Pradyot Ranjan Jena (Germany)

A study of changing patterns of energy consumption and energy efficiency in the Indian manufacturing sector

Abstract

In the present economic scenario, the key concerns in policy making in India are: how to achieve higher energy efficiency in the key sectors and how to reduce the vulnerability of the economy to external shocks. In this paper, an attempt is made to study the changing pattern of commercial energy consumption in the manufacturing sector, which is the largest user of commercial energy and to identify the alternative energy saving processes through technological upgradation. For this purpose, we have adopted Divisia index decomposition method, which decomposes the aggregate energy intensity index into structural intensity index and the energy intensity index. The findings of the paper suggest that while several sub-sectors have shown increasing trends of technical efficiency, there is still a lot of scope for energy saving potential in the industrial sub-sectors. Further, it is found out that the change in the aggregate energy intensity index has not been influenced much by the structural effects. Instead, major segment of the change in aggregate intensity index is explained by the reduced energy intensity index.

Keywords: energy consumption, divisia decomposition method, India, efficiency.
JEL Classification: Q40, Q41, Q43.

Introduction

The relation between energy consumption and economic growth in developing countries has been established by many studies. They have typically found that increase in energy consumption has positively affected the growth in income level in several developing countries including India. Over the years, energy consumption in many developing countries that are transforming into industrial powers has increased many folds and India is no exception to it. India is the second largest consumer of commercial energy after China in Non-OECD East Asia. The two key socio-economic indicators that have led to increased demand in energy in India are population growth and rising gross domestic product (GDP). India has experienced rapid growth in both the parameters that have driven the pace of energy demand in the country. The GDP has taken a significant leap since the structural reform that took place in the country in 1991. The annual GDP growth rate has risen from 4.4% in 2000-01 to 8.1% in 2003-04.

In addition, population is another crucial factor for increased energy demand that has grown by 180.6 million between 1991 and 2000. The population in the country has crossed the 1 billion mark, which constitutes one-sixth of the world population. A noteworthy feature of the Indian demographic scenario has been a significant growth rate of urban population that has enhanced the residential energy consumption in the country. The cumulative effect of both population and GDP growth has led to an increase in energy consumption in India. It was estimated that by the end of the Tenth Five-year Plan, the energy demand would grow at a rate of 5% (TERI, 2003-04). India's incremental energy demand for the next decade is projected to be among the highest in the world.

Against this backdrop, an attempt is made in this paper to analyze the demand scenario for energy in various broad sectors of the country in general and that of the manufacturing sector in particular. In section 2, a brief account of the supply potential of different primary commercial energy sources in the country is provided. Section 3 shows the energy balance matrix of the country by explaining both energy demand and supply situations together. A specific study of the manufacturing sector is undertaken in section 4 in order to identify the key factors contributing to aggregate energy intensity of the sector. In this section, Divisia index decomposition technique is employed to decompose the aggregate effect into two individual effects, viz., structural intensity effect and energy intensity effect and an attempt is made to measure the net effect of those changes.

1. Supply of primary sources of commercial energy in India

Traditionally, a large part of the total energy supply in India is drawn from non-commercial energy sources such as fuelwood, cow dung, charcoal, and crop residues. It was estimated that over 60% of the Indian households depend upon these traditional sources of energy (TERI, 2003-04). However, over the years, there has been a significant change in the pattern of supply of energy in the country. The share of commercial fuels in the total energy supply in India has risen from 41% in 1970-71 to approximately 70% in 2003-04. The total domestic primary commercial energy supply in India has risen from 147.05 million tones of oil equivalent (mtoe) in

1970-71 to 248 mtoe in 2003-04, with an average annual growth of 3.2%. Among different sources of primary commercial energy (such as coal, oil, electricity, and natural gas), coal is the most abundant source of commercial energy in India. India is the third largest producer of coal in the World after U.S and China with total coal reserves of 92.4 billion tones in 2004 (BP Statistical Review, 2004). While the Indian coal reserves have increased from 62.54 billion tones (BT) in 1991 to 92.4 BT in 2004, the world coal reserves have declined from 1040.52 BT to 924.45 BT during the same period (provided in Table 1). In terms of reserve to production (R/P) ratio for coal, India has higher potential than the world average. In fact, most of the International Energy Agency (IEA) countries[1] have reduced their coal production during nineties, where as it has remained higher in India during the same period.

Table 1. Proven reserves of fossil fuels and R/P ratio

Fuel	India		World	
	End 1991	End 2004	End 1991	End 2004
Coal (bn tones)	62.54 (195)	92.44 (229)	1040.52 (239)	909.64 (164)
Crude oil (bn tones)	0.8 (25.6)	0.7 (18.6)	135.4 (43.4)	161.9 (40.5)
Natural gas (trillion cubic meter)	0.7 (48.8)	0.92 (31.3)	124.0 (58.7)	179.53 (66.7)

Source: BP Statistical Review (2004).

