ECONOMIC REFORMS, ENERGY CONSUMPTION CHANGES AND CO2 EMISSIONS IN INDIA: A QUANTITATIVE ANALYSIS

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Energy based on fossil fuel consumption is very closely linked with environmental pollution in the form of CO2 emissions, a major element in global climate change. This paper analyses the changes in India's energy consumption and CO2 emissions during the five-year period following the 1991 reforms, i.e. 1991/92 to 1996/97. The authors extend the energy Input-Output Structural Decomposition Analysis (SDA) to identify changes in energy consumption during this period. Results indicate that India's energy consumption, which increased by 5.7 per cent a year in this period, was determined by a number of forces. The most significant role was played by the final demand structure followed by technical change and interaction between final demand structure and technical change. The CO2 emission trends reveal that the most dominating sectors have been petroleum products and electricity. The paper makes some broad policy recommendations for the future pattern of energy use in India.

Faced with rising inflation and a balance of payments crisis in mid-1991 the Government of India introduced a fairly comprehensive policy reform package, comprising currency devaluation, deregulation, de-licensing and privatization of the public sector. The Government of India also initiated new strategies for the energy sector in tune with the economic reforms in mid-1991. The energy strategies were: i) to initiate a shift from non-renewable sources of energy to renewable sources and to provide wider access for the rural and urban poor to adequate energy supplies at affordable costs, ii) to ensure efficiency in the use of energy in all production processes, iii) to review the use of all energy intensive materials and provide for their substitution by less energy intensive materials through Rand D, iv) to ensure efficiency in the use of equipment in the energy sector, especially in thermal and nuclear power generation through improved plant availability, v) to initiate measures aimed at reducing energy intensity in different sectors, through changes in technology and/or processes, vi) to

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optimise inter-fuel substitution, vii) to propagate renewable resources based on decentralised and environmentally benign non-conventional technologies and viii) to maximise the availability of indigenous energy resources such as oil, natural gas, coal and hydroelectric power, as well as non-conventional energy by way of bio-gas, solar energy and wind energy.

As is known, energy consumption based on fossil fuel consumption is closely linked with environmental pollution through CO2 emissions, which is contributing to global climate change. Global climate change has become one of the most important issues of recent times. The CO2 emissions from fossil fuel combustion have been identified as the single most significant source of GHG (green house gas) emissions into the atmosphere from human activities. In the global context, a comparison of the CO2 emissions from India with the global total indicates that the total Indian contribution from various sources is about 2.2 per cent of the global emissions. The emissions of CO2 in India are of the order of 1191 tgc (teragram, or 1 million, metric tons of carbon). The energy sector is the largest contributor to GHG emissions in India. A large amount of CO2 is emitted from the combustion of fossil fuels in India. Of these, coal accounts for nearly 70 per cent and oil for 26 per cent, while the rest is from natural gas. Steel plants, thermal power plants, the cement industry and railways are the major industrial consumers of coal.

Considering the above energy problems and aspects of environmental pollution, especially of CO2 emissions, a detailed quantitative analysis of energy consumption changes and of the resultant CO2 emissions is called for. The object of this paper is to analyze energy consumption changes and CO2 emissions in India during the period 1991-92 to 1996-97 and to draw relevant policy conclusions from the analysis.

As a first step in this exercise a Structural Decomposition Analysis for energy consumption changes is specified. It is an ideal technique to study "over-period" changes. Similar attempts have been made by Rose and Chen (1991) for Taiwan Province of China, Lin and Polenske (1995) for China, Han and Lakshmanan (1994) for Japan, and Wier (1998) for Denmark. For CO2 intensities we have used an input-output technique. The methodology for relating input-output activity to the natural environment in an input-output framework is familiar and popular for environmental studies. Numerous studies have dealt with energy and environmental analysis by applying the input-output method. Among them Leontief and Ford (1972) for the U.S., Breuil (1992) for France, Gay and Proops (1993) for the U.K., Hayami and others (1993) for Japan, Lin (1998) for China, Chang and Lin (1998) for Taiwan Province of China, Zhang and Folmer (1998) for Germany should be mentioned. Sengupta (1992), Dash and Saxena (1995), Majumdar and Parikh (1995), Chaturvedi (1997), Gupta and others (1997), Mukhopadhyay and Chakraborty (1999, 2000), Mukhopadhyay (2000, 2001) have studied the problems of the energy sector in India.

However, these works have not analysed quantitatively the contribution of the different causative factors, for example the role of technology, exports, imports, household consumption and Government consumption in changes in energy consumption changes during the period under study. This paper will accordingly make an attempt to understand the changing pattern of energy consumption in the Indian economy after reforms in the early 1990s and the various factors responsible for these changes. It will make estimates of CO_2 emissions and its intensities based on a multi-sectoral framework. The paper is organized as follows: the theoretical model adopted for energy consumption changes is outlined in section 1. The data and empirical results are presented in section II. Section III presents the methodology and results for CO_2 emissions and intensities. Section IV concludes the paper with some broad policy recommendations.

I. THE MODEL

We start our model formulation from a static monetary input-output model. Mathematically, the structure of the input-output model can be expressed as:

$$X = Ax + Y \qquad \text{..........} \quad (1)$$

The solution of (1) gives

$$X = (I - A)^{-1} Y \qquad \text{..........} \quad (2)$$

Where $(I - A)^{-1}$ is the matrix of total input requirements. For an energy input-output model, the monetary flows in the energy rows in equation (2) are replaced with the physical flows of energy to construct the energy flows accounting identity, which conforms to the energy balance condition.

We apply a "hybrid method". This method always conforms to energy conservation conditions.

In equation (2), X is a hybrid unit total output vector (nx1) in which the outputs of energy sectors are measured in million tons of coal replacement (MTCR), while the outputs of other sectors are measured in million rupees (M.RS). Y is a hybrid unit final demand vector (nx1), A is a hybrid unit technical coefficient matrix (nxn), I is an identity matrix (nxn).

