Decomposition of Industrial Energy Consumption in Indian Manufacturing: ***The Energy Intensity Approach***

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Abstract

Increasing energy consumption has been one of the major issues in the environmental and industrial economics in the context of global climate change. Recent literature has dealt with several methodological and application issues related to the technique of decomposing changes in industrial energy consumption. In this paper, we examine these issues in the contest of another commonly adopted approach to decomposition of aggregate changes in energy intensity of Indian manufacturing industries. The industrial sector accounts for about 37 percent of the total final energy consumption in India. Of this the manufacturing sector consumes about 66 percent (2004-05). The manufacturing sector is one of the energy intensive industries among other industries in India. The scope of the study includes an empirical analysis of General Parametric Divisia Method. This paper follows the *energy intensity approach* rather the *energy consumption approach*. This method involves decomposition of the aggregate energy intensity index measured in terms of energy consumption per unit of output. The analysis also includes a comparison of the time series analysis versus the period-wise decomposition. The factors considered are changes in production structure and sectoral energy intensities. The results of the analysis confirm that the changes in sectoral energy intensity play a greater role in the variation in the total energy intensity of Indian Manufacturing compared to the changes in the production structure of the Industries.

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1 Introduction

Energy intensity is an indicator to show how efficiently energy is used in the economy. The energy intensity of India is over twice that of the matured economies, which are represented by the OECD (Organization of Economic Co-operation and Development) member countries. India's energy intensity is also much higher than the emerging economies. However, since 1999, India's energy intensity has been decreasing and is expected to continue to decrease (GOI, 2001). The indicator of energy–GDP (gross domestic product) elasticity, that is, the ratio of growth rate of energy to the growth rate GDP, captures both the structure of the economy as well as the efficiency. The energy–GDP elasticity during 1953–2001 has been above unity. However, the elasticity for primary commercial energy consumption for 1991–2000 was less than unity (Planning Commission, 2002). This could be attributed to several factors, some of them being demographic shifts from rural to urban areas, structural economic changes towards lesser energy industry, impressive growth of services, improvement in efficiency of energy use, and inter-fuel substitution.

With this brief outline, this work aims at decomposing the energy intensity in Indian manufacturing. The manufacturing industries are one of the energy intensive industries among other industries in India. This study is an attempt to explore the possible relationship between the major components those drive the energy intensity at the industry level, such as the structural effect, the sectoral energy intensity effect and the effect of production on the energy intensity of the industries at aggregate level. The next section deals with a brief outline of the overall energy scenario of India and the energy scenario of the Indian manufacturing industries at the aggregate level from 1990 to 2008. Detail review of literature and the methodology adopted is given in the next sections. Moving ahead the decomposition analysis of the Indian manufacturing from 1990-2008 using the energy intensity approach is carried out in the last section with a brief discussion and a concluding remark to the work.

2 Energy Scenario in India

India being an oil importing country witnessed significant changes in the energy consumption pattern due to the oil shocks during the 1970s. Faced with rising inflation and a balance of payment crisis in mid 1991 the government of India introduced a comprehensive policy reform package comprising currency devaluation, deregulation, de-licensing, and privatization of the public sector. The government of India initiated these policy changes to overcome the critical situation. The rising oil import bill has been the focus of serious concerns due to the pressure it has placed on scarce foreign exchange resources.

The Indian economy uses a variety of energy sources, both commercial and non-commercial. Fuel-wood, animal waste and agricultural residue are the traditional or `non-commercial' sources of energy that continue to meet the bulk of the rural energy requirements even today. However, the share of these fuels in the primary energy supply has declined from over 70% in the early fifties, to a little over 30% as of today (Mukhopadhya, 2002). The "commercial fuels" such as coal, lignite, petroleum products, natural gas, and electricity are gradually replacing the traditional fuels. At the time of Independence, the country had a very poor infrastructure in terms of energy production and supply. The per capita consumption of energy was abysmally low and the access to energy was very inadequate for the common people. The economy was dependent largely on the non-commercial sources of energy for meeting the requirements of the households and on animal and human energy in case of agriculture and transport. During the last 60 years the demand for energy, particularly for commercial energy, registered a high rate of growth contributed largely by the changes in the demographic structure brought about through rapid urbanization, need for socio-economic development and the need for attaining and sustaining self-reliance in different sectors of the economy[1].

India's energy consumption is increasing rapidly, from 4.16 quadrillion Btu (quads) in 1980 to 12.8 quads in 2007. This increase is largely the result of India's increasing population and the rapid urbanization of the country. Higher energy consumption in the industrial, transportation, and residential sectors continues to drive India's energy usage upwards at a faster rate even than China, which experienced a 130% increase in energy consumption from 1980 to 2007. Despite the rapid growth between 1980 and 2007, India's energy consumption is still below that of Germany (14.35 quads), Japan (21.92 quads), China (39.67 quads), and