The breakup of primary commercial energy production for various fuels from 1970-71 to 2003-04, given in Table 2 shows that the share of coal in the total primary commercial energy production has declined from 54.42% in 1970-71 to 45.5% in 1990-91 and again increased to 54.17% in 2003-04. Despite the fact that during this time there is significant increase in the production of natural gas and other non-conventional energy sources; coal continues to be the single largest source of total energy production in India. On the other hand, crude petroleum accounts for approximately 10% of the total energy production in India. Its share has increased from 9.74% in 1970-71 to 15.47% in 1990-91 and after that it has started declining to 11.84% in 2000-01 and to 10.7% in 2003-04. In contrast to crude oil, natural gas production has shown remarkable growth potentials over the years. Its share in total energy production has increased from a meager 1.9% in 1970-71 to 9.43% in 2003-04 and that share is expected to double by 2020.

Table 2. Production of primary sources of conventional energy in India (figures in peta joules)

Source	1970-71	1980-81	1990-91	2000-01	2003-04
Coal and lignite	1,598	2,491	4,063	5,683	7,067
Crude petroleum	286	440	1,383	1,358	1,397
Natural gas	56	91	693	1,135	1,231
Electricity (hydro & nuclear)*	996	1,784	2,800	3,286	3,349
Total	2,936	4,806	8,939	11,462	13,044

Source: Ministries of Coal, Power, and Petroleum and Natural gas.
* Thermal electricity is not a primary source of energy.

The second highest source of commercial energy production in the country is electricity. Over the years, the energy mix in several key energy intensive sectors is changing in favour of electricity. The substitution of electricity in place of coal is taking place due to high end-use of the former. The installed capacity of both hydro and thermal power has grown significantly from 1700 MW (550 MW of hydro and 1153 MW of thermal) in 1950 to 112058 MW (29500.23 MW of hydro, 77968.53 MW of thermal, 2720 MW of nuclear, and 1869.66 MW of wind) in 2004. Despite the impressive increase in the installed power capacity, the electric power supply continues to remain short of demand. The demand projections made in the 16th Electric Power Survey conducted by the Central Electricity Authority (CEA) indicate that over 100000 MW additional generation capacity needs to be added by 2012 to bridge the gap. The total energy shortage during 2000-01 was 39816 million units amounting to 7.8% of peak demand and the peak shortage was 10157 MW translating to 12.6% of the peak demand.

The analysis thus far has provided a picture of the availability and production potentials of different sources of commercial energy. Since India has huge coal reserves, most of the energy demand is met through coal production. But, the matter of concern is that since coal is a fossil fuel and non-renewable, over dependence on it might lead to energy insecurity in future. Therefore, the government is focusing heavily on natural gas production and harnessing of other non-conventional energy sources to reduce burden on coal consumption. In order to gain a clearer picture of the energy scenario in the country it is essential to analyze the supply and demand side of energy balance together.

Table 3. Commercial energy balance for India (figures in million tons of oil equivalent)

Year (1)	Production (2)	Imports (3)	Exports (4)	Availability (5)	Conversion (6)	Consumption* (7)
1980-81	72.6	24.5	4.5	92.6	23.9	68.8

[1] There are 16 member countries in IEA, which are mostly OECD countries. India is not a member of IEA.

Table 3 (cont.). Commercial energy balance for India (figures in million tons of oil equivalent)

Year (1)	Production (2)	Imports (3)	Exports (4)	Availability (5)	Conversion (6)	Consumption* (7)
1985-86	117.5	20.2	6.2	131.5	38.0	93.5
1990-91	158.7	32.5	6.9	184.3	59.4	124.9
1995-96	205.97	54.61	25.02	235.56	76.30	159.26
2000-01	193.86	96.33	9.81	280.38	105.58	170.52
2001-02	202.27	98.53	19.02	300.44	108.33	171.33

Source: TERI Energy Data Directory and Yearbook (TEDDY), various issues.
Notes: * Consumption figures are equal to net availability.

Table 3 shows the overall energy balance in which several aspects of energy supply and demand are provided for the time period of 1980-2002. The net inflow of energy is calculated as the addition of production and imports (i.e. columns 2 and 3) and the net outflow is exports and stocks changes taken together (column 4). Total commercial energy supplies figures (column 6) are obtained by subtracting the net outflow of energy from the net inflow figures. The net availability of energy is calculated by subtracting the conversion loss of energy from the total availability of energy. So, the net availability of energy is equal to the total consumption of energy given in the column 7.

Total commercial energy supplies (after taking into account the changes in stocks) in India has increased from 92.6 mtoe in 1980-81 to 300.44 mtoe in 2001-02 with an annual average growth rate of 6%. During the same period, indigenous production of commercial energy has grown from 72.6 mtoe to 202.27 mtoe, at a rate of over 7.8% a year. From 1980-81 till 1995-96, the indigenous energy production remains dominant source of total energy supply, with its share increasing from 78% to 87% during that period. However, since 1995-96, domestic production has declined in absolute terms and its share is also reduced to 67% in 2001-02. On the other hand, the share of imports in total energy supply has increased continuously from 26.45% in 1980-81 to 32.8% in 2001-02. These imports are mainly in the form of coking coal, crude oil, and petroleum products. It is projected that India would be importing about 88% of the total oil consumption by 2006-07, which has become a major concern given the fact that world oil prices have been rising continuously. In addition, India is also a net importer of high quality coal. Imports of superior grade coal were 0.74 mtoe in 1980-81, which has gradually increased to over 10 mtoe in 2001-02.

