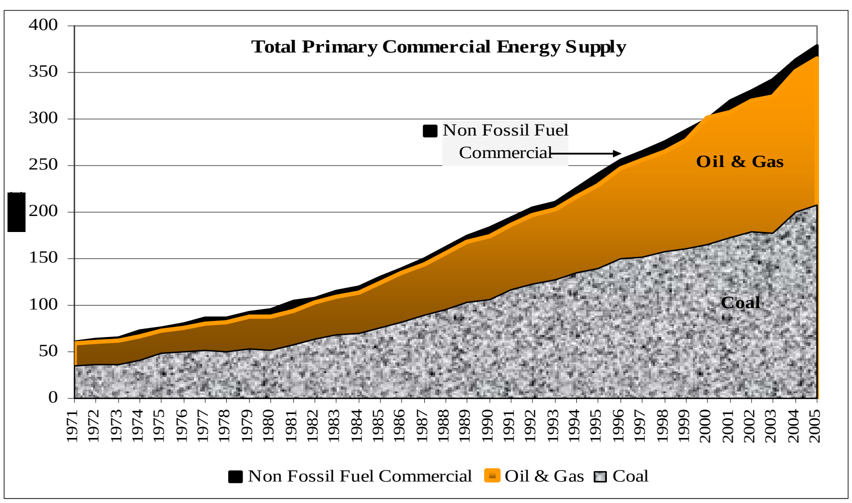


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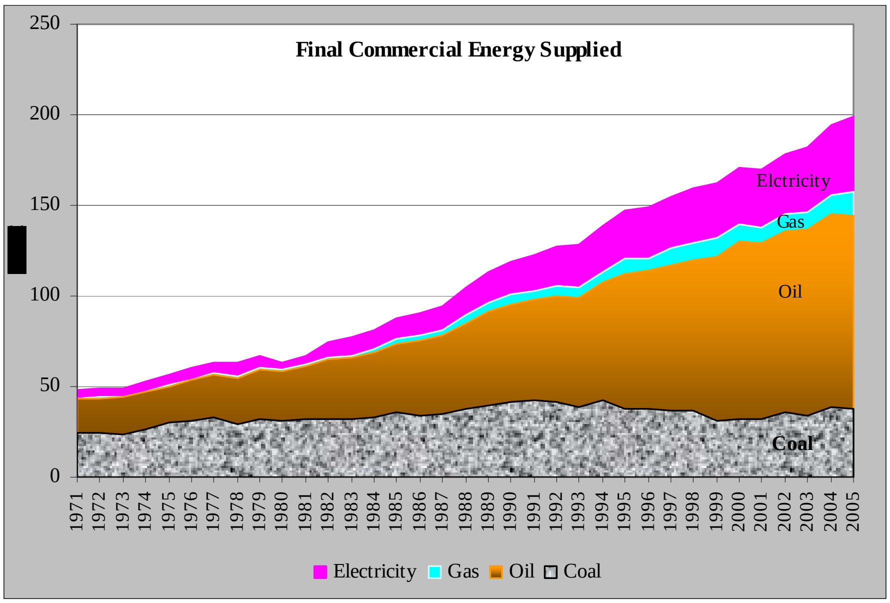
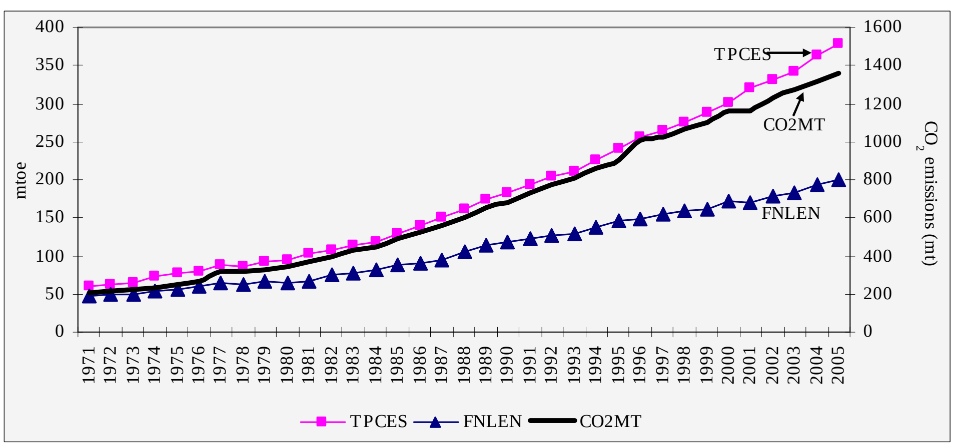
Chart 4



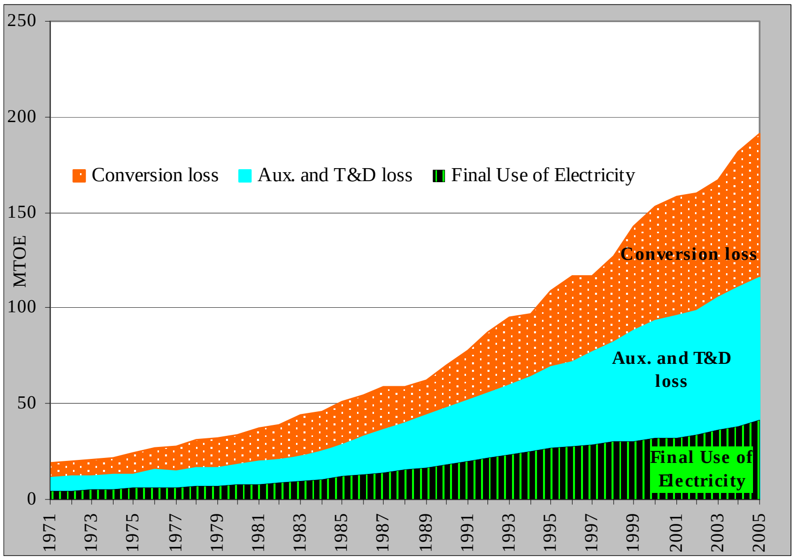
Source: Based on IEA Data on Energy balances of Non-OECD countries, different volumes.