[1] Planning Commission Government of India, Plan Documents

the United States (97.05 quads). In addition, India's per capita energy consumption, which stood at 12.6 million Btu in 2007, is well below most of the rest of Asia and is one of the lowest in the world (although this may be more the result of India's large population rather than a low level of energy consumption). The rise in India's per capita consumption between 1980, when per capita energy usage was just 6.2 million Btu, and 2007, is more problematic in the long-term, however. Coal accounts for just over 50% (6.5 quads) of India's energy consumption. The power generation sector uses the majority of this coal, with heavy industry a distant second. Petroleum (4.4 quads) makes up 34.4% of India's energy consumption, while natural gas (6.5%) and hydroelectricity (6.3%) account for much of the remainder. Natural gas is growing in importance, as its share of India's energy consumption has risen from just 1.4% in 1980, while hydroelectricity which made up 11.5% of the country's energy usage in 1980 has declined in relative importance. Nuclear (1.7%) and geothermal, wind, solar, and biomass (0.2%) made up a very small share of the country's energy consumption in 2007[2]. Between 1990 and 2007, India's carbon emissions increased by an astonishing 61%, a rate surpassed only by China's 111% increase during the same time. India's carbon emissions are expected to continue to increase throughout the decade, offsetting the planned reduction in GHGs from the European Union and other countries that plan to implement the Protocol's emissions cut requirements. The rise in India's carbon emissions has been exacerbated by the low energy efficiency of coal-fired power plants in the country. With the high capital costs associated with replacing existing coal-fired plants, a scarcity of capital, and the long lead time required to introduce advanced coal technologies, it stands to reason that many of India's highly-polluting coal-fired power plants will have to remain in operation for the next couple of decades[3]. As such, India's contribution to world carbon emissions is expected to increase in coming years, with an estimated average annual growth rate between 2001 and 2025 of 3.0% in the EIA International Energy Outlook 2003 reference case (compared to 3.4% in China and 1.5% in the United States)[4]. India's per capita carbon emissions are relatively low at 0.25 metric tons of carbon per person in 2007, India's per capita carbon emissions were less than one-quarter of the world average and 22 times less than the United States. However, the country's per capita carbon emissions are expected to increase in the coming years due to the rapid pace of urbanization, a conversion away from noncommercial towards commercial fuels, increased vehicular usage and the continued use of older and more inefficient coal-fired plants. In fact, due to fast-paced industrialization, per capita emissions are expected to triple

[2] Planning Commission Government of India, Plan Documents
[3] Plan Documents, Planning Commission, Government of India
[4] EIA International Energy Outlook, 2003

by 2020[5]. The brief discussion about the commercial energy shows that the country is having potential in some cases but utilization is not up to the desired level. From the oil front, it is apparent that country has to rely on import. Due to the volatility of the international market country's import bill is rising. On the other hand, transmission and distribution losses are making the electricity sector critical. The industrial sector in India is a major energy user, accounting for about 65% of the commercial consumption (EIA, 2004). There are wide variations in energy consumption among different units within the same industry using comparable technology. India's per capita commercial energy consumption, increased from 9% of global average in 1965 to 19.4% in 2000 (TERI, 2000). In 1998-99, commercial energy consumption in India was estimated at 195.11 MT of oil equivalent, indicating a 75% growth over a decade. However, India's per capita consumption of commercial energy continues to be much lower than the global average of about 1684 Kg of oil equivalent and is 5-10% that of developed countries like; Japan, France and the USA. In India, commercial energy demand grew at six percent (CMIE, 2001).

2.1 Variation in Energy Consumption in Indian Manufacturing

To begin with, we are looking at the percent changes in the consumption pattern of the entire manufacturing industries at aggregate level. The annual consumption data for the industries are collected from the PROWESS database from the year 1990 to 2008. The data are collected based on the energy consumption of electricity, coal and petroleum these industries. Following the standard conversion (Table-1A) all the different energy sources are converted in to the standard *Metric Tons of Oil Equivalent* (hereafter TOE). The attempt here is to understand the pattern of energy consumption at the industries level and specifically to look at the changes in energy consumption and energy intensity. This will help us to link with the changes in the energy intensity as we are considering changes in production for these industries as well. Table-1, summarizes the CAGR changes in the energy consumption of Indian Manufacturing and the industries in the Manufacturing from 1990-2008.

[5] Plan Documents, Planning Commission of India

Table-1: Compound Annual Growth Rate of Energy Consumption in Indian Manufacturing and the sub industries for different time periods from 1990-2008 (in percentage)

Sl No.	Industries/Year	1990-94	1995-99	2000-04	2005-08	1990-08
1	Aggregate Manufacturing	16.77	9.23	8.01	11.98	9.80
2	Chemicals	15.46	9.09	8.90	7.69	9.76
3	Diversified	12.87	5.57	5.64	18.63	5.66
4	Food & beverages	19.11	5.41	10.53	7.77	10.38
5	Machinery	18.84	9.43	5.43	9.10	9.13
6	Metals & metal products	15.49	11.78	9.34	15.33	10.77
7	Miscellaneous manufacturing	18.08	5.46	4.88	7.52	7.04
8	Non-metallic mineral products	19.73	9.92	7.60	17.09	10.63
9	Textiles	15.86	6.49	3.92	7.84	7.77
10	Transport equipment	21.71	12.21	10.02	12.56	12.63

Table above shows the compound annual growth rate of energy consumption of Indian industries from 1990 to 2008. We have tried to calculate the CAGR for four different periods for a better understanding of the changing pattern of energy consumption of Indian manufacturing industries. The CAGR of the aggregate manufacturing has the highest from the period 1990-94 and least for the period 2000-04, however the overall growth rate of the energy consumption is calculated to be 9.80%. The chemical industries had recorded the highest growth in energy consumption from 1990-94 and the growth rate stated declining and the next period the chemical industries has recorded 9.09% growth in the energy consumption as compared to 15.46% in the previous period. The growth rate in the energy consumption has continued to decline in the further period also. The least growth rate in the consumption of the energy resources has recorded for the period 2005-08. The overall growth in the energy consumption for the chemical industries remained at the 9.76 percentage from 1990-2008. It's indeed interesting to notice that the overall growth in the energy consumption for the chemical industries was less than that of the aggregate manufacturing industries in India.