The above analysis suggests that the gap between aggregate demand and domestic supply has increasingly been widened over the years. This has led to many energy-intensive industries to depend crucially on imports for their energy requirement. Particularly, imports of high quality coal and oil have risen rapidly after 1995-96, following massive increase in the scale of production in certain energy intensive industries such as steel and non-ferrous metal industries and due to spiraling growth of urban population.

2. Aggregate and sector-wise energy consumption and intensity

As it is mentioned in the beginning that energy consumption and GDP are closely related, it is necessary to examine – how this inter-linkage between energy consumption and GDP has changed over time? According to conventional wisdom, energy consumption and GDP relationship is shown by their ratio, which is called energy intensity. This measure shows how much of energy is required to produce one unit of GDP in a country. In fact, energy intensity, further leads to investigation of many interesting aspects related to energy consumption in the country. Important among them are structural changes and technological improvement in energy use. As a matter of fact, aggregate energy intensity in a country is considered to be composed of both structural effects and technology induced intensity effects (the details are given in the next section). With a view to analyze the changing pattern of energy consumption and energy intensity, total primary commercial energy consumption (TPCEC) and energy intensity for the period, 1980-81 to 2003-04 are plotted in Figure 1. The figure shows that TPCEC has increased substantially in India over the last two and half decades with an annual average growth rate of 5.74%. On the other hand, energy consumption per unit of GDP has increased from 1980-81 to 1990-91 with an annual average growth rate of 1.63%, after which it started declining in absolute terms. From 1990-91 to 2003-04, energy consumption per unit of GDP has grown at a negative rate of -1.35%, which suggests that overall energy intensity in the country is declining since last one and half decades.

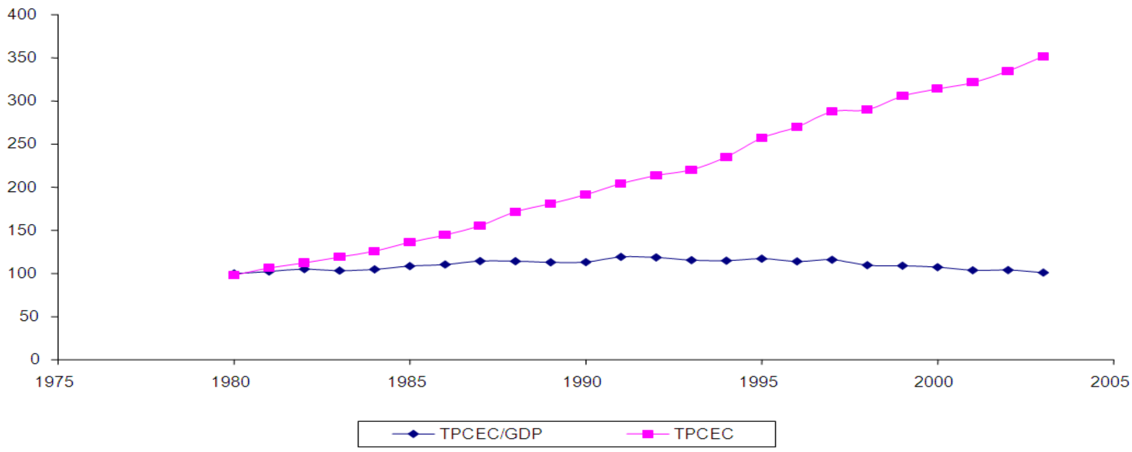

Fig. 1. Energy consumption and energy intensity in India

There are several factors responsible for the growth of energy intensity during 1980 to 1990, one of them being the switch from non-commercial to commercial fuels in the use of energy[1]. Similarly, the decline in commercial energy per GDP after 1990 could potentially be explained by a slowdown of the shift from non-commercial to commercial fuels. However, an estimate by IEA shows that non-commercial fuels per GDP has fallen more between 1990 and 1998 than during the period of 1971-1990, on average 4.1% per year vis-à-vis 2.5% per year (IEA study report, 2002). This indicates the shift away from non-commercial fuels have not actually stagnated. Hence, we have to look into other factors to explain the turning of the energy per GDP trend in India. One such factor is changes in economic structure. These changes can have an impact on the energy per GDP ratio since GDP represents economic activities that require energy services in varying degrees. For example, generating one unit of GDP from producing electronics requires much less energy that if the same unit of GDP is generated from producing steel. Thus, a shift away from heavy industries (e.g. steel) to less energy intensive production (e.g. electronics) could drive down a country's energy demand, all else being equal. This shift towards a less energy intensive structure has injected a downward force on the energy per GDP ratio in a majority of IEA countries since 1970s.

A perusal of the structural changes taken place in Indian economy since 1980 till 2002 reveals that the share of industry in total GDP has increased from a low base of 15.5% in 1980-81 to 20.4% in 1995-96 and then declined marginally to 19.4% in 2001-02 (see Table 4). During the same period, the share of agriculture in GDP has declined from 35.8% in 1980-81 to 22.2% in 2001-02. The major beneficiary of the declining share of agriculture however, is the service sector which has grown from 36.6% in 1980-81 to over 55% in 2001-02. While, analyzing the changing pattern of energy consumption due to changes in structures of economic activity, it can be assumed that both agriculture and service sectors consume nearly same amount of energy to produce one unit of GDP, but if the same unit of GDP is produced by industry then more energy is required. Thus, the rise in aggregate energy intensity in the country during 1975-1990 can be partially explained by the rising share of industry in the economic structure.