Next, we develop a Structural Decomposition Analysis (SDA) in this model, which involves analysis of economic changes by means of a set of comparative static adjustments of key parameters of Input-Output tables.

Now the energy balance equation of an economy can be formed as:

$$EX = E\,(I - A)^{-1}\, Y \qquad \text{..........} \quad (3)$$

Where E is a selective energy matrix (nxn), which is a diagonal matrix composed of ones and zeros, with ones appearing in the diagonal locations that correspond to energy sectors and all the other elements of the matrix being zeros.

Equation (3) is still under the assumption that energy consumption is entirely supplied through domestic production. However, energy imports constitute a significant portion of total energy consumption. Conceptually, imports are excluded from GDP, but energy imports are consumed in the economy and energy exports and changes in stocks are excluded from the economy. Therefore, the total energy consumption of an open economy should be the total energy equivalence of domestically produced energy plus energy contained in energy imports minus energy contained in energy exports and energy contained in changes in stocks.

Now, adding energy imports and subtracting energy exports and changes in stocks, equation (3) will be

$$EX + Em - Eu - Ew = E\,(I - A)^{-1}Y + Em - Eu - Ew = e \qquad \text{.......... (4)}$$

e is the vector (nx1) of total energy consumption in the economy;
Em is the energy imports vector (nx1) whose elements are the actual imports for energy sector and zero for the other sectors;
Eu is the energy export vector (nx1) whose elements are the actual exports for the energy sector and zero for the other sectors;
Ew is the energy change in stock vector (nx1) whose elements are the actual change in stock for the energy sector and zero for the other sectors.

The new final demand can be written as

$$y' = Y + m - u - w$$
$$\text{or } y' - m + u + w = Y$$

Therefore, using $F = (I - A)^{-1}$, equation (4) would be

$$\begin{aligned} e &= EF\,(y' - m + u + w) + Em - Eu - Ew \\ &= EFy' - EFm + EFu + EFw + Em - Eu - Ew \\ &= EFy' - E\,(F - I)m + E\,(F - I)\,u + E\,(F - I)w \qquad \text{.......... (5)} \end{aligned}$$

A change in the energy consumption of an economy between any two years (year o and year t) can be expressed as:

$$\Delta e = e_t - e_o$$

Substituting equation (5), we obtain

$$\begin{aligned} \Delta e \;=\; & EF_t\, y_t' - E\,(F_t - I)m_t + E\,(F_t - I)u_t + E\,(F_t - I)w_t - [EF_o\, y_o' - E\,(F_o - I)m_o \\ & + E\,(F_o - I)u_o + E\,(F_o - I)w_o] \qquad \text{.......... (6)} \end{aligned}$$

From equation (6), we have finally

$$\Delta e = E(F_t - F_o)y_o + EF_o(y_t' - y_o') + E(F_t - F_o)(y_t - y_o) - E(F_o - I)(m_t - m_o) + E(F_o - I)(u_t - u_o) + E(F_o - I)(w_t - w_o) \qquad \text{..........} \quad (7)$$

The first term on the right-hand side of equation (7) is clearly the effect of technical change on energy consumption in an economy. The second term signifies the effect of change in the new final demand, which includes energy imports but excludes exports and changes in stocks. The third term is the interaction between change in technologies and change in the new final demand. The fourth term is defined as the effect of change in the fuel mix of energy imports. The fifth and sixth terms clarify the effect of change in the fuel mix of energy exports and energy change in stock.

(a) Expansion of the first term of equation (7)

Let us assume that changes in energy use technology and changes in non-energy – use technology within each sector are separable. The effect of technical changes can be further decomposed into three components: i) the effect of technical change on energy consumption, ii) the effect of technical change in non-energy consumption and iii) the effect of interaction between the two using a row replacing method (Han and Lakshmanan, 1994). It implies that the energy rows of the technical coefficient matrix change while keeping the non-energy rows unchanged, and keeping the energy rows of the technical coefficient matrix unchanged, while the non-energy rows of the technical coefficient matrix change. It can be symbolized as $A(e_t . n_o)$ which is a hypothetical technical coefficient matrix with new energy input coefficient rows (i.e. for period t) and old or base period non-energy input coefficient rows (i.e. for period o). Similarly, $A(e_o\, n_t)$ is a hypothetical technical coefficient matrix with old or base period energy input coefficient rows and new or current period non-energy input coefficient rows.

According to our previous formulation, we have

$$F(e_t\, n_o) = [I - A(e_t\, n_o)]^{-1}$$

$$F(e_o\, n_t) = [I - A(e_o\, n_t)]^{-1}$$

The effect of technical changes, i.e. the first term on the right-hand side of equation (7), can be expressed as

$$\begin{aligned} & E(F_t - F_o)y_o \\ = \; & E[F_t - F(e_t\, n_o) + F(e_t\, n_o) - F(e_o\, n_t) + F(e_o\, n_t) - F_o - F_o + F_o]y_o \\ = \; & E[\{F(e_t\, n_o) - F_o\} + \{F(e_o\, n_t) - F_o\} + \{F_t - F(e_o\, n_t)\} - \{F(e_t\, n_o) - F_o\}]y_o \end{aligned}$$

$$= E [F (e_t n_o) - F_o]y_o + E[F(e_o n_t) - F_o]y_o + E [(F_t - F (e_o n_t) - (F (e_t n_o) - F_o)]y_o \quad \text{..........} \quad (8)$$

The first term on the right-hand side indicates the effect of changes in energy input coefficient; the second term implies the effect of changes in the non-energy input coefficient; and the third term defines the effect of interaction between two kinds of change.

All terms of equation (8) bear clear economic meanings. The interaction term $E [F_t - F (e_o n_t)]y_o$ is the effect of changes in energy input coefficients under the new or current non-energy input coefficient environment. Thus, it includes both the pure effect of changes in energy input coefficients, i.e.