When we discuss the performance of the diversified manufacturing we can see that the changes in the growth rate in energy consumption was recorded the highest for the period 2005-08. As our analysis begins from 1990 we can see that the change in the energy consumption for the diversified manufacturing was recorded 12.87% from the period 1990-94. Suddenly the growth rate declined to 5.57% in the period from 1995-99. With a marginal increase in the growth rate in the energy consumption in the next period from 2000-04, the growth rate in the energy consumption reached the ever highest of 18.63% for the period 2005-08. However all the fluctuations keeping apart the growth rate in the energy consumption for the diversified manufacturing from 1990-2008 was calculated to be 5.66% of compound annual growth. In case of the food and beverages industries the growth rate of energy consumption was the highest for the period 1990-94 and lease for 1995-99, with an overall growth rate of 10.38% from 1990-2008. For these industries the rise in the growth rate in energy consumption was recorded in two different periods (1990-94 & 2000-04).

The machinery industries recorded the highest growth rate in energy consumption in terms of growth for the period 1990-94 and least for the period 200-04 with an overall growth rate of 9.13% form 1990-2008. From 1990-94, the metals and metal products industries have recorded a growth of 15.49% in energy consumption. With 10.77% of CAGR these industries have the least growth rate from 2000-04. The miscellaneous manufacturing industries have a growth of 18.08% in energy consumption for the period 1990-94, which came down to 5.46% in the next period. Further with a marginal decline the energy consumption of these industries have reached to 7.52% in the period 2005-08. However the overall CAGR of these industries were calculated to be 7.04%. The computed CAGR in energy consumption for the non-metallic mineral products was 19.73% in 1990-94 which declined to 9.92% in the next period. With a further decline to 7.60%, the CAGR of these industries reached to 17.09% for the period 2005-08. However the overall CAGR of these industries were calculated to be 10.63% from 1990-2008.CAGR of 15.86% was calculated for the textile industries from the period 1990-94. Further for continuously for two periods the CAGR of energy consumption for the textile industries declined and reached to ever low CAGR of 3.92% from 2000-04. However in the next period there has a positive change and higher consumption in energy resources have recorded and the CAGR of the textile industries reached to 7.84% for 2008-08, with an overall CAGR of 7.77 percent. In case of the transport equipment industries the CAGR of the energy consumption was calculated to be 21.71% in the first period from 1990-1994. However the growth rate declined to 12.21% in the next period, which further declined to 10.02% in 2000-04. However in the next period the CAGR of the industries in terms of energy consumption increased to 12.56%, with an overall CAGR of 12.63% from 1990-2008.

The analysis of the annual growth rates provides an outlook of the changes in energy resources of the Indian manufacturing industries as well as the nine sub industries independently. However it’s more of interesting to notice the performance of the nine industries in each year with respect to the aggregate manufacturing industries. Hence when we observe the CAGR of the each industries and the aggregate manufacturing for the period 1990-94, we can see that the growth of energy consumption for the aggregate manufacturing was calculated to be 16.77%. However, in the same period the CAGR of the transport equipment industries was much higher than that of the aggregate manufacturing and calculated to be 21.71%. In the same period we can see that the CAGR of the diversified manufacturing industries have recorded the least as compared to the other eight industries as well as the aggregate manufacturing industries and recorded a growth of 12.87%. Moving forward in the next period from 1995-99, we can observe that the transport equipment industries again have recorded a highest CAGR in terms of energy consumption as compared to the other industries.

On the other hand the food and beverages industries have recorded the least CAGR for the same period as compared to all other industries in the study. The highest compound annual growth rate in energy consumption for the period 2004-05, was calculated for the food and beverages industries and the least growth in energy consumption was calculated for the textile industries, which is much lower from the aggregate manufacturing industries. The diversified manufacturing industries have recorded the highest CAGR of 18.63% for the period 2005-08 as compared to the aggregate manufacturing industries as well as compared to the other eight other manufacturing sub-industries. Further when we look at the overall performances of the industries in terms of the energy consumption from 1990-2008, we can see that the CAGR of the aggregate manufacturing was 9.80%, while the highest growth was calculated for the transport equipment (12.63%) and the least CAGR was calculated for the diversified manufacturing industries (5.66%).

From the discussion it is clear that the there is a changing pattern of the energy consumption is clearly visible for the Indian manufacturing industries. There is fluctuation in the growth rate for the aggregate manufacturing as well for the other sub-industries in study. Hence there is the possibility of changing energy intensity of the industries as well. As the approach of the study is to decompose the energy intensity of the Indian manufacturing industries, the inter industries changing pattern of energy consumption is of more importance. However it is of importance to look at the changing pattern of the output share of the each of the industries in the stated period too for a better picture to study the energy intensity variations in the Indian manufacturing industries.