An analysis of the sectoral energy consumption shows that four major sectors, namely agriculture, industry, transport, and residential together have constituted nearly 90% of the total energy consumption in India (see Table 4). Further, the figures reveal that the shares of both industry and transport sectors have declined over the time period 1980-81 to 2001-02. One explanation for the declining energy consumption in the transport sector is the reduction of energy consumption in railways, which has been the major constituent of transport sector. Railway sector has achieved significant improvement in energy efficiency over the years. On the other hand, energy consumption in both agriculture and residential sectors grew constantly since 1980-81 to claim shares of 8.6% and 13.3% respectively in total energy consumption by 2001-02.

With a view to examine the trends of energy requirement per unit of economic activity in various major sectors, we have calculated energy intensity of four sectors, namely, agriculture, industry[2], transport, and residential (provided in Table 4).

Intensity for agriculture and industry are calculated as commercial energy use (in mtoe) per unit of val-

[1] In fact, it can be argued that the historical growth in the use of commercial energy in India does not represent the growth of demand for such energy but rather the growth of its actual availability in view of the prevailing energy shortages.

[2] Industry consists of manufacturing and electricity, gas and water supply.

ue added (Rs lakhs) expressed in 1993-94 prices. Intensity for transport is calculated by dividing transport energy use with total GDP and for residential, energy use in residential per unit of personal expenditures. The intensity figures in Table 4 show that energy intensity in the industrial sector has been declining on a continuous basis since 1980-81 till 2001-02. It is important to note that even though, both manufacturing production and energy consumption in this sector have grown significantly since 1980, energy intensity has declined.

There could be mainly two reasons for the declining energy intensity in the industrial sector. First, the structure of manufacturing (energy-intensive vis-à-vis non energy-intensive production) may be changing, and second, the sector may have achieved significant energy efficiency. With a view to examine the effect of structural changes and technical changes in the manufacturing sector to aggregate energy intensity, we have attempted a decomposition analysis of the manufacturing sector in the next section.

Table 4. Economic structure, energy shares and energy intensity indices of major sectors

		Agriculture	Industry	Transportation	Residential
1980-81	GDP share*	35.8%	15.5%		
	Energy share**	2.32%	53.6%	25.3%	8.14%
	Intensity	100	100	100	100
1985-86	GDP share	33%	17.1%		
	Energy share	2.56%	53.5%	23.2%	9.41%
	Intensity	126.7	95.9	97.3	129.1
1990-91	GDP share	29.5%	19%		
	Energy share	4%	54%	22.4%	10%
	Intensity	210.5	80.9	93.2	148.7
1995-96	GDP share	25.6%	20.4%		
	Energy share	5.3%	48.7%	23%	9.6%
	Intensity	327.1	71.2	95.3	148
2001-02	GDP share	22.2%	19.4%		
	Energy share	8.6%	42.9%	19.5%	13.3%
	Intensity	472.7	50.7	61	174.9

Notes: * Data for GDP contributions from various sectors (value added) are from CMIE National Income Statistics, various issues, ** Data for shares for sectoral energy use in total final consumption of commercial fuels are obtained from TERI Energy Data Directory and Yearbook (TEDDY), various issues.

3. Estimation method

We have already mentioned in the last section that energy consumption in a sector like manufacturing would crucially depend upon the energy consumption patterns of its constituent sub-sectors. Therefore, in order to explain the observed trend of energy consumption in manufacturing sector, a close examination of the energy consumption trends of its sub-sectors is required. The alteration in the composition of energy-intensive vis-à-vis non energy-intensive sub-sectors over a period of time would significantly affect the overall energy consumption of the broad sector. In addition, with technical improvements, some sub-sectors are expected to achieve energy efficiency, which implicitly means that requirement of energy per unit of production in these sub-sectors would decrease. Such intensity effects would also significantly affect the overall energy consumption of the manufacturing sector. An attempt is made in this paper to decompose the manufacturing sector into various sub-sectors and then to relate changes in the sub-sectoral energy intensities and production to changes in the aggregate energy intensity index of the manufacturing sector.

The basic decomposition methodology involves decomposition of both aggregate energy consumption and energy intensity (i.e. the ratio of energy use to output) into two or more distinct components. In the energy consumption approach, total industrial energy consumption is decomposed over time into contributions from changes in aggregate production/output (output effect) and spectral energy intensities (intensity effect). In the energy intensity approach on the other hand, changes are decomposed into contributions from structural and intensity effects only. In both the approaches and depending upon the method, the observed change is expressed in terms of either in sum, or the product of the resulting decomposition components.