$E (F (e_t n_o) - F_o)y_o$, and the interaction between changes in non-energy input coefficients and changes in energy input coefficients. Subtracting the pure effect of changes in energy coefficients from the interaction term, we get the effect of interaction between the two kinds of change, i.e. the effect when the two kinds of change happen simultaneously.

(b) Expansion of the second term of equation (7)

The second term of equation (7) identifies the new final demand which can be further decomposed into domestic final demand (including private consumption, public consumption, gross final capital formulation), exports, imports and changes in stocks.

Public consumption plus private consumption and gross final capital formulation are contained in the vector y^d, which represents domestic final demand (nx1).

y^x represents non-energy exports (nx1) whose elements for energy sectors are zero.
y^m represents non-energy imports (nx1) whose elements for energy sectors are zero.
y^c represents non-energy change in stock (nx1) whose elements for energy sectors are zero.

Let p be the row summation vector (1xn) that consists entirely of ones and define

$\lambda^d = py^d{}_t/py^d{}_o$, $\lambda^x = py^x{}_t/py^x{}_o$

$\lambda^m = py^m{}_t/py^m{}_o$, and $\lambda^c = py^c{}_t/py^c{}_o$

Considering the preceding statement, final demand, as given by the second term in equation (7), can be restructured as

$$EF_o\,(y_t' - y_o')$$
$$= EF_o\,[(y^d_t + y^x_t - y^m_t + y^c_t) - (y^d_o + y^x_o - y^m_o + y^c_o)]$$

By putting the above elements and after derivation we get

$$= EF_o\,[(y^d_t - \lambda^d y^d_o) + (y^x_t - \lambda^x y^x_o) - (y^m_t - \lambda^m y^m_o) + (y^c_t - \lambda^c y^c_o) + \lambda^d y^d_o + \lambda^x y^x_o - \lambda^m y^m_o + \lambda^c y^c_o - (y^d_o + y^x_o - y^m_o + y^c_o)] \quad (9)$$

The term $EF_o\,(y^d_t - \lambda^d y^d_o)$ gives the effects of changes in domestic demand; $EF_o\,(y^x_t - \lambda^x y^x_o)$ gives the effects of changes in the structure of non-energy exports; $EF_o\,(y^m_t - \lambda^m y^m_o)$ gives the effects of changes in the structure of non-energy imports $EF_o\,(y^c_t - \lambda^c y^c_o)$ gives the effects of changes in the structure of non-energy change in stock; and

$EF_o\,[(\lambda^d y^d_o + \lambda^x y^x_o - \lambda^m y^m_o + \lambda^c y^c_o) - (y^d_o + y^x_o - y^m_o + y^c_o)]$ gives the effects of changes in the macro structure of final demand.

Here, the macro structure of final demand refers to the changes in final demand components.

Finally, we calculate the contribution of an individual product or product group k from the structure of final demand of equation (9) as

$$\Delta e_{y,\,k} = EF_o\,(y'_t - y'_o)$$

where $\Delta e_{y,\,k}$ is the matrix of energy consumption changes associated with each product k and y'_t and y'_o denote the diagonal matrices of the final demand vectors in periods t and o. It also estimates how much of energy use resulting from final demand shifts comes directly from the purchases of energy product (k) and how much of it comes indirectly from the purchase of non-energy products.

II. DATA AND EMPIRICAL RESULTS

To implement the model and conduct the Structural Decomposition Analysis of energy consumption changes and to calculate the CO2 emission trend we have used input-output data prepared by the Government of India, Planning Commission (1995), price indices from the NAS (National Accounts Statistics), and energy flow data published and information on CO2 emissions from the relevant national and international agencies.

Results and Discussion

Energy consumption changes and sources of change

Energy consumption and the causes of changes are presented in table 1. Table 1 records the changes in absolute amounts during the period 1991/92 to 1996/97. It is observed from table 1 that during this period India's total commercial energy consumption increased by 278.65 mtcr (table 1) or 5.7 per cent p.a. Although the coal sector performed reasonably well in 1991/92 to 1996/97, some major weaknesses have also emerged. It is observed that during this period coal and lignite consumption increased by 58 mtcr (table 1) or 4.83 per cent p.a. from 1991-92 to 1996-97, oil and gas sector also recorded an increase at 5.5 per cent p.a., while electricity consumption was the highest i.e. 7 per cent p.a during this period an increase by 79 mtcr.

In fact, electricity, gas and water supply have decelerated sharply from an average growth of 9.5 per cent in the Seventh Plan to 7.4 per cent in the Eighth Plan period. Effective reforms in all these areas have been limited. The rate of growth of power generating capacity has declined during 1996/97. During the first half of the 1990's oil production increased at an annual rate of less than 1 per cent p.a. The 19 per cent increase in production in 1994/95 arrested the declining trend. The shortfalls are on account of uncertain reservoir behaviour in the Bombay offshore basin, problems in the north-eastern region and delays in implementation of joint venture projects. On the consumption front it reflects a moderate increment i.e. 5.5 per cent p.a. or 141.65 mtcr (table 1) between 1991/92 and 1996/97. Natural gas consumption peaked gradually during the period to 6 per cent p.a. Out of it, 56 per cent of gas was utilized for energy purposes, mainly for power generation, and 44 per cent was used as feedstock, mainly for fertilizer plants. More remarkable change occurred between 1995/96 and 1996/97: consumption of crude oil picked up at 75.4 mt; being 10.8 per cent higher than in 1994/95. This spurt in growth matches with a pick-up in industrial activity during 1995/96. During 1991/92 to 1996/97, the growth of hsd (high speed diesel) increased at a rate of 7.3 per cent p.a. The increase in coal consumption in the power sector has been mainly due to improved PLF (plant load factor) performance of the existing plants.

Sources of change

Six different factors can be identified which contributed to the change in energy use: i) technical change, ii) change in the final demand structure, iii) change in energy imports, iv) change in energy exports, v) change in stocks and vi) interaction between technical change and the structure of final demand.