Table-2: Sectoral Share of Output in Indian manufacturing sub-sectors from 1990-2008 (in percentage)

Sl No.	Industries/Year	1990	1995	2000	2005	2008
1	Chemicals	38.55	39.20	45.11	46.39	46.67
2	Diversified	4.03	2.67	1.75	1.61	1.79
3	Food & beverages	7.94	8.91	8.88	8.34	6.93
4	Machinery	13.33	12.60	10.96	9.39	10.57
5	Metals & metal products	14.08	13.58	11.05	12.82	14.01
6	Miscellaneous manufacturing	2.42	2.46	2.26	2.16	1.65
7	Non-metallic mineral products	4.60	5.09	4.94	4.91	5.35
8	Textiles	8.29	8.20	6.76	5.11	3.69
9	Transport equipment	6.74	7.29	8.29	9.28	9.35
10	Aggregate Manufacturing	100.00	100.00	100.00	100.00	100.00

The changing pattern of the sectoral share of the each sub industries is given in the table-2. We can see from the table that the chemical industries are continuously growing in its sectoral share in output from 1990-2008. With a share of 38.55% in 1990, the industries have grown to 46.67% in the year 2008. However in case of the diversified manufacturing industries we can see that the percentage share of the industries were the highest for year 1990 at the 4.03%, which came down to 2.67% in 1995, with further decline to 1.75% and 1.61% for the years 1995 and 2000 respectively. The share of the diversified industries has marginally gone up in the year 2008, with a marginal increase to 1.79%. The highest share of the food & beverages industries was calculated for the period 1995 to be 8.91% which is higher than that of the year 1990 (7.94%). However the share of these industries, have fallen down continuously from 1995 till 2008 and the least share of the industries was calculated for 2008 at 6.93%.

In case of the machinery industries the highest share of the industries have calculated for the year 1990 at 13.33%, which declined to 12.60% for the year1995 and continuously till 2005 at 9.39% and increased to 10.57% for the year 2008. When we observe the metal and the metal product industries, the highest share of the output is calculated for the year 1990. The share of the industries declined till 2000 at 11.05% and increased to 12.82% in 2005. The share of the industry increased further and accounted for 14.01% in the year 2008. 2.42% sectoral share was calculated for the year 1990 for the miscellaneous industries. The share of the industry registered highest for the year 1995 at 2.46% and started declining further till 2008. The least share of the industries have calculated for the year 2008 at 1.65%. The least share in the output was calculated at 4.60% for the non-metallic product industries for the year 1990. In 1995 the share of these industries to the total manufacturing industries increased to 5.09% and further declined to 4.94% and 4.91% in the years 2000 and 2005 respectively. However in the year 2008 the output share of the industries increased and recorded the highest share at 5.35%. The textile industries have a share of 8.29% in the year 1990, which is calculated to be the highest percentage share from 1990 till 2008. Further the share of this industry declined till 2008 and recorded least share for the year 2008 at 3.69%. However the case of the transport equipment industries is quite different from the textile industries. The output share to the total manufacturing production of the industries has least share for the year 1990 (6.74%) and continuously increasing from 1990, and recorded the highest share in the year 2008 at 9.35%.

The discussion above gives an idea of the changing pattern of the output share of the sub-industries to the total manufacturing industries. We can see that, the sectoral share of the output of the industries is being changing over the period of time. The output of an industry has a direct relation to the calculation of the energy intensity of the industry. Hence in the decomposition of energy intensity this is one of the major variables. Now the question arises what happens when the sectoral share of the industries changes to the change in the energy consumption of the industry? To deal with the question les us observe both the table simultaneously.

Comparing both the tables we can see that in case of the chemical industries, the output share of the industries is growing up and the growth of the energy consumption is decreasing till 2005, and started growing up in the next period. However when we observe the diversified manufacturing the picture is not that clear. The output share of the industries is decreasing over time however the changing pattern of the energy consumption is not following. Rather the growth of the energy consumption is not following a certain trend, at long term definitely it’s increasing. Hence we can assume that the industries are not performing well in terms of the energy consumption as compared to the chemical industries. In case of the food and beverages industries we can see that the growth rate of the energy consumption in the initial period is much higher as compared to the other time period. At the same time there is no much change in the sectoral share of the output of the industries.

In case of the machinery industries it can be observed that the output share of the industries is decreasing till 2005 and increasing hereafter. However in case of the growth rate of the energy consumption we can see that in the first period from 1990-94, the change in the energy consumption is much higher as compared to the other time periods and from 1990-94 the CAGR of the industries is declining as decline in the output share and further increasing as the output share is increasing. In case of the metal and metal product industries is can be observed that the growth in the energy consumption is decreasing as the output share of the industries is decreasing and further increasing as the output share of the industries is increasing. However the case of the miscellaneous manufacturing industries is following a different pattern. Even the output share of the industries is decreasing there is a increasing trend in the energy consumption of the industries. In case of the non-metallic mineral products industries there is not much variation in the output share of the industries, however a greater fluctuation can be seen in case of the growth of the energy consumption of the industries.

The output share of the textile industries is declining from 1990-2008 and the growth rate of the energy consumption is also decreasing till a point up to 2000-04. However after this period the growth rate of energy consumption of these industries are increasing even the share of the output of the industries is decreasing. The transport equipment industries output share is increasing from 1990-2008. When we observe the growth rate of the energy consumption of these industries we can see that only for the period 1990-94, the industries have recorded a higher growth rate and is declining. Further the growth rate of the energy consumption is increasing with the increase in the output share of the industries.