Chart 5: Supplies of Total Primary and Final Commercial Energy and CO_2 Emissions



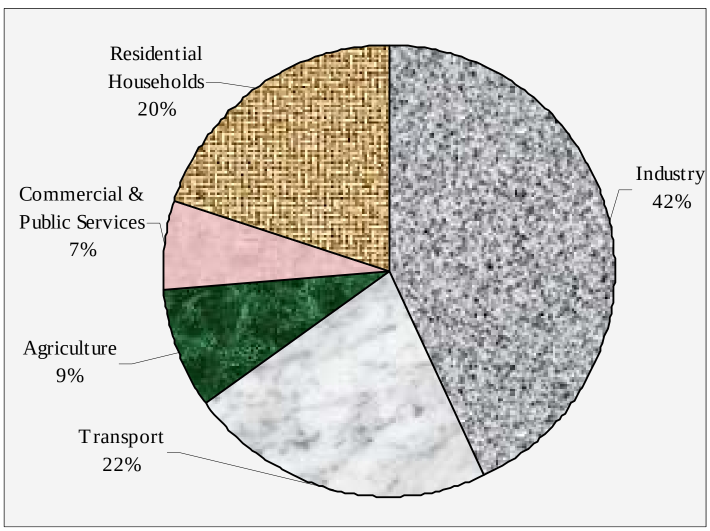
Source: Based on IEA Data on Energy balances of Non-OECD countries, different volumes.

Chart 6: Total Energy Input, Losses and Final Use of Electricity



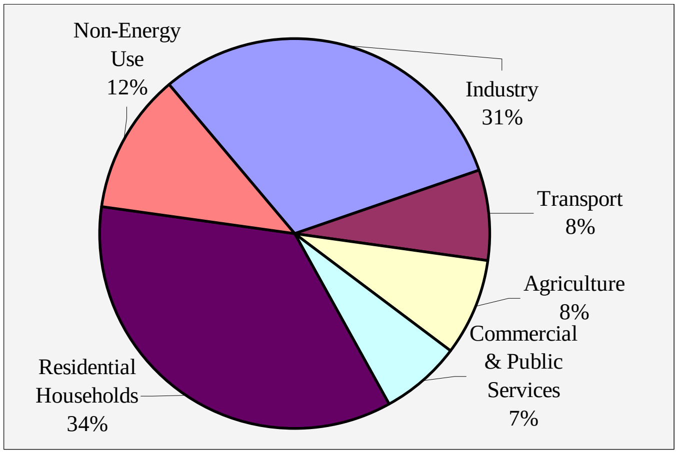
Source: Based on IEA Data on Energy balances of Non-OECD countries, different volumes.

Chart 7: Sectoral Distribution of Final Commercial Energy Use
Unit: % Sectoral share



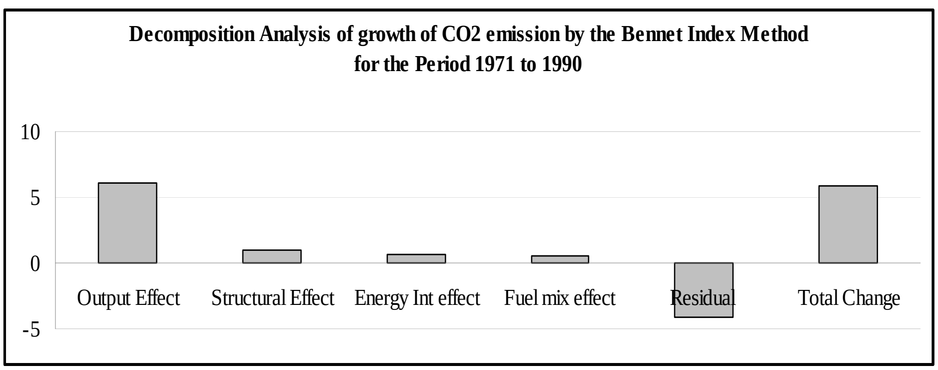
Source: Based on IEA Data on Energy balances of Non-OECD countries, different volumes.

Chart 8: Sectoral Distribution of Total Direct and Indirect Primary Energy (including Traditional Fuels) in 2005



Source: Based on Author's own estimation as derived from IEA Data on Energy balances of Non-OECD countries, different volumes