Table 1. Structural decomposition analysis of energy consumption changes in India from 1991-92 to 1996-97 (Mtcr)

	Coal and Lignite	*Cr. oil and Natural Gas*	*Electricity*	*Total*
Total Energy Consumption Change	58.000	141.650	79.000	278.650
Technical change	-39.000	-41.860	-5.660	-86.520
Changes in energy input coefficient	-56.000	-221.000	-19.440	-296.900
Changes in non-energy input coefficient	22.570	215.740	15.390	253.700
Interaction term	-5.370	-35.870	-1.600	-42.840
Changes in final dd structure	109.650	139.440	88.350	337.440
Effects of changes in str of dom. dd	36.940	83.160	18.440	138.540
Effects of changes in str of non-energy export	0.690	9.470	0.930	11.090
Non-energy import	-2.180	-2.500	-1.750	-6.430
Non-energy changes in stock	2.970	-1.300	2.350	4.020
Macro structure of final dd	75.740	49.890	68.930	194.560
Sector wise contribution				
Coal and lignite	37.700	2.050	0.670	40.420
Crude oil and natural gas	0.000	0.090	0.000	0.090
Electricity	13.600	8.260	33.230	55.090
Agriculture	7.700	83.940	8.260	99.900
Mining and quarrying	-2.690	-26.530	-4.930	-34.150
Sugar	0.350	3.070	0.290	3.710
Food and beverages	3.930	22.170	2.810	28.910
Textile and textile products	13.380	54.110	15.430	82.920
Wood and wood products	0.040	0.355	0.040	0.435
Paper and paper products	-0.040	-0.090	-0.020	-0.153
Leather and leather products	2.140	13.700	2.090	17.930
Rubber and plastic products	0.700	5.100	0.770	6.570
Petroleum products	-5.040	-284.400	-0.880	-290.300
Fertilizer	-1.250	-12.630	-1.040	-14.920
Chemical and chemical products	2.580	20.490	2.840	25.910
Cement	-0.750	-0.800	-0.320	-1.870
Other metallic and mineral products	0.910	3.160	0.250	4.320
Iron and steel	-0.100	-0.290	-0.040	-0.430
Basic metal products and machinery	8.420	38.070	6.880	53.370
Construction	12.360	54.170	8.960	75.490
Transport services	5.310	101.500	3.280	110.090
Trade and other services	10.340	54.530	9.720	74.590
Changes in energy import	-0.220	-3.440	-0.280	-3.940
Changes in energy export	-0.040	-0.060	-0.030	-0.130
Changes in energy changes in stock	-0.260	-1.050	-0.330	-1.640
Interaction of tech ch and final dd structure	-12.270	49.990	-3.320	34.400

(i) Technical change

During 1991/92 to 1996/97 moderate technical changes took place to reduce energy consumption. Though the percentage impact was very little small, it was spearheaded by three sectors (coal, crude oil, and electricity). The contribution in this respect was 39 mtcr or 3.25 per cent in the case of coal, 41.86 mtcr or 1.64 per cent annually in the case of crude oil and natural gas, but electricity shared a small amount i.e. 5.66 mtcr or 0.44 per cent p.a.

Thus, it would appear that the coal sector has improved technically more than electricity. The efficient technology in the coal sector is hidden under exploration, exploitation, and benefication for improving the quality and efficient utilization of coal. New mining technologies have been introduced during the reform period with a fair degree of success.

The slight technical improvement in the case of oil and natural gas has been possible due to the minimization of the flaring of the associated gas, the higher off-take of natural gas and the minimization of the risks of exploration both by an optimal mix of exploration in different basins in India and vigorous measures for energy conservation and inter-fuel substitution.

But, in the case of electricity technical change did not occur as in coal and oil and gas. Agricultural pump sets increased at the rate of 7.7 per cent p.a. and electricity consumed in the agricultural sector increased at the rate of 13.3 per cent p.a. Electricity consumed in agricultural pump sets installed has increased from an average of 3,672 kwh to 7,880 kwh in the five years to 1996/97. This has happened due to energy inefficiency. The effect of technical change can be classified as (i) change in energy input coefficient, (ii) change in non-energy input coefficient and (iii) interaction between the previous two.

Changes in energy input coefficient reduced energy use by 296.90 mtcr (table 1) or 6.09 per cent annually. The major contribution was by crude oil and natural gas in this respect, by 221 mtcr or 8.7 per cent p.a. However, changes in the non-energy portion of production technology increased energy consumption and reduced energy savings by 253.7 mtcr or 5.2 per cent annually. The changes in non-energy input coefficient also have an energy impact. Here also the major portion is shared by crude oil and natural gas. This increased energy consumption by 215.74 mtcr or 8.47 per cent p.a.

To minimize flaring the Government had undertaken a major gas flaring reduction programme. During the period 1991/92 to 1996/97 both creation of capacity and its utilisation improved substantially. Due to technical improvement in capacity utilisation the growth rate of crude throughput also performed well at 58.6 per cent in 1995/96 which was 4 per cent higher than 1991/92.

The non-energy input coefficient in case of electricity sector increased energy consumption by 15.39 mtcr (table 1). The flat tariff structure and high level of subsidy provided by the Government and free electricity to farmers has permitted the inefficient use of electricity. Over-used and ill-maintained pump sets cause wasteful consumption of electricity and also of water. Efficiency in the use of electricity declined in the production of newsprint, cotton and blended yarn, polyster-filament yarn, aluminium and steel. But the interaction between the energy and non-energy coefficients reduced energy use by 42.84 mtcr (table 1) or 0.08 per cent p.a. with the crude oil sector contributing more.