From the discussion above we are not sure which is more important in order to know the changing pattern of the energy intensity of the Indian manufacturing industries. In other words which is the most important factor that influences the energy intensity of the Indian manufacturing? From the above analysis we can see both the sectoral change as well as the variation in the energy consumption in intra-industries is the important contributors of the changes in the energy intensity of the Indian manufacturing industries. To deal with the question we have tried to decompose the energy intensity of Indian manufacturing in the next section. However it is important to look at the variation of the energy consumption and the energy intensity of Indian manufacturing from 1990-2008.

The variation in energy consumption of Indian manufacturing industries is given in firure-1. From the figure it can be seen that the energy in terms of absolute terms is following a rising trend from 1990-2008. A steep rise in the energy consumption is observed from 1991-1992. However from 1992 to 1994 the energy consumption decreased and then increased till 2008.

The energy intensity of Indian manufacturing is given in figure-2. From the figure we can see that from 1990 the energy intensity of the manufacturing industries started decreasing and it reached the ever lowest intensity value in the year 1992. However from 1992 the intensity of the energy consumption started growing up till 1994. Again from 1996, the energy intensity of Indian industries went up as compared to the previous year till 1998. However from 1990 to 2008 the energy intensity of Indian industries is following a decreasing trend.

Figure-1: Energy Consumption of Indian Manufacturing from 1990-2008 (TOE)

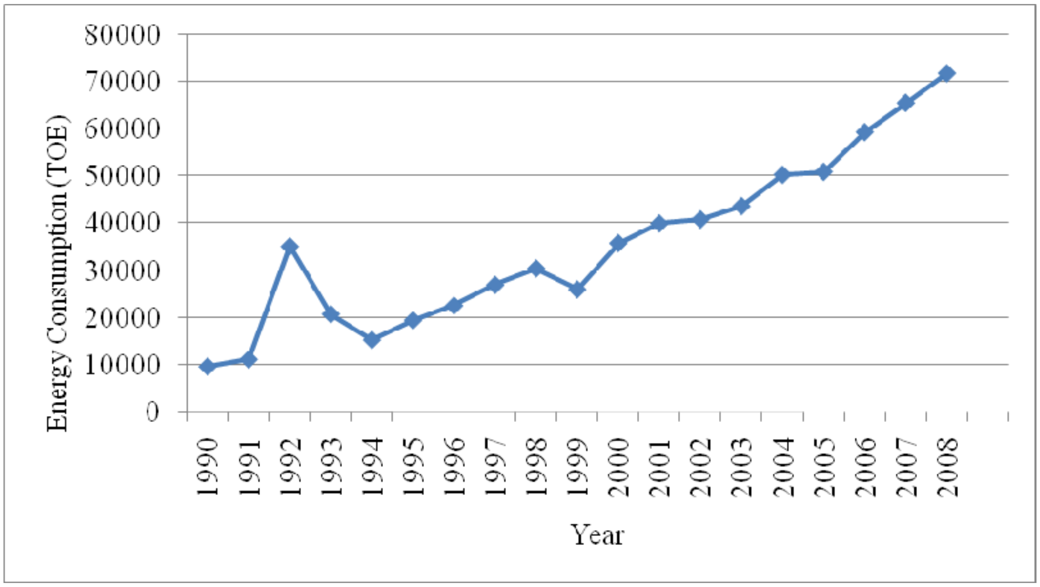

Figure-2: Energy intensity of Indian manufacturing from 1990-2008 (TOE/Output)