The impact of changes in the composition of economic activities and sub-sectoral energy intensities on aggregate measures of energy intensity has been the subject of empirical analysis since Myers and Nakamura (1978), which was reviewed by Ang and Zhang (2000). These studies have either implicitly or explicitly made the connection to the economic theory of index numbers. For example, many earlier studies used a fixed base year index that is analogous to the Laspeyers index, (for an example, see DOE, 1989). On the other hand, Boyd, McDonald et al. (1987) have explicitly made an appeal to index numbers when they introduced the "Divisia Index Approach" and the "Tornqvist approximation" for this purpose. The Tornqvist approximation and other forms of the Divisia Index have been widely used in energy analysis since then[1]. Recently, there has been interest in developing official government statistics of energy intensity similar to those prepared for prices or productivity, using index number decomposition methods (Lermit and Jollands, 2001; and Padfield, 2001).

Many studies have discussed the problem of the residual term, or a perfect decomposition. When an index number has a residual term, there is some portion of the change in energy intensity from the base period to the current period that remains unexplained. The Laspeyers index and most applications of the Divisia index suffer from this problem. If the residual term is large enough, the empirical exercise may have little meaning. Ang and Choi (1997), Ang and Liu (2001) and Sun (1998) offer two approaches to address this problem. They are *log mean Divisia* method and the *refined Laspeyers* method respectively. Due to the superiority of the log mean Divisia method over other methods of decomposing index number, we have used the former in this exercise.

The log mean Divisia method is a modification over the traditional Divisia method, in the sense that the former uses a logarithmic mean weight system instead of the arithmetic mean system that is used in the traditional Divisia index methods. This modification in the traditional method is able to circumvent the problem of large unexplained residuals. The method is described below.

Generally, aggregate energy intensity given by total energy consumption divided by gross output is taken as an energy performance indicator in energy demand analysis. The aggregate energy intensity (I) can be written as:

$$I = \sum_i E_i / Y = \sum_i (Y_i/Y)(E_i/Y_i) = \sum_i y_i I_i, \quad (1)$$

where, E is the total energy consumption in physical units, E_i is the energy consumption in sector I, Y is the total production/gross output in real terms, Y_i is the production in sector i, and y_i is the production share of sector i (Y_i/Y]. I is the aggregate energy intensity and I_i is the energy intensity of sector i (E_i/Y_i).

[1] As aggregator functions in production or consumption analysis they have been in wide use since the 1970s; see, for example, Diewart (1974) and Berndt, Morrison, and Watkins (1981).

Further, let D_{tot} be the ratio of the aggregate energy intensity of current year T to that of the base year 0.

$$D_{tot} = I_t / I_0. \quad (2)$$

Decomposition is carried out on this ratio, which is called the aggregate energy intensity index. The total effect (D_{tot}) then gets decomposed into structural effect (D_{str}) and an intensity effect (D_{int}), so that

$$D_{tot} = D_{str} / D_{int}. \quad (3)$$

According to the conventional Divisia method, a common practice is to use the arithmetic mean weight scheme, which results in the following two equations

$$D_{str} = E\left[\sum_i \left(w_{i,T} + w_{i,0}\right) / 2 \ln\left(y_{i,T} / y_{i,0}\right)\right] \quad (4)$$

$$D_{\text{int}} = E\left[\sum_i \left(w_{i,T} + w_{i,0}\right) / 2 \ln\left(I_{i,T} / I_{i,0}\right)\right] \quad (5)$$

where, $w_i = E_i / E$.

Equation (3) now becomes

$$D_{tot} = D_{str} D_{int} D_{rsd} \quad (6)$$

The term D_{rsd} is the residual term or the interaction term. Decomposition is perfect when D_{rsd} is exactly equal to unity.

On the other hand, log mean Divisia method uses a logarithmic mean instead of arithmetic mean that is used in equations (4) and (5). Logarithmic mean is calculated as:

$$L(x, y) = (y - x) / \ln(y/x). \quad (7)$$

Here, x and y are positive numbers and $L(x,y)$ has the range of $xy^{1/2} < L(x,y) < (x + y)/2$, where, x is not equal to y. replacing x and y in equation (7) by $w_{i,T}$ and $w_{i,0}$ respectively yields

$$L\left(w_{i,T}\right) = \left(w_{i,T} - w_{i,0}\right) / \ln\left(w_{i,T} / w_{i,0}\right). \quad (8)$$

The sum of the weight function when taken over all the sectors is not unity. It is slightly less than unity. Therefore, equation (8) can be normalized in order to reduce the residual term. The normalized weight function can be written as:

$$w_i^* = L\left(w_{i,0} w_{i,T}\right) \Big/ \sum_i \left(w_{k,0} w_{k,T}\right), \quad (9)$$

where the summation in the denominator denotes, that sum is over the L function of all the selected sectors. Hence, the formula for the log mean Divisia index method for energy intensity decomposition is

$$D_{str} = E\left[\sum_i w_i^* \ln\left(y_{i,T}/y_{i,0}\right)\right], \quad (10)$$

$$D_{int} = E\left[\sum_i w_i^* \ln\left(I_{i,T}/I_{i,0}\right)\right]. \quad (11)$$

Application of equations (10) and (11) leaves no residual, i.e. $D_{rsd} = 1$.