Changes in energy input coefficients and interactions both worked to drive down the energy consumption of the Indian economy, while the non-energy input coefficient changes have totally offset the negative effect of both energy input coefficient changes and interaction that increases energy use. The opposite effects of these changes imply that one major characteristic of India's technical change in this period was the substitution of material inputs for energy inputs. Actually, material inputs or non-energy inputs embody a large quantity of energy. So smaller energy input requirement per unit of output worked directly and indirectly to reduce the total energy use, while bigger non-energy material input requirement per unit of output worked indirectly to increase total energy use through increased output levels.

(ii) Changes in final demand structure

These have been an important factor behind the increase in energy consumption during 1991/92 to 1996/97. The share of individual sectors are 109.65 mtcr or 9.13 per cent p.a. for coal, 139.44 mtcr or 5.47 per cent for crude oil and natural gas and 88.35 mtcr or 7.85 per cent p.a. for electricity in this respect. The demand for coal during 1991/92 to 1996/97 from the various coal consuming sectors has shown a sharp and unanticipated increase. The demand for the power sector alone is 210 million tons of coal in the year 1996/97 as against 185.30 million tons indicated for the year at the beginning of the Eighth Five Year Plan and 194 million tons demanded at the mid-term appraisal carried out in September 1994. At the same time, as a result of various constraints, including those of finance, land acquisition and transportation, the coal companies have indicated a domestic production of only 288.65 million tons for 1996/97. This implies an increase of 6.8 per cent over actual production in 1995/96.

On the electricity front, the pattern of utilisation of electricity from public utilities has undergone a small change between 1992/93 and 1996/97. The share of the domestic sector has increased from 19.37 per cent to 23.52 per cent. The shares of commercial and miscellaneous sectors have increased very sharply from 10.28 per cent in 1992/93 to 13.38 per cent in 1996/97. The demand for electricity in the household sector is expanding rapidly as the pressure of urbanisation continues to increase and the availability of consumer durables also continues to expand. It is estimated that 40 per cent of the total electricity consumed in the household sector is used for lighting. Fans consumed another 31 per cent of the electricity used while refrigerators, air conditioners and televisions account for about 28 per cent of the electricity consumed by the household sector during our study period. Nearly 50 per cent of the total electricity consumed in major power consuming industries was from captive power plants in 1994/95. Several of the relatively newer and faster growing industries, such as gems and jewellery, garments and electronics, are far more energy intensive; on the other hand, electricity consumption in fertilizer and pesticides and casting and forging has declined in absolute terms during the study period.

If we separate the final demand structure under five heads like macro structure of final demand, effects of changes in domestic demand, effects of changes in the structure of non-energy exports, non-energy imports, non-energy change in stocks, we observe that the lions share goes to macro structure of final demand i.e. 194.56 mtcr or 3.99 per cent annually. The positive effect of change in the structure of final domestic demand on energy consumption has far reaching significance as the growth of the Indian economy is becoming more domestic demand driven. In the case of coal, macro structure of final demand is greater (75.74 mtcr) than the structure of domestic demand (36.94 mtcr). But in the case of crude oil, the opposite consequences happened, i.e. 83.16 mtcr in domestic demand and 49.89 in macro structure of final demand. The electricity sector showed a wide gap between the structure of domestic demand (18.44 mtcr) and macro structure of final demand (68.93 mtcr). The rapid pace of urbanisation and diverse urban growth patterns involve many structural changes in the economy which have major implications for energy use. Out of the remaining three heads, the non-energy import sector slightly reduced the energy use of the economy during our study period i.e. 6.43 mtcr.

The sector-wise contribution resulting from final demand structure shows that the contribution made by the energy product is 95.60 mtcr out of 337.44 mtcr and non-energy products is 241.84 mtcr out of 337.44 mtcr during 1991/92 to 1996/97. Coal and electricity have a major share of energy products. So, the intensity of these sectors has been rising sharply mainly on account of higher coal consumption by the power sector and higher electricity consumption by the industrial sector, i.e. 33.23 mtcr. During the Eighth Plan period 40 per cent of electricity was consumed by the energy sector itself and the remaining 60 per cent was consumed by energy intensive industries like textiles (15.43 mtcr), agriculture (8.26 mtcr), basic metals, metal products and machinery (6.88 mtcr), construction sector (8.965 mtcr), trade and other (9.72 mtcr) and transport. The consumption of electricity per unit of product in the above industries is much higher than that in developed countries (Teddy, 1995/96). Part of it reflects the dated vintage of the production processes in use.

Consumption of kerosene increased at an annual rate of 1.6 per cent during the period 1991/92 to 1996/97. Diesel consumption in the country has almost doubled in the 10 years from 1986/87 to 1996/97. It had a growth of 7.3 per cent p.a. during this period. During our study period, consumption of lubes and greases grew by almost 5 per cent p.a. One major agricultural operation is irrigation, which is largely performed by using diesel and electric energy. The number of electric and diesel pumps has increased to 10.5 million and 4.9 million respectively by 1993/94. Power consumption in the agricultural sector expanded at the rate of 12-13 per cent p.a. during 1971 to 1996. As a result this sector's share in the total power consumed has increased steadily from 10 per cent in 1970/71 to nearly 30 per cent in 1996/97. The increase in power consumption in the agricultural sector is the result of an increase in irrigation pump sets in use and a sharp increase in the usage hours of the pump sets.

The industrial sector relies only partly on the utilities for its power requirements. Nearly 48 per cent of the total electricity consumed in major power consuming industries was from captive power plants. The findings show that product groups like textile products, petroleum products, chemicals, basic metals etc. are the leading sectors that have increased energy consumption. Chemicals, construction, transport, trade, basic metals, metal products and textile machinery, increased the consumption of crude petroleum. The share of commercial energy consumed in the transport sector in the total commercial energy consumed has increased steadily. Besides, the consumption of oil in the transport sector has gradually increased mainly because of greater use of private modes of transport. Also oil has gradually replaced coal as a fuel. This is evident from the declining share of coal from about 30 per cent in 1970/71 to 5 per cent in 1994/95, whereas the share of oil increased from 30 per cent to 95 per cent in the same period. This change is attributed to greater dependence on road transport, and shift from steam traction to diesel and electric traction in the railways.