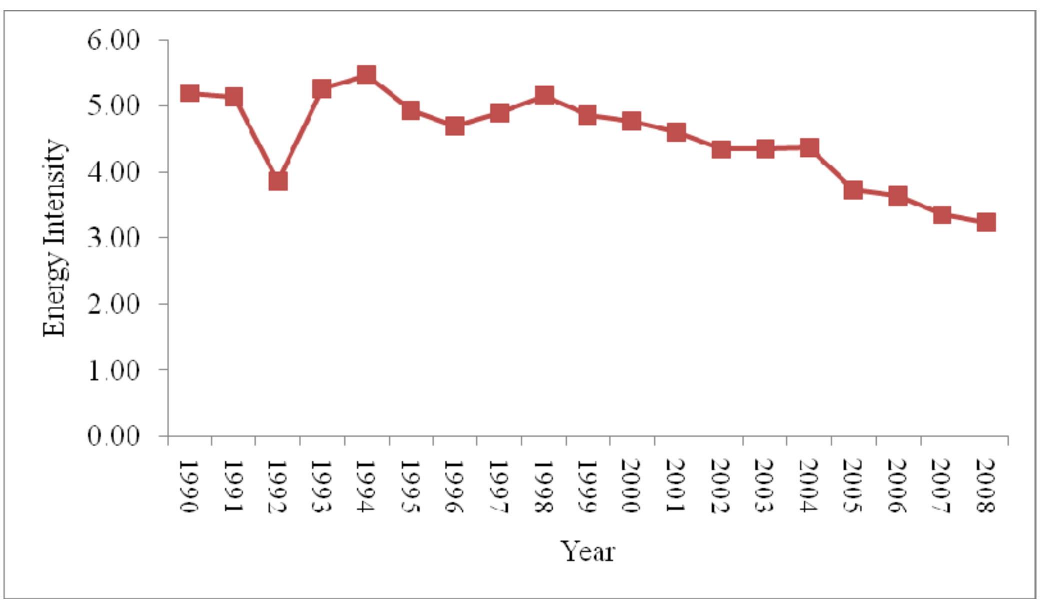

Figure-2, gives an idea of the changing pattern of the energy intensity of Indian manufacturing. For a detail analysis we have tried to look at the mean changes at different period from 1990-2008. Table-3 gives the mean changes in the energy intensity of the Indian manufacturing industries. For the aggregate manufacturing industries we can see that the energy intensity is decreasing from 1990 to 2008. We can see that from 1990-94 the mean energy intensity of aggregate manufacturing industries was calculated to be 4.98, which continued to decline to 3.49 during 2005-08. The overall energy intensity of the Indian manufacturing industries was calculated to be 4.51. The chemical industries are too following the same pattern as the total manufacturing industries. In each of the stated period the energy intensity is falling (from 3.90 to 2.01). There is a continuous decrease in the energy intensity in each period. The overall energy intensity from 1990 to 2008 for the chemical industries was calculated to 3.13, which is much lesser than that of the total manufacturing. In case of the diversified manufacturing industries we can see that the mean energy intensity was calculated to be 6.60 for the period 1990-94. The energy intensity of these industries increased at reached at 7.08 for the period 1995-99. However further the energy intensity of the industries decreased and the overall energy intensity of the diversified manufacturing were calculated to be 6.26.

The energy intensity of the food & beverages industries is much lesser than the aggregate manufacturing industries. The mean energy intensity of the industries are not much fluctuating. The overall mean energy intensity of the industry was calculated to be 2.50. The mean energy intensity of the machinery industries for the period 1990-94 was 1.44 which went up in the next period from 1995-99. With a further rise in the energy intensity to1.73 the mean energy intensity of the industries came down to 1.23 for 2005-08. The overall energy intensity of the machinery industries was calculated to be 1.52. The mean energy intensity of the metal and metal products industries are recorded highest for 2000-04 and the least mean energy intensity were calculated for 2005-08, with an overall energy intensity of 8.52. The mean energy intensity of these industries is higher than that of the aggregate manufacturing industries.

From 1990-94 the mean energy intensity of the miscellaneous manufacturing industries was calculated to be 11.06 which increased in the next period of the study, hereafter the mean energy intensity of these industries decreased an very recently the mean energy intensity of the industries was calculated to be 6.99, with an overall energy intensity of 9.62. However in case of the non-metallic mineral products there has been a fluctuation in the changes in the mean energy intensity from 1990 to 2008. In case of the textile industries we can see that from 1995-2004 the industries had recorded a higher energy intensity compared to the other two periods. For the transport equipment industries we can see that a constant decrease in the energy intensity from 1990-2008. The overall mean energy intensity of these industries was calculated to be 1.88. From this analysis we can see that the changes in the mean energy intensity of the sub-industries are not following the same way that the aggregate manufacturing industries are following. Hence the sectoral energy intensity changes are too crucial in order to determine the energy intensity changes in the Indian manufacturing.

Table-3: Mean changes in the energy intensity of Indian manufacturing from 1990-2008

Sl No	**Variable**	**1990-94**	**1995-99**	**2000-04**	**2005-08**	**1999-08**
1	Aggregate Manufacturing	4.98	4.90	4.48	3.49	4.51
		(0.64)	(0.17)	(0.19)	(0.23)	(0.67)
2	Chemicals	3.90	3.38	3.00	2.01	3.13
		(0.31)	(0.23)	(0.19)	(0.24)	(0.72)
3	Diversified	6.60	7.08	6.11	5.02	6.26
		(0.56)	(0.43)	(0.27)	(0.36)	(0.85)
4	Food & beverages	2.52	2.58	2.58	2.27	2.50
		(0.29)	(0.15)	(0.13)	(0.08	(0.21)
5	Machinery	1.44	1.64	1.73	1.23	1.52
		(0.27)	(0.11)	(0.06)	(0.18)	(0.25)
6	Metals & metal products	8.15	9.09	9.39	7.18	8.52
		(1.77)	(1.12)	(0.45)	(0.52)	(1.34)
7	Miscellaneous manufacturing	11.06	11.17	8.73	6.99	9.62
		(2.51)	(1.09)	(0.92)	(0.10)	(2.20)
8	Non-metallic mineral products	14.90	16.45	14.72	12.42	14.74
		(3.73)	(0.82)	(1.04)	(0.59)	(2.36)
9	Textiles	6.89	7.04	7.62	6.97	7.14
		(0.43)	(0.63)	(0.26)	(0.21)	(0.49)
10	Transport equipment	1.98	1.98	1.96	1.54	1.88
		(0.19)	(0.12)	(0.08)	(0.10)	(0.22)

Note: SD given in brackets, Data sources: CMIE

3 Review of Literature

Numerous studies by national and international experts have referred to the large scope and potential for energy efficiency in the Indian economy. Energy intensity in Indian industry is among the highest in the world. The manufacturing sector is the largest consumer of commercial energy in India. In producing about a fifth of India's GDP, this sector consumes about half the commercial energy available in the country. Energy consumption per unit of production in the manufacturing of steel, aluminum, cement, paper, textile, etc. is much higher in India, even in comparison with some developing countries.