In order to execute the exercise described above, it is required to select the manufacturing sub-sectors. In fact, manufacturing is a heterogeneous collection of production activities with varying energy intensities. National Industrial Classification (NIC), which is the counterpart of the International Standard Industry Classification (ISIC) for India classifies the manufacturing sector into various 2-digit, 3-digit, and 4-digit industry groups. Although, there are twenty-six 2-digit industry groups in the classification, we have considered twenty industries in this paper excluding industry groups electricity (40), gas and steam generation and distribution through pipes (41), water works and supply (42), non-conventional energy generation and distribution (43), storage and warehousing (74), and repair services (97). Among the excluded industries, 40 through 43 are the electricity generating industries. Since, electricity is one of the energy sources consumed by industry that we are examining in this paper, we have excluded these industries. The other two industries that are excluded, namely 74 and 97 are storage and repair services, which are not strictly manufacturing activities. Moreover, the NIC industrial classification was changed after 1997-98. So, we have followed the concordance table provided by the Annual Survey of Industries (ASI) to match the NIC-98 industrial codes onto NIC-87 industrial codes. By doing so, it was required to club some industrial groups in order to maintain consistency in the dataset. We have made three such clusters. The clustered industry groups are food products and other food product (20 and 21), cotton textiles, wool, silk and man-made fibre textiles (23, 24 and 25), and machinery and equipment other than transports and repair of capital goods (35, 36, and 39). In fact, the clubbed industrial groups are so similar in nature, in terms of their production activities that no harm is done by clubbing them together.

As we were in need of data for energy consumption in physical units and real output at constant prices for the 20 industries, such data have been collected from the ASI reports. The time period of the study spans from 1992-93 to 2001-02. But, since data for 1993-94 and 1994-95 are not available, these two years have been excluded from the analysis. In addition, data for more recent years i.e. post 2001-02, are also not reported yet. Therefore, the analysis is done on the 8 years for which we have data. The ASI reports published data on fuel consumption by industry in various original units for a variety of fuels, namely coal including coke and lignite, LPG, natural gas, petrol, diesel, residual fuel oil, firewood including charcoal and electricity till 1996-97. But, after 1996-97, such detailed data for fuel consumption are not reported. Instead, they have been clubbed into three broad fuel categories, namely coal, electricity, and petroleum products. Both value in rupees and quantity in original units are available for coal and electricity and value in rupees for petroleum products. So, with a view to maintain consistency in the data set, we have taken coal and electricity as the energy sources for our analysis since quantity figures are available for both these fuels for all the years.

Since, coal and electricity are measured in two different units, namely, tonne and kilowatt-hour; they need to be expressed in one common unit. According to conventional wisdom in energy consumption valuation, the common unit of measurement that is used for analysis purpose is mtoe. Therefore, all fuel quantities are converted into mtoe and then finally added up to give the total commercial energy consumption of the industries. Further, data on total output of the industries are given in nominal terms (Rs lakhs) in the ASI reports. In order to calculate real output at constant prices, these nominal values are deflated by the corresponding wholesale price indices taking base 1993-94 = 100[1].

4. Discussion of results

The energy intensity of the manufacturing sector as a whole and that of individual sub-sectors, calculated as energy consumption in mtoe per real value added are plotted in Figure 2. It shows that manufacturing energy intensity has increased from 1992-93 to 1995-96 and then started declining. It has again shown some increasing trend in the last two years of analysis, i.e. 2000-01 and 2001-02. While, comparing the energy intensity trend to the energy consumption trend of manufacturing sector, we find a very similar picture in both the cases. Energy consumption in manufacturing have also increased initially from 1992-93 to 1995-96 and then started declining. It has again increased in the last two years, which has led the intensity to rise. It is interesting to note that even though the real value added in manufacturing has declined in 2000-01 and 2001-02, energy intensity has risen mainly due to rising energy consumption. This trend shows that energy

[1] Wholesale price indices for various years for all the industries are available in Ministry of Industry and Commerce documents.

consumption is dominant in explaining the behaviour of energy intensity.

The energy intensities of six major industries that account for more than 90% of the total energy consumption (shown in Figure 2) suggests that food products, basic metals, and textiles have shown two declining periods, one after 1995-96 till 1997-98, after which they have increased, and another is from 2000-01 onwards. The energy intensities in other three industries, namely chemicals, non-metallic minerals, and paper and pulp have been erratic through out the period and seem to have increased after 2000. Overall, the analysis of energy intensity trends of aggregate manufacturing sector and its constituent sub-sectors present that energy intensity in most of the cases are volatile, but they seem to have followed a similar pattern that they have increased in the initial year, i.e. from 1992-93 to 1995-96 and then started declining. These intensities have again increased since 2000 onwards.