(iii) Change in energy imports

This covers the limited amount of 3.94 mtcr (table 1) in the period 1991/92 to 1996/97. The major portion was on account of rise in domestic crude oil and natural gas production.

(iv) Change in energy exports

During the period 1991/92 to 1996/97 energy consumption increased slightly i.e. 0.13 mtcr. India is not a major exporter of coal. However, coal exports meet the demand from neighbouring countries. Coal exports are destined to Bangladesh, Nepal, and Bhutan. The quantity of coal exported during 1995/96 was about 0.098 mt.

(v) Change in energy stocks

This behaved in a similar fashion to imports. It decreased energy consumption by 1.64 mtcr during 1991/92 to 1996/97.

(vi) Interaction between technical change and change in final demand structure

In the period 1991/92 to 1996/97 this interaction has increased energy consumption by 34.40 mtcr. The lion's share of it goes to crude petroleum by 49.99 mtcr or 1.96 per cent p.a., but two other sectors i.e. coal and electricity shared very little (12.27 mtcr and 3.32 mtcr respectively). Thus, the reform period shows that final demand expansion increased India's energy consumption by 6.9 per cent p.a. while, on the other hand, production technology changes reduced energy consumption by 1.77 per cent p.a. The consumption of energy produces consequences for the environment. The commercial energy activities cause air pollution. This includes the use of fossil fuels (coal and oil), industrial processes etc. The air pollutants are mainly CO2 emissions. Before any alternative strategies for energy consumption can be advanced it is necessary first to try to calculate the level of CO2 emissions and their intensity in the next section.

III. THE METHODOLOGY AND RESULTS OF CO2 EMISSIONS

In this section an attempt has been made to estimate carbon dioxide emissions and their intensities in major energy consuming industries with the help of an input-output model. In reality, CO2 is released mainly from fossil fuel combustion and from bio-mass combustion. The sources of fossil fuel combustion are coal, oil and gas. Here we consider fossil fuel combustion only. The CO2 emissions from fossil fuel combustion have been estimated by the following IPCC (Intergovernmental Panel on Climate Change) guideline, wherein total CO2 emissions = (actual fuel consumption) * (carbon emission factor) * (fraction of carbon oxidized) * (molecular weight ratio of CO2 is to carbon i.e. 44/12 or 3.66).

For an analysis of CO2 emissions we need to extend the above conventional input-output framework in one important respect i.e. we have to compute the amount of CO2 emission that takes place in various activities. We apply the fuel specific carbon emission factors to the row vector of the fossil fuel sector of the respective input-output table to estimate the total CO2 emitted by the coal and oil sectors. We use an emission factor of 0.55 (mt of CO2)/mt for coal and 0.79 (mt of CO2)/mt for crude oil and 0.67 mt of CO2/m.c.m for natural gas to arrive at carbon emissions by different sectors due to coal and oil and natural gas separately. The values of the fraction of carbon oxidized for the fuels are 0.98 for coal and lignite, and 0.99 for crude oil and natural gas. We then follow the normal convention of measurement of carbon dioxide in carbon equivalent units.

For conversion to CO2 units the carbon emission figures are multiplied by 3.66. The estimated figures are displayed in tables 2 and 3. The total quantity of CO2 emitted owing to burning of fossil fuel inputs used by various production sectors and final demand is shown in table 3. On the basis of the above estimated figure we calculate the direct carbon dioxide emission coefficient and total (direct and indirect) carbon dioxide emission coefficient.

Now C = C (j)---- (3*) is a vector of fossil fuel emission coefficients representing the volume of CO2 emissions per unit of output in different sectors. That is when the sectoral volume of CO2 emissions is divided by sectoral output, which then gives us the direct CO2 emission coefficient. This is shown in table 4. The direct and indirect carbon emission coefficient of sector j can be defined as $\Sigma C_j r_{ij}$, where r_{ij} is the (i, j) th element of the matrix $(I - A)^{-1}$. The direct and indirect CO2 of a sector is defined as emission caused by the production vector needed to support final demand in that sector. The next part reports the findings.

Findings

Table 2. CO2 emissions (In mt of CO2) in India from 1991/92 to 1996/97 (fossil fuel combustion)

	Coal	*Oil and gas*	*Total*
1991-92	473.05	110.59	583.80
1996-97	595.20	172.62	767.82

Table 3 displays estimated CO2 emissions by sectors for the years 1991/92 and 1996/97 respectively. During 1991/92 to 1996/97 the rate of growth of emissions has been observed at 6.29 per cent. We can observe from table 2 that coal combustion releases more CO2 than oil. The emission released from the coal sector is rather high thus affecting the overall CO2 emissions. During the early years of reform energy consumption grew at 5.6 per cent p.a. and the released CO2 was 6.29 per cent. This fact suggests that during this period the consumption of coal (4.8 per cent) and oil (5.5 per cent) had been reduced. The high emission was primarily due to the high rate of energy consumption itself. Out of the three fossil fuel sectors, electricity contributes a major part and its contribution gradually rises from 171.15 mt of CO2 in 1991/92 to 214.60 mt of CO2 in 1996/97 (table 3). The petroleum product sector emits CO2 at a fairly high level i.e. 222.98 mt of CO2 in 1991/92 rising in 1996/97 to 250.89 mt of CO2.

As we have observed from our study the electricity sector, which is the major user of coal in India, accounts for more than 25 per cent of total emissions in the country throughout the period. In the same manner, petroleum products, which are the major user of crude oil, account for more than 40 per cent of total emissions in the country throughout the period. Iron and steel, transport, textiles, other metallic mineral products, basic metals, metal products and machinery are the top sources of CO2 emissions compared to other non-energy activities.