Chart 9



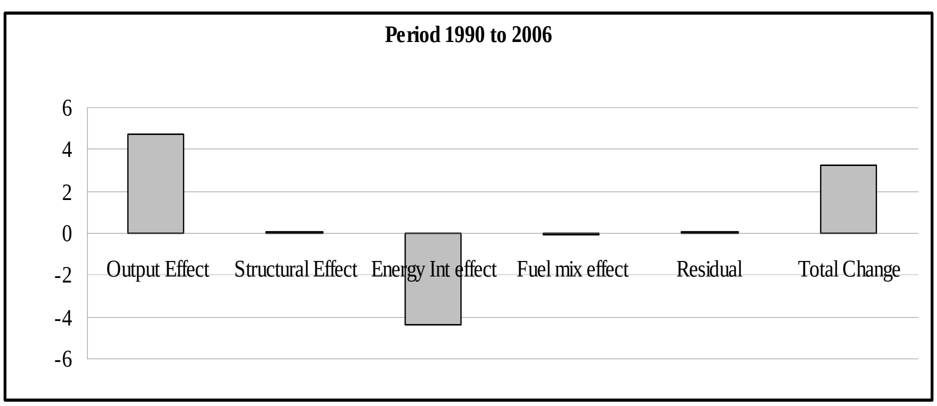


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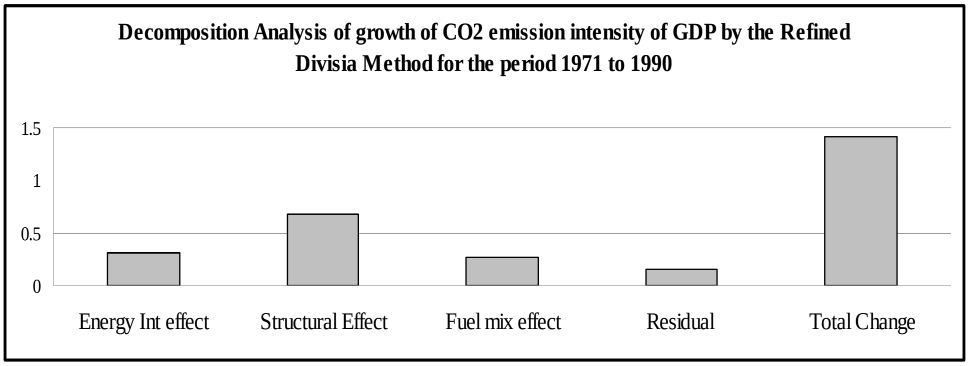
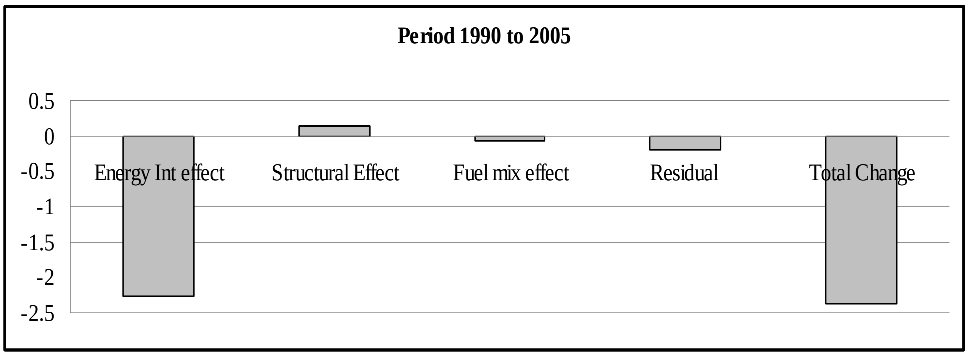
Chart 10





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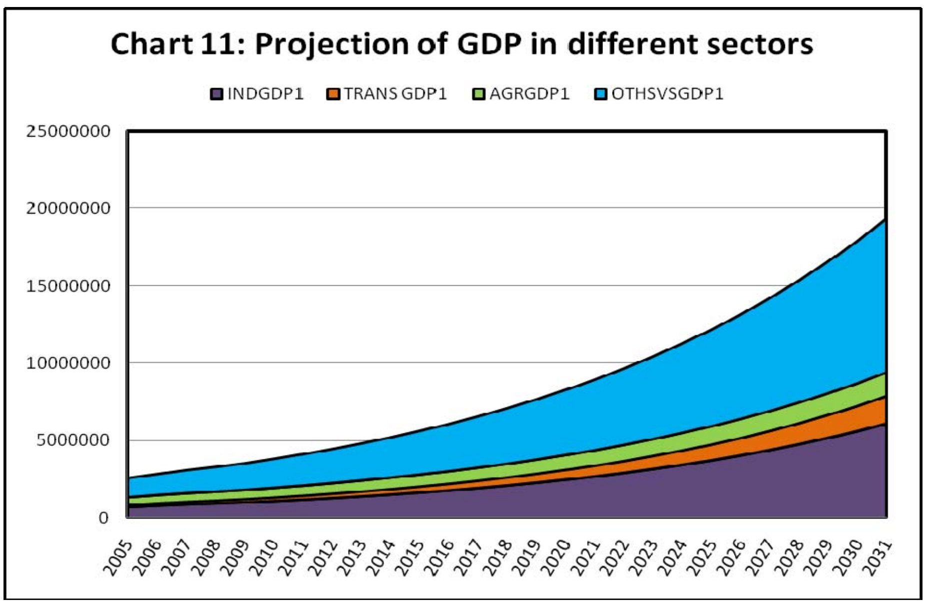

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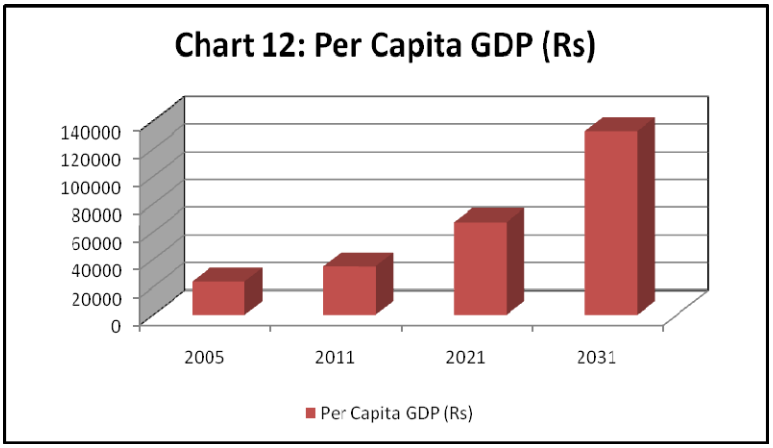