One of the index methods available to compare and decompose energy consumption and energy intensity is the Divisia index model (Difference and ratio). Rose and Caster (1996) have summarized various types of decomposition methods. In all these studies, residual term is considered as zero. Ang and Lee (1994) observe that a major part of the observed changes in the energy consumption being decomposed is left unexplained. This means that the residuals give large estimation error in the decomposition analysis. Park (1992) has shown that the structural effect, calculated as a residual raises a number of logical questions. First, he takes the mean value of the variable in question between the base period and the end period. Like the net effect, structural change on industrial energy consumption between any two periods can be isolated by measuring a change in energy consumption associated with a change in the industrial composition during the period. This can be done while holding all other variables of the base period constant at their initial values (energy intensities of the individual industry branches and total industrial output in this case). Similarly, separate industrial output effect can be measured by allowing the industrial output to change, while the values of other variables are kept constant at their initial values. In short, this method may relate more closely to this ceteris paribus change concept**.** Second, and more importantly, the method failed to introduce structural change explicitly as a variable in the equation. As a result, this method may yield estimates at variance with those obtained from a method that incorporates the structural change variable. Hence, the structural effect calculated as a residual by the method contains more than the effect of structural change (including the joint effects of other variables). Sun (1998) has used a complete decomposition model where residuals are decomposed by the jointly created and equally distributed rule and compared the results with the general decomposition modeling. Bhattacharya and Paul (2001) used the total decomposition approach on energy consumption and energy intensity at sectoral level (agriculture, industry, transport, others). They have shown that the intensity effect contributes significantly to energy conservation.

Trend decomposition is probably one of the most common methods employed in the analysis of energy or emissions trends. Particularly, in the case of industrial energy analysis, where energy consumption is characterized by a multitude of very diverse uses, decomposition has proven to be a useful technique for the attribution of changes in energy consumption to such factors as changes in industrial structure or output mix, declines in energy intensity (e.g., energy efficiency improvements), and a number of other factors. Although widely used by a variety of researchers and organizations, no single or standard method for energy trend decomposition has emerged. Without a standard or generally accepted method, analysts are confronted with not only the issue of identifying and collecting data, but also the issue of selecting the appropriate method.

The decomposition of industrial energy consumption to study the energy impacts of structural change (i.e. shifts in the composition of industrial production) and energy efficiency improvements has been an actively researched topic. Many studies, both methodological and empirical, have been published. In one of the papers of Liu et al, 1997 looked into the methodological aspect and proposed two general parametric decomposition methods based on the Divisia index. They introduced a framework for formulating decomposition methods and showed that a number of the previously proposed methods are special cases of the two general methods. Ang and Lee, 1994 extended the work of Liu et al, 1997 by considering five specific decomposition methods. They discussed several application issues such as method selection and result presentation, and compared periodwise decomposition and time series decomposition. Periodwise decomposition is a single decomposition based on the energy and production data for two benchmark years and the data for the intervening years are not considered, whereas time series decomposition involves yearly decomposition using the time series energy and production data.

The studies by Liu et al, 1997 and Ang & Lee, 1994 deal with decomposition techniques that we shall refer to as the energy consumption approach, i.e. decomposition changes in total industrial energy consumption over time into contributions from changes in aggregate production (the production effect), production share (structural effect) and sectoral energy intensities (intensity effect). Several methods have also been proposed by various analyses using the energy intensity approach where decomposition is carried out on changes on aggregate energy intensity. Aggregate energy intensity is defined as the ratio of the total industrial energy consumption to industrial output. In the energy intensity approach, changes in the intensity are decomposed into contributions from structural and intensity effects only. Examples of such studies are Jenne and Cattell , 1983, Bending et al, 1987, Boyd et al, 1987, and Howarth et al, 1991. The energy intensity approach has been used in a large number of empirical and country specific studies. Examples of such studies are Bossanyi, 1983, Jenne and Cattell, 1983, Ang, 1987, Li et al, 1990, Gardner, 1984, and Huang, 1993.

While Liu et al, 1992 and Ang & Lee, 1994 have studied the general methodological and application issues related to the energy consumption approach, similar studies for the energy intensity approach have so far reported only in Ang 1994. The aim of this paper is to support the findings of such study for Indian Manufacturing industries. Figure-3 summarizes the general framework of the decomposition based on the scope of three studies. Based on the energy intensity approach, we shall introduce the two general parametric Divisia methods which are equivalent to those given in Liu et al, 1992 and describe their formulation in the multiplicative and additive forms. Further we then consider the five specific methods which are equivalent with Ang & Lee, 1994. Comparisons will also be made between the energy intensity approach and the energy consumption approach for the Indian Manufacturing industries.