Table 3. Estimated CO2 emissions in India during 1991-92 to 1996-97 by sectors (Mt of CO2)

Serial No.	*Sectors*	*1991-92*	*1996-97*
1	Coal and lignite	2.34	2.16
2	Cr. oil and Natural Gas	0.00	0.00
3	Electricity	171.15	214.60
4	Agriculture	5.75	4.74
5	Mining and quarrying	0.04	0.05
6	Sugar	0.99	1.01
7	Food and beverages	15.77	16.89
8	Textile and textile products	24.53	25.53
9	Wood and wood products	0.32	0.35
10	Paper and paper products	10.53	10.86
11	Leather and leather products	0.57	1.07
12	Rubber and plastic products	0.94	1.15
13	Petroleum products	222.98	250.89
14	Fertilizer	12.21	14.89
15	Chemical and chemical products	6.90	9.22
16	Cement	18.25	17.68
17	Other metallic mineral products	16.87	18.55
18	Iron and steel	66.30	77.30
19	Basic metal, metal products and machinery	20.58	21.97
20	Construction	6.15	6.85
21	Transport	30.32	31.25
22	Trade and other services	22.32	19.08
23	Total	656.16	746.08
24	Total final	-72.36	21.74
25	Gross	583.80	767.82

The CO2 emissions from final demand (private consumption + Government consumption + investment demand + net export demand) gradually increased from -72 mt of CO2 in 1991/92 to 21 mt of CO2 in 1996/97 (table 3). Here the sign of final demand component is negative due to the high import amount of the crude oil sector. One positive aspect from the result of final demand shows that the imported amount has been gradually controlled. The study also reflects that the CO2 emissions in private consumption were highest during 1991/92 (108.60 mt of CO2).

We now turn to the direct and total CO2 emission coefficient as presented in table 4. The results contained in table 4 show that all the sectors show a more or less similar pattern in case of direct and total coefficients throughout the period. The total coefficient is higher in all sectors than the direct coefficient. However, some sectors deserve attention. The results reveal that electricity ranks the highest among all

Table 4. Direct and total CO2 emissions coefficient in India during 1991-92 to 1996-97 (Mt of CO2/mtcr)

Serial no.	*Sectors*	*1991-92 Direct*	*1996-97 Direct*	*199192 Total*	*1996-97 Total*
1	Coal and Lignite	0.00957	0.00731	0.07806	0.07870
2	Cr. Oil and Natural Gas	0.00000	0.00000	0.05346	0.05844
3	Electricity	0.82052	0.80731	1.41212	1.31151
4	Agriculture	0.00001	0.00001	0.00108	0.00104
5	Mining and Quarrying	0.00002	0.00001	0.00395	0.00516
6	Sugar	0.00005	0.00006	0.00098	0.00101
7	Food and beverages	0.00014	0.00024	0.00124	0.00141
8	Textile and textile products	0.00012	0.00008	0.00124	0.00133
9	Wood and wood products	0.00003	0.00002	0.00082	0.00078
10	Paper and paper products	0.00057	0.00042	0.00225	0.00204
11	Leather and leather products	0.00004	0.00002	0.00086	0.00080
12	Rubber and plastic products	0.00004	0.00003	0.00123	0.00122
13	Petroleum products	0.03668	0.02995	0.04191	0.03445
14	Fertilizer	0.00096	0.00083	0.00489	0.00375
15	Chemical and chemical products	0.00009	0.00016	0.00199	0.00230
16	Cement	0.00429	0.00275	0.00828	0.00678
17	Other metallic mineral products	0.00118	0.00137	0.00424	0.00465
18	Iron and steel	0.00133	0.00114	0.00581	0.00544
19	Basic metal, metal products and machinery	0.00005	0.00008	0.00151	0.00157
20	Construction	0.00000	0.00000	0.00241	0.00230
21	Transport	0.00022	0.00012	0.00834	0.00655
22	Trade and other services	0.00004	0.00002	0.00051	0.00046

sectors throughout the period. It can be seen that the total coefficient (direct and indirect) of the electricity sector in 1991/92 was 1.41 but that it dropped to 1.31 in 1996/97. In the case of coal, it is observed that it remains constant between 1991/92 and 1996/97 i.e. 0.078. A similar pattern has been reflected in the case of direct emissions. For crude oil the figure is a little higher. A rising trend is observed during 1991/92 to 1996-97 i.e. 0.058. Of the other sectors, petroleum products contribute somewhat higher than the other sectors. The transport sector was 0.0083 mt of CO2/mtcr in 1991/92 moving to 0.0065 mt of CO2/mtcr in 1996/97. The direct coefficient also shows a similar trend. The intensity of the cement sector gradually falls from 0.0082 to 0.0067. The performance regarding carbon intensities in the cement sector has really improved. It has occurred in conjunction with the installation of relatively expensive new technologies such as pre-calcining facilities, high efficiency roller mills and variable speed motors. Actually higher efficiency and improved technology lead to low intensity of carbon emission. The direct intensity of the construction sector is lowest among all sectors. This is because it does not make much use of fossil fuel based energy to construct a building or a road. However, the construction sector uses many energy intensive materials such as bricks, cement, iron and steel, aluminium glass and asbestos. Hence, the indirect part achieves prominence in this respect leading to high value of total intensity. These facts indicate that sectors like construction, textiles, trade, agriculture and transport emit CO2 at a fairly high level largely due to indirect effects.

Given the higher value of indirect coefficients and the larger volume of activity, the above sectors turn out to be the most responsible for CO2 emissions in India when they are viewed in terms of total (direct and indirect) emissions due to the magnitude of final demand in each sector.

IV. SUMMARY AND CONCLUSIONS

This paper has shown that India's energy consumption increased by 5.7 per cent p.a or 279.27 mtcr (table 1) from 1991/92 to 1996/97. Six different forces behind this increase have been identified. Among them the most significant role, as garnered from the empirical results, has been played by the structure of final demand, technical change and the interaction between the structure of final demand and technical change. The remaining forces had very little impact on energy consumption. The CO2 emission trends has revealed that the most dominating sectors are petroleum products and electricity. This phenomenon is due to the direct effect of crude oil and coal respectively. The next positions are occupied by the iron and steel and transport sectors respectively. Overall, CO2 emissions have risen gradually from 1991/92 to 1996/97. As far as the intensities are concerned, electricity contributes a major part. In actual fact, the increase in emissions is most strongly correlated with fuel consumption, which, in turn, is influenced by population growth and rising income levels.