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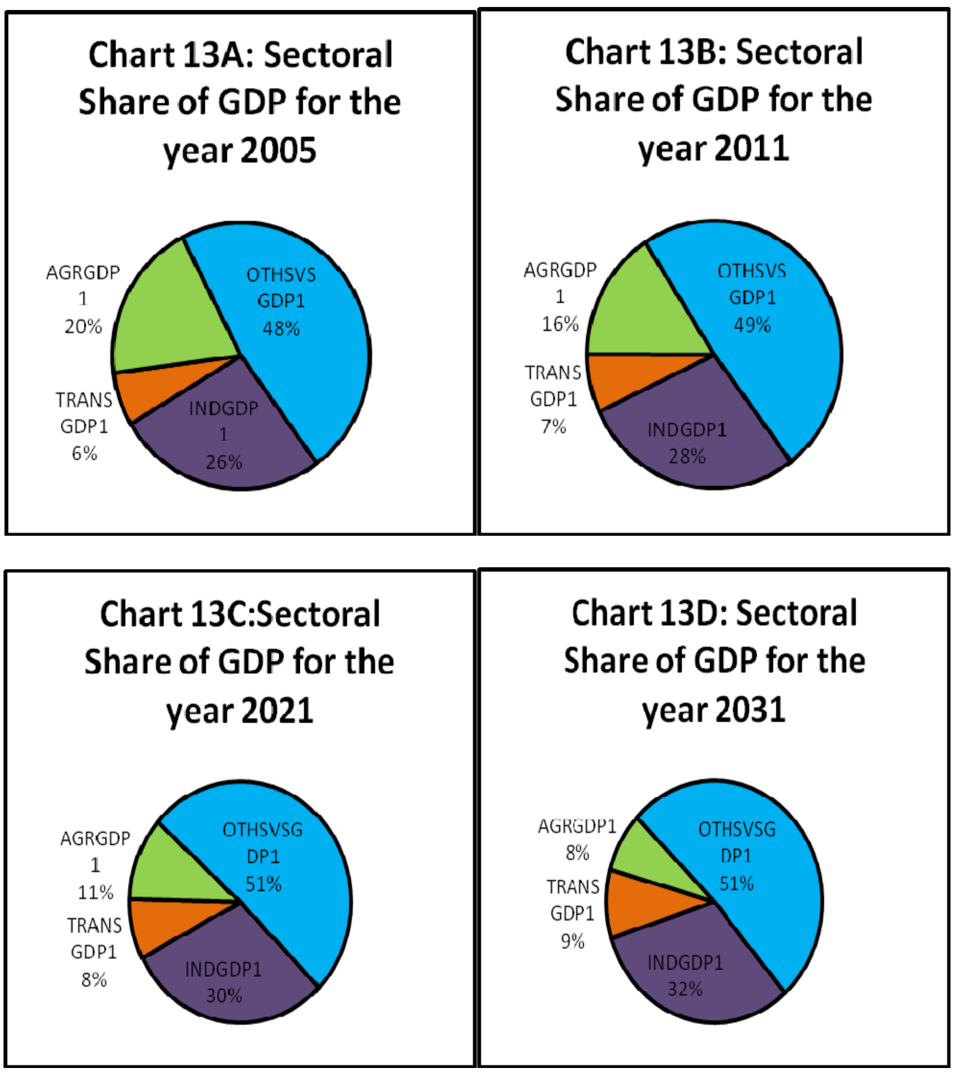

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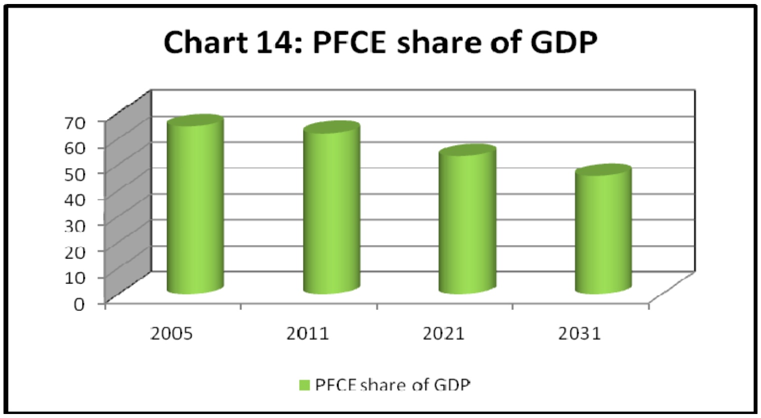

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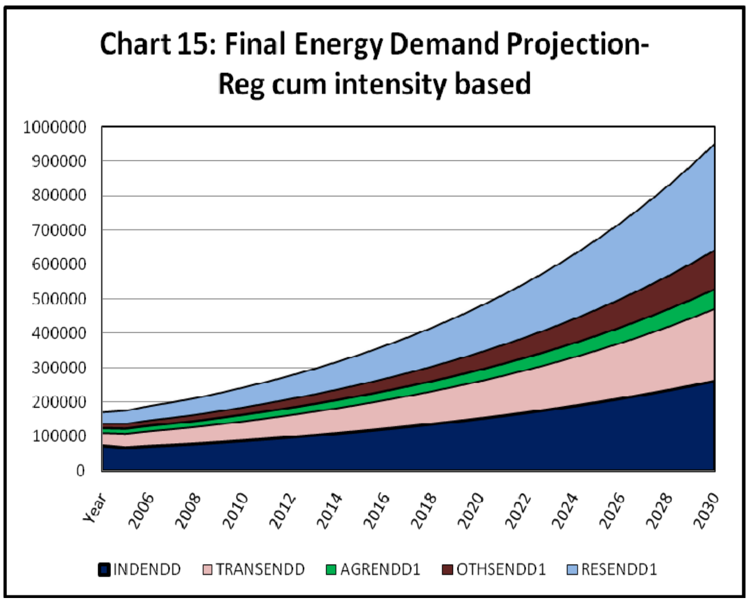