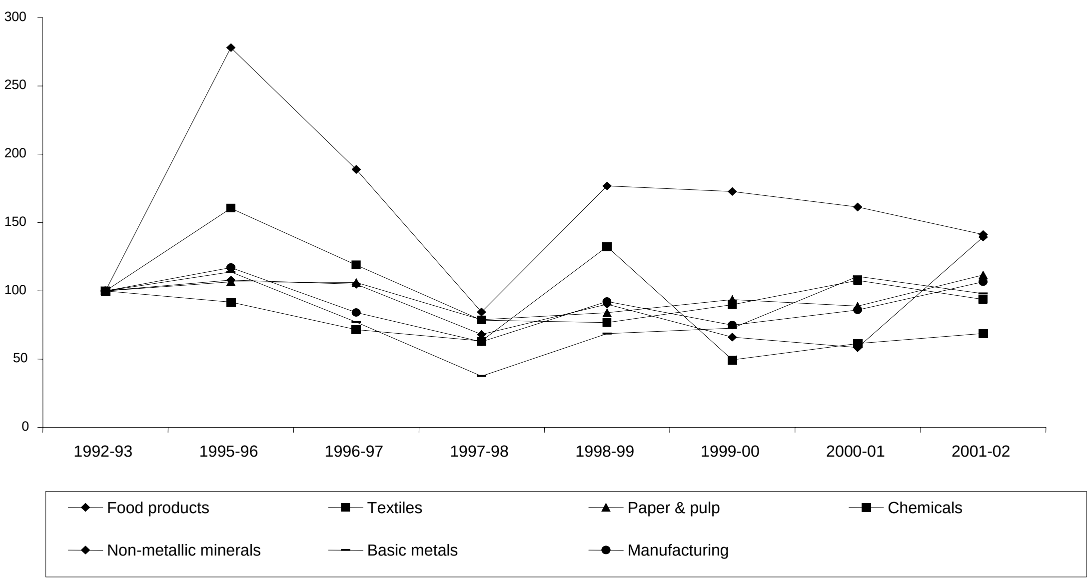

Fig. 2. Energy intensity index of manufacturing and selected industry groups

Table 5. Results of log mean divisia index decomposition method

Year	Aggregate intensity	Structural intensity	Energy intensity
1992-93	1.00	1.00	1.00
1995-96	1.19	1.02	1.16
1996-97	0.87	0.93	0.93
1997-98	0.64	1.03	0.62
1998-99	0.94	0.99	0.94
1999-00	0.75	1.02	0.73
2000-01	0.87	1.01	0.86
2001-02	1.09	0.99	1.10

Source: Own estimation.

The results of the Divisia decomposition method are presented in Table 5. It shows that the aggregate energy intensity index of the manufacturing sector has increased initially from 1992-93 to 1995-96, but has declined since then till 1997-98. After 1997-98, it has shown extreme volatility by following almost a zigzag path. The structural intensity index, which shows the composition of output of energy-intensive and non energy-insensitive sub-sectors shows that it is positive in 1995-96, in the sense that the structural index component is greater than unity. During the same year, the energy intensity index, which is an indicator of the energy efficiency achieved by the sub-sectors through technological improvement in their production process, is also greater than unity. This suggests that the rising aggregate energy intensity in 1995-96 is an outcome of the increase in both the output of energy-intensive industries as well as energy required to produce those output. However, the aggregate index has declined from 1995-96 till 1997-98 from 1.19 to 0.64. During this period, the structural index remained higher than the aggregate index, but energy intensity index declined from 1.16 in 1995-96 to 0.62 in 1997-98. This result reveals that though the production of energy-intensive industries remained higher, energy efficiency achieved through technical improvements have kept the aggregate energy requirement low during this period. This trend continued for the next three years that is till 2000-01. Although, aggregate index has been unpredictable, first increasing in 1998-99, then decreasing in 1999-00 and again increasing in 2000-01, the structural index has always remained higher than the aggregate index. The gap between aggregate and structural index has been bridged by the energy intensity index which has remained lower than the aggregate in all the three years. The only exceptional case was noticed in 2001-02, where aggregate as well as energy intensity indices have increased from the previous year and exceeded unity, but the structural index has decreased from the previous high and remained lower than the unity. Overall, we find that the composition of industries has not altered adequately in favor of non energy-intensive industries; rather it is the energy intensity of the sub-sectors, which has declined to keep the aggregate intensity lower. This finding suggests that the Indian industries are showing a trend of reduced energy requirement in their production process.

Concluding remarks

This paper has touched upon several aspects of the energy scenario in India while focusing on an in-depth analysis of the manufacturing sector in India. It is found out that though, the production of indigenous sources of primary commercial energy has been increasing since the last three decades they have fallen well short of the energy requirement in the country. This widening gap between domestic supply of and demand for energy has increased the dependence on external markets to ease the supply constraints. Though, the energy requirement in the country per one unit of gross domestic product has been declining over the last three decades, the rapidly increasing demand for energy required to keep the growth rate higher has raised crucial questions regarding alternate sources of energy production as well as achievement of energy efficiency in the key sectors. The increasing demand for energy in the country is mostly contributed by the manufacturing sector, which consumes more than 40% of the total energy consumption in the country. Since, manufacturing is the major consumer of energy and posses the potential to save energy though higher energy efficiency, we have undertaken a detailed study of this sector.

In fact, manufacturing is a heterogeneous collection of production activities with varying energy intensity. The energy requirement in manufacturing as a whole crucially depends upon the energy consumption pattern of its constituent sub-sectors. Therefore, with a view to examine the energy consumption pattern in manufacturing and to identify the key factors influencing the energy requirement in this sector, we have undertaken the Divisia index decomposition approach in this paper. A Divisia index method decomposes the changes in the aggregate energy intensity of a broad sector into changes in the composition of production activities among the sub-sectors and changes in the energy intensity of the sub-sectors. Finally, both these intensity effects, namely structural and energy intensity effects determine the changes in the aggregate energy intensity of the broad sector.