So far as energy strategies are concerned, specifically strategies to conserve energy and to minimize CO2 emissions over time, India has not been able to develop any credible framework or policy approaches to meet such objectives. The strategies that have been adopted by the Government during the period 1991 to 1996 for reducing the consumption have not been successful. Though the 25 leading industries recorded significant energy savings and have received national awards for energy conservation in the year 1996 the performance of major sectors like transport and agriculture have not been successful in conserving energy.

Considering the above, it would be worthwhile to point out a few important issues that should get appropriate weightage in any future energy policy. These issues can be summarised as:

(i) The Government of India must adopt an overall policy that promotes the growth of less energy-intensive components of final demand.

(ii) The Government should develop energy conservation legislation to enforce punitive action under the law and to ensure stricter implementation.

In the latter context, it is suggested that much higher priority has to be given to the conservation of energy in national policy-making. This will play a significant role in alleviating the shortage of energy and in reducing environment pollution. The Government must take measures, such as publicity campaigns and differential taxes and subsidies, to promote energy conservation in the country. The enhancement of national consciousness in this regard and progress in the understanding of the underlying scientific and technological issues involved in energy conservation would promote rationalization and greater efficiency in energy consumption in the country.

In this connection it is recommended that efficiency and conservation of energy is also possible through inter-fuel substitution. Inter-fuel substitution can help to mitigate the problem of carbon emissions. Replacing high carbon coal and mid-range oil with lower carbon natural gas, or with zero carbon renewable and nuclear power can dramatically lower CO2 emissions. In the industrial sector substituting natural gas for coal is the most obvious shift. More specifically, in the case of electrification, the promotion of biomass-based power plants would be an appropriate policy option to mitigate CO2 emissions. The use of plant material as fuel and feedstock in place of fossil fuels can have a significant effect on the reduction of net CO2 emissions. Alcohol biomass fuels for transport have played a major role in Brazil (Goldenberg and others, 1993) and plantations in other countries, including India, could provide significant quantities of bio fuels (Hall and others, 1993).

Out of the fuel sector electricity emissions show the highest increase among energy sources suggesting that local electric plants should increase the share of non-fossil fuels and natural gas to reduce CO2 emissions in India. Thus pollution can be reduced or even prevented by the use of alternative energy sources. Some wind energy, small scale hydro and conversion of waste to energy are already competitive even with conventional sources of supply. A few other renewable technologies may be appropriate for India. Among these are solar hot water systems for meeting process heat requirements in industries, solar dryers, fuel cell technology and the application of hydrogen energy and bioliquid fuels for surface transport.

Reducing emissions by preventive options for pollution control (improved efficiency and switching to other energy sources) are generally considered advantageous over control options. Furthermore, it is possible to decouple economic growth from primary energy consumption by investing in more efficient supply frameworks, improving energy efficiency amongst end-users and substituting renewable energy technologies for fossil fuels.

A proper weightage should be given to the iron and steel industry in India as it is one of the major sources of air pollution as our findings report. It involves not only upgrading the industry's processing procedures but also increasing the effective utilization of coal consumption in the production of steel.

For energy conservation, efficiency and research and development and technological upgradation a suitable national energy price policy has to be framed. It is a fact that energy prices are low in the country. In India coal, kerosene and natural gas are subsidized. Ideally, all energy prices should truly reflect the cost of using fossil fuels including the cost to society from pollution and environmental degradation. Therefore, until there is a realistic consensus on how environmental standards are to be met, fossil fuel subsidies should not be encouraged. Clearly, such changes are not easy to implement. Hence, the Government of India should devise appropriate fiscal incentives linked to energy savings and tax concessions, rather than subsidies, in order to achieve economy in the use of energy over the long term.

A mix of information, market-based tax and investment credits, better regulations, higher efficiency standards, enhanced use of voluntary agreements like the energy star programme, removal of trade and investment barriers and resolving the international disagreements over intellectual property rights will all be needed for industry to reduce the problem of CO2 emissions and green house gases further.

For controlling CO2 the use of natural gas is gaining wide popularity across the globe as it is comparatively cleaner than the other fuels and has around half the carbon content of coal. Its development, coupled with the adoption of suitable technology such as combined cycle gas turbines for electricity generation, is likely to lead to natural gas taking a larger share in primary energy requirements. Across the land, pipeline networks would have to be set up to distribute natural gas. Though the high cost of transportation makes it presently uncompetitive with other fuels the possibility of increasing its use has to be explored judiciously.

The Government should consider introducing clean energy technology. Clean energy technology (CET) is defined as those technologies that combine more efficient processes and reduced pollutant production without necessarily entailing a change in the form of energy used. Clean coal technologies like integrated gasification combined cycle (IGCC) plants should be encouraged in industry and power generating plants. These technologies typically reduce emissions of CO2 and provide improvements in energy efficiency when compared with traditional coal combustion technologies.

One other aspect deserves mention in this context. Emitted gases have the capacity to be transported over large distances, sometimes many hundreds of kilometers, and may give rise to depositions in another country. The potential for such transboundry air pollution was evident in the recent Indonesian forest fires. The area affected by the air pollutants from the fire spread for more than 3,200 kilometers east to west, covering six Asian countries and affected around 70 million people. Major weather patterns in Asia facilitate the transboundry transport of air pollutants from land to sea and the reverse in summer. Pollutants can thus be carried from country to country in the region. It is, therefore, not possible for individual countries to solve the associated problems alone. There is an obvious and strong need for regional intergovernmental co-operation in this field (SEI, 2000).

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