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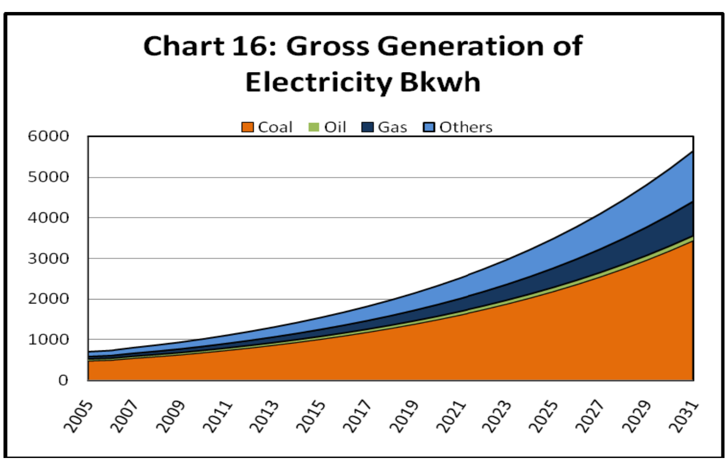

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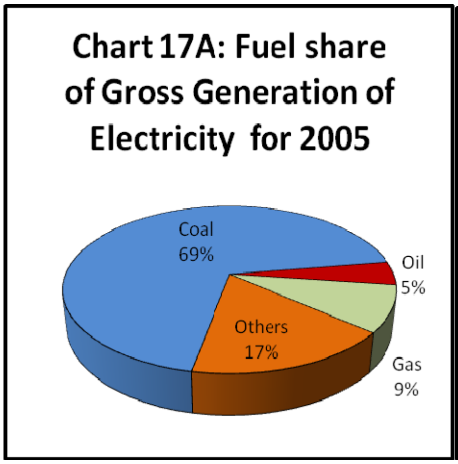

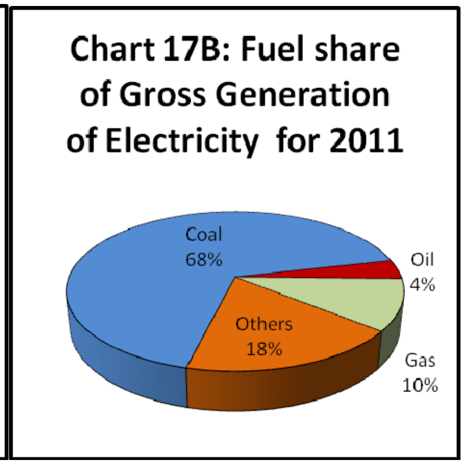

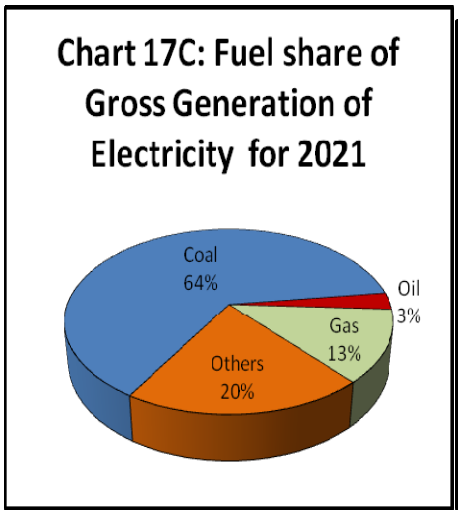

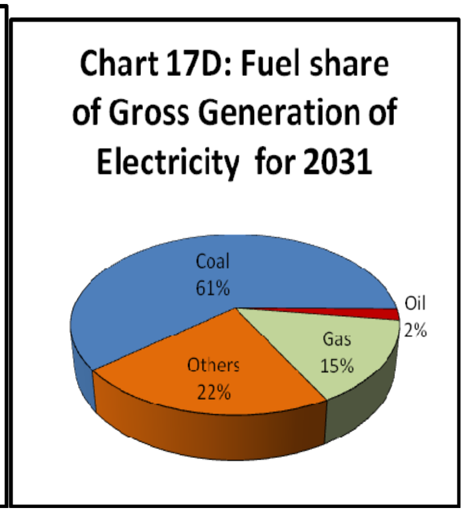

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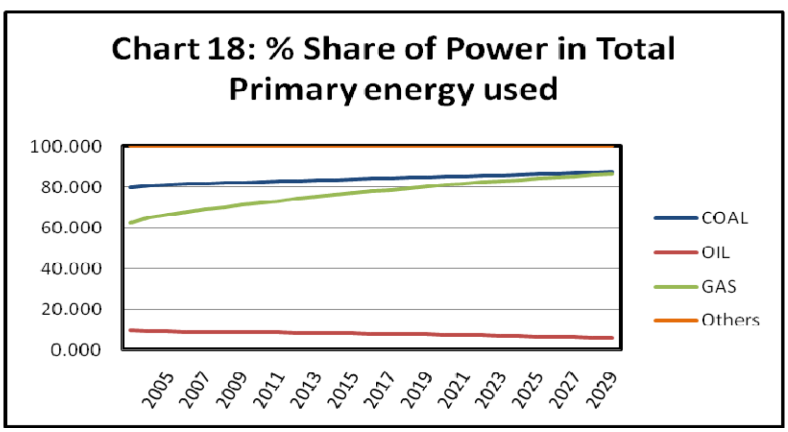