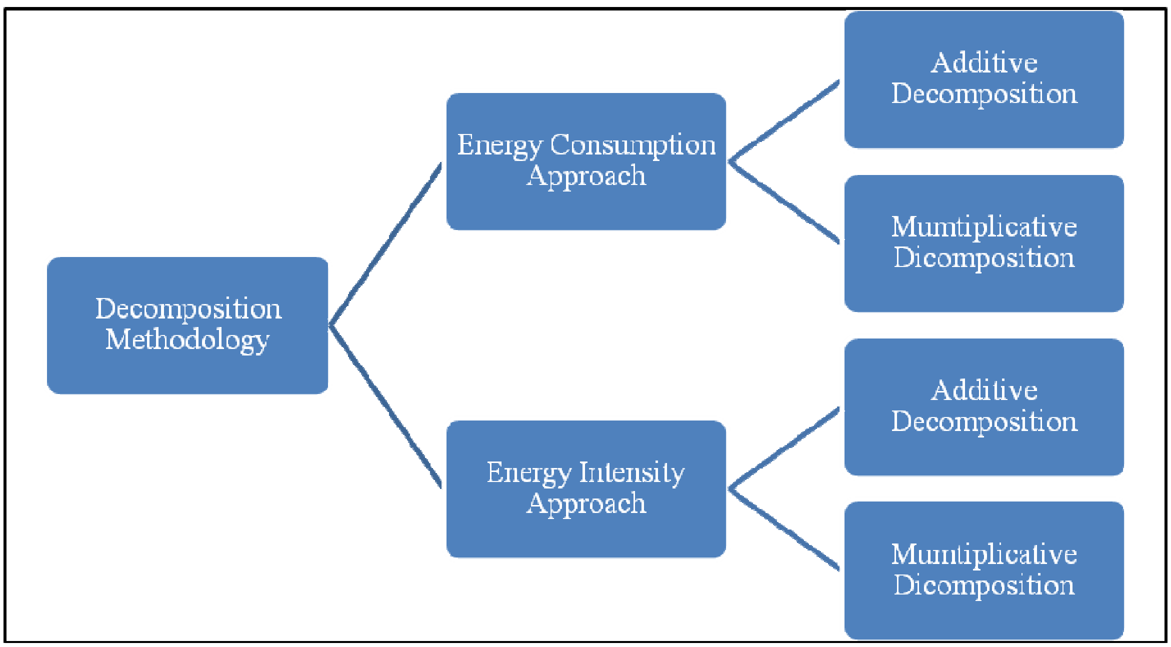

Figure-3: Decomposition Methodology: A general Framework (Ang, 1994)

4 Methodology and Empirical Results[6]

The detail methodology followed in the study is narrated to explain the underlying concept with reference to the decomposition of a change in the aggregate energy intensity of Indian Manufacturing Industry. We are following the two-factor case in which a change in the aggregate intensity is decomposed to give the impacts of structural change and sectoral energy intensity change. As stated we have decomposed the energy consumption of Indian manufacturing industries with the energy intensity approach.

Let us assume that total energy consumption is the sum of consumption in "***n***" different industrial sectors time "***t***". As defined earlier the we have defined the energy intensity as a ratio of the energy consumed (converted to Metric Tons of Oil Equivalent) for the industry "***i***" at time "***t***" to the total out of the same industry for the same time in monetary values (Rupees in Cr.)

E_t = Total Energy Consumption in industry

$E_{i,t}$ = Energy Consumption in industrial sector i

Y_t = Total Industrial Production

$Y_{i,t}$ = Production of industrial sector i

$S_{i,t}$ = Production share of sector i $(=Y_{i,t}/Y_t)$

I_t = Aggregate energy intensity $(=E_t/Y_t)$

$I_{i,t}$ = Energy intensity of sector i $(=E_{i,t}/Y_{i,t})$

Let us express the aggregate energy intensity as a summation of the sectoral data as:

$$I_t = \sum_i S_{i,t} I_{i,t}, \qquad (0.1)$$

Where the summation is taken over the n sectors

[6] For detail methodology please see *B. W. Ang, 1994, Energy Economics, V-16, No.3*

To quantify the impacts, two approaches- the Laspeyres index approach and the Divisia index approach, have been widely adopted. We are following both the approaches. The Laspeyres Index approach follows Laspeyres price and quantity indices by isolating the impact of a variable by letting that specific variable change while holding the other variables at their respective base year values (in this case, Year 0).

4.1 The Multiplicative Laspeyres Decomposition Technique

The aggregate energy intensity is expressed in terms of production share and sectoral intensity. Suppose the aggregate energy intensity varies from I_0 in year 0 to I_t in year *t*. Such a change can be expressed as,

$$D_{tot} = I_t / I_0 \tag{0.2}$$

Where D_{tot} refers to the aggregate change in energy intensity, which is in terms a ratio. Accordingly, decomposition may be conducted using multiplicatively and hence, the expressions takes the following form

$$D_{tot} = I_t / I_0 = D_{str} D_{\text{int}} \tag{0.3}$$

Where D_{str} denotes the impact of structural change, and D_{int} denotes the impact of sectoral intensity change. In multiplicative case all the terms are given in indices.

Further equation 1.8 can be written as:

$$D_{str} = \sum_i S_{i,t} I_{i,0} / \sum_i S_{i,0} I_{i,0} \tag{0.4}$$

$$D_{\text{int}} = \sum_i S_{i,0} I_{i,t} / \sum_i S_{i,0} I_{i,0} \tag{0.5}$$

$$D_{res} = D_{tot} / (D_{str} D_{\text{int}}) \tag{0.6}$$

Where D_{res} and D_{tot} are the residuals and the total intensity change over a period. In the Multiplicative Laspeyres Index Approach, the residual terms D_{rsd} denote the part that is left unexplained. Decomposition is considered perfect if D_{rsd} =1

The results of the decomposition is as stated based on the multiplicative lasperyres index approach. In this exercise we have tried to explore the linkages between the structural change, aggregate energy intensity changes and the sectoral energy intensity changes. Given the data set in use and the methodology adopted the results vary from one method to the other. And hence this gives an opportunity to study and compare the different methods. In this study we are using mainly two approaches (Lespeyres and the Generalised Parametric Divisia method). Comparing the two methods gives firstly a methodological advance as well as the empirical differences which gives us space in modifying and creating new methods in future. Each of the methods can be computed with additive as well as in multiplicative approach. However, at this stage we have worked out for the multiplicative approach.