It is found out that six industrial groups, namely basic metals including iron and steel and aluminum, chemicals including fertilizers and organic and inorganic chemicals, non-metallic minerals including cement, textiles, paper and pulp, and food products are the major energy consuming subsectors within the manufacturing with a share of more than 90% in total energy consumption. The trend of energy intensity among these six industries during the period of 1992-2002, reveals that while basic metals, textiles and food products have achieved limited energy efficiency in their production process, which is reflected through their declining energy intensity towards the end of the last decade, the other three industries such as chemicals, non-metallic minerals and paper and pulp have not shown any significant sign of energy efficiency. The huge potential for energy saving in these energy-intensive industries, which if achieved, would save substantial amount of energy. Therefore, special policy outlines need to be designed to enhance energy efficiency in these industries through improvement in technology.

The results from Divisia index decomposition shows that the change in the aggregate energy intensity index has not been influenced much by the structural effect. Instead, major segment of the change in aggregate intensity index is explained by the reduced energy intensity index. Most of the industries in the manufacturing sector have shown some degree of energy efficiency improvements in recent years, which have ultimately led to the reduced energy intensity in manufacturing sector. This linkage can be traced to penetration of more end-use devices, technological improvements in conversion equipment and inter-fuel substitution with more efficient alternatives. In fact, the structural component is driven mainly by incomes and by forces not directly related to energy or energy policies. The energy intensity components are related to energy use technologies and efficiencies that are often the object of energy policies.

Finally, we would like to state that there is sufficient scope for further refinement and expansion of the analysis towards policy formulation. Moreover, due to data constraints we have excluded petroleum products from the analysis that is a major source of energy consumption in the industries, which if included, could have made some changes in the observed results. However, the present study bears important implications for energy policy. Since, the government is recently drafting a full-fledged energy policy, it is important to know the energy-intensive industries that are showing energy efficiency, so that specific policies can be formulated for such industries through incentive packages. Other energy-intensive industries which have not yet achieved technological improvements are required to provide technical know how and R&D facilities.

References

1. Ang, B.W. (1994). "Decomposition of Industrial Energy Consumption: the Energy Intensity Approach", *Energy Economics*, Vol. 16, No. 3.
2. Ang, B.W. and F. Liu (2001). "A New Energy Decomposition Method: Perfect in Decomposition and Consistent in Aggregation", *Energy*, Vol. 26, No.6, pp. 537-548.
3. Ang, B.W. and F. Zhang (2000),"A Survey of Index Decomposition Analysis in Energy and Environmental Studies", *Energy*, Vol. 25, No.12, pp. 1149-1176.
4. Ang, B.W. and Ki-Hong Choi (1997). "Decomposition of Aggregate Energy and Gas Emission Intensities for Industry: A Refined Index Method", *The Energy Journal*, Vol. 18, No. 3, pp. 59-73.
5. Berndt, E.R., C.J. Morrison and G.C. Watkins (1981). *Dynamic Models of Energy Demand: An Assessment and Composition*, In Berndt, E.R. and B.C. Field (Eds). Modeling and Measuring Natural Resource Substitution, Cambridge: The MIT Press.
6. Boyd, G.A., J.F. McDonald, M. Ross, and D. Hanson (1987), "Separating the Changing Composition of U.S. Manufacturing Production from Energy Efficiency Improvements: A Divisia Index Approach", *The Energy Journal*, Vol. 8, No. 2, pp. 77-96.
7. Boyd, G.A. and Joseph M. Roop (2004). "A Note on the Fisher Ideal Index Decomposition for Structural Change in Energy Intensity", *The Energy Journal*, Vol. 25, No. 1, pp. 87-101.
8. BP Statistical Review (2004). BP Statistical Review of World Energy.
9. Diewert, W.E. (1974). "Functional Forms for Revenue and Factor Requirements Functions", *International Economic Review*, Vol. 15, No. 1, pp. 119-130.
10. IEA (2002). IEA Agreement on the Production and Utilization of Hydrogen: Annual Report 2002. National Renewable Energy Laboratory Golden, CO USA, http://ieahia.org/pdfs/2002_annual_report.pdf.
11. Lermit, Jonathan and Nigel Jollands (2001). *Monitoring Energy Efficiency Performance in New Zealand: A Conceptual and Methodological Framework*. Report prepared for the Energy Efficiency and Conservation Authority, web address: http://www.energywise.co.nz.
12. Myers, J. and L. Nakamura (1978). *Saving Energy in Manufacturing*, Cambridge, MA: Ballinger.
13. Padfield, C.J. (2001). *The Canadian Decomposition Experience: from 10 to 54 Industries*, paper presented at the 2001 ACEEE Summer Study on Energy Efficiency in Industry, Proceedings Vol. 1, July, pp. 621-630.
14. Sun, J.W. (1998). "Changes in Energy Use in China: 1984-94", *Energy*, Vol. 23, No. 10, pp. 835-949.
15. TERI (2003-04). TERI Energy Data Directory (TEDDY) 2004.
16. U.S. Department of Energy (1989). *Energy Conservation Trends: Understanding the Factors that Affect Conservation Gains in the U.S. Economy*, DOE/PE-0092, Washington, DC.