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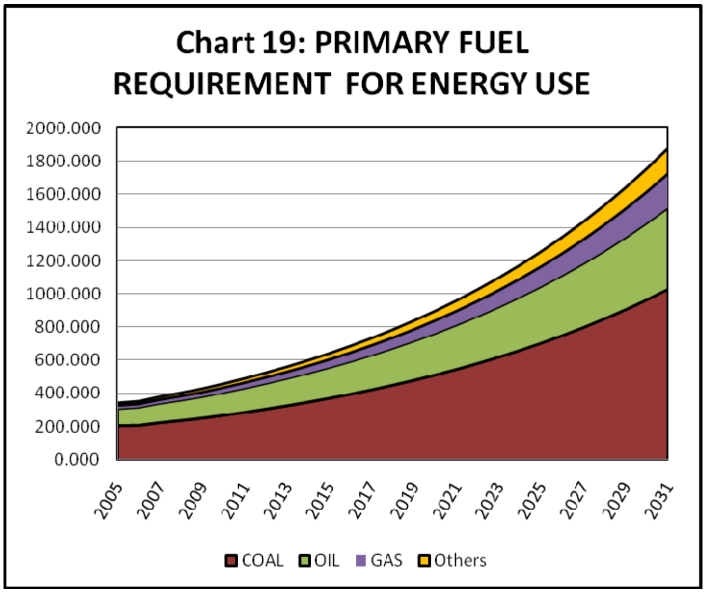

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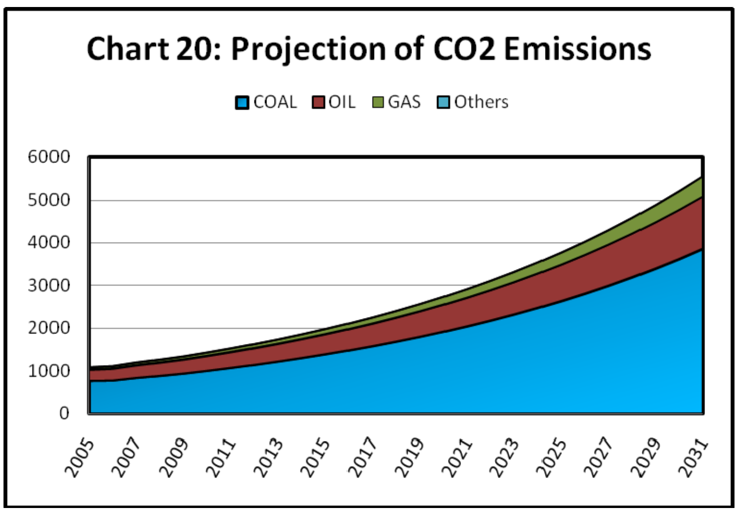

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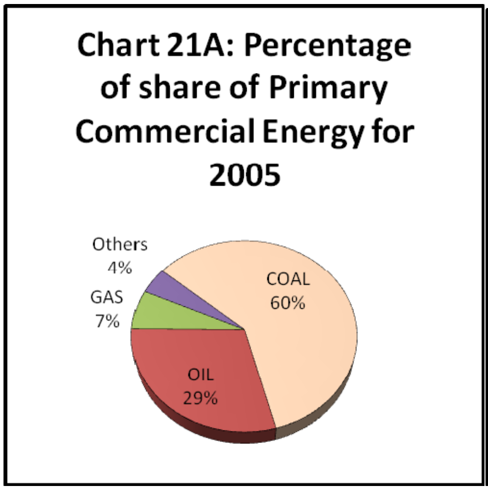

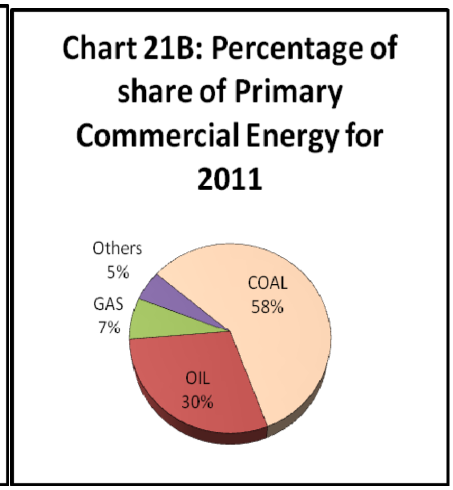

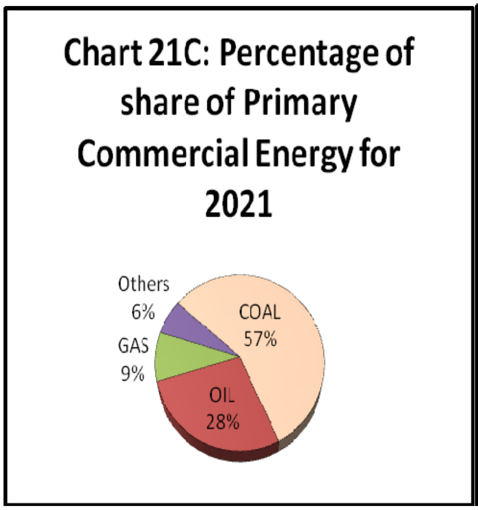

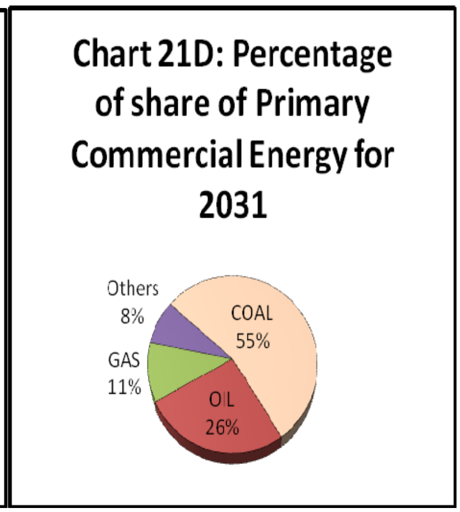

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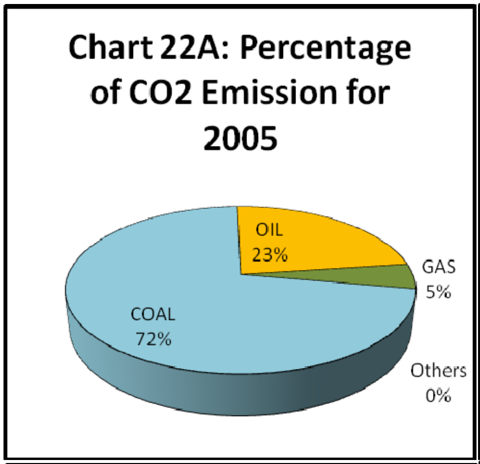


Chart 22A: Percentage of CO2 Emission for 2005

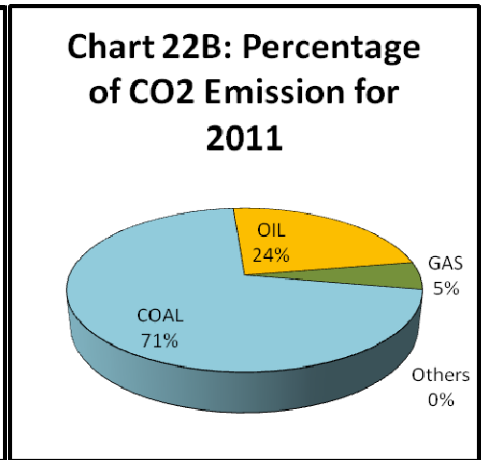


Chart 22B: Percentage of CO2 Emission for 2011

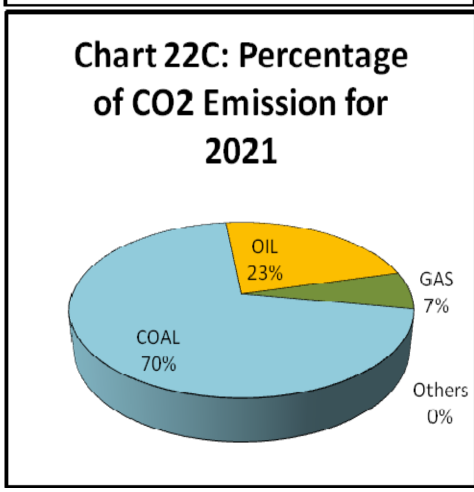


Chart 22C: Percentage of CO2 Emission for 2021

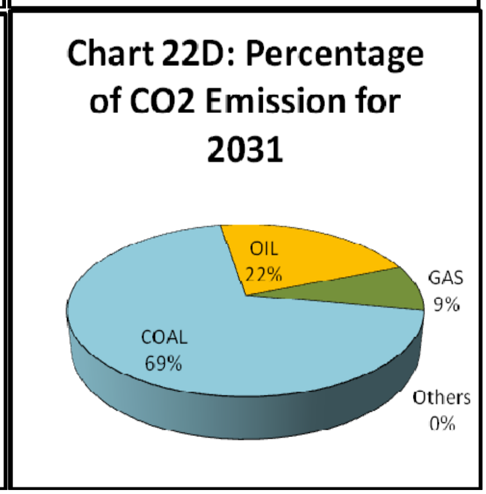


Chart 22D: Percentage of CO2 Emission for 2031

Source: Author

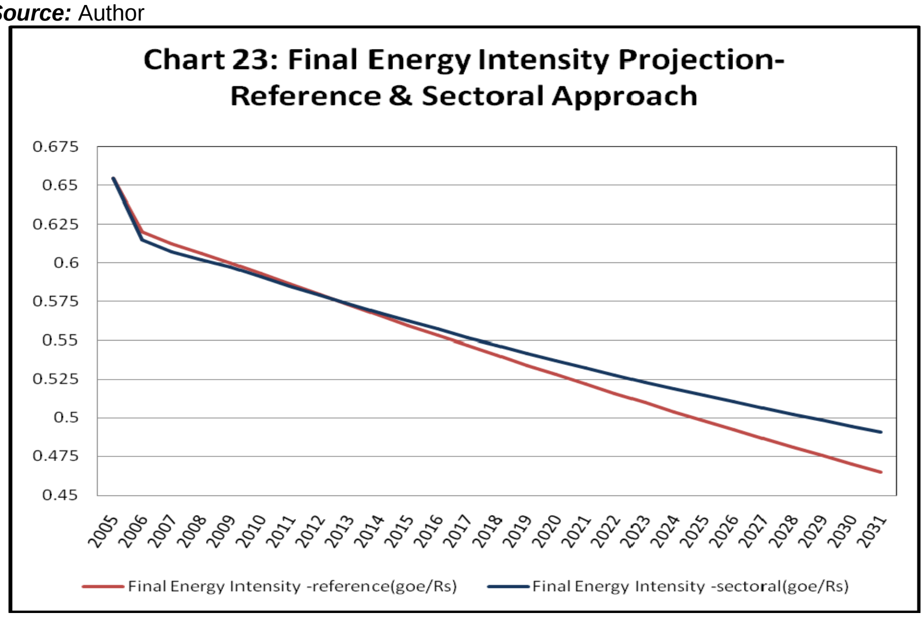
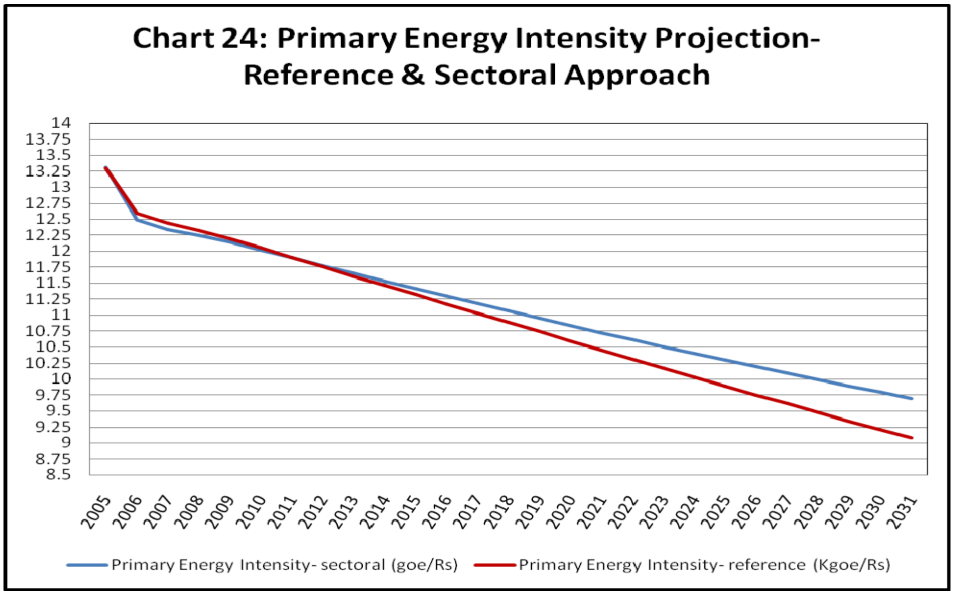
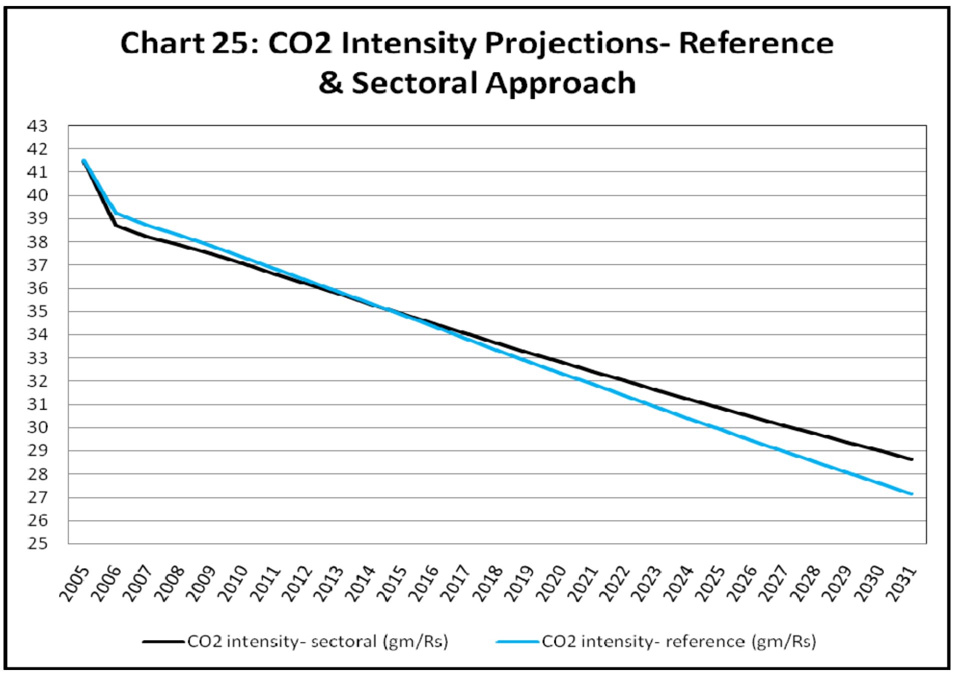


Chart 23: Final Energy Intensity Projection- Reference & Sectoral Approach

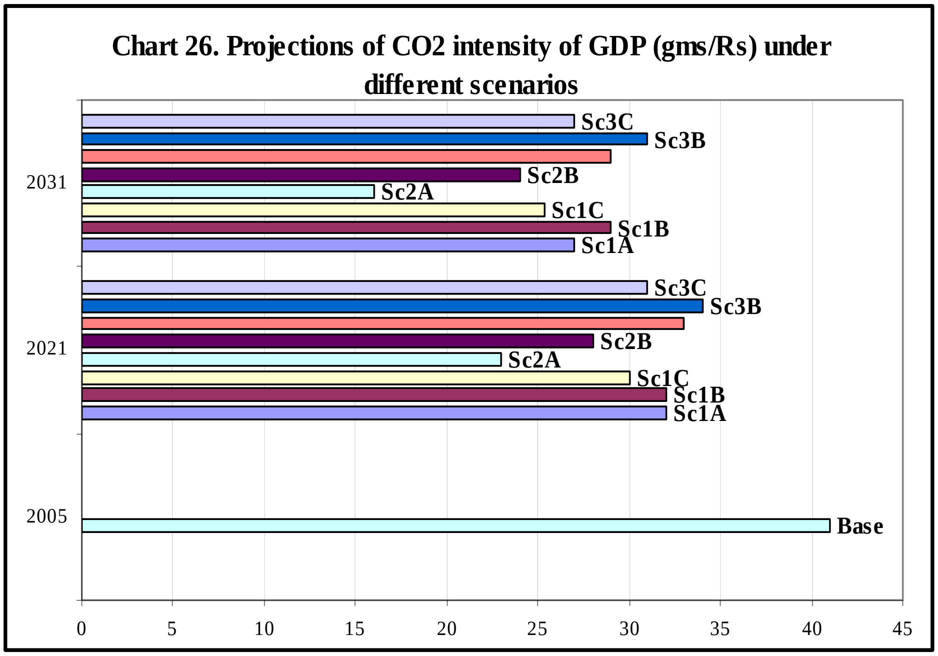
Source: Author



Source: Author



Source: Author



Source: Author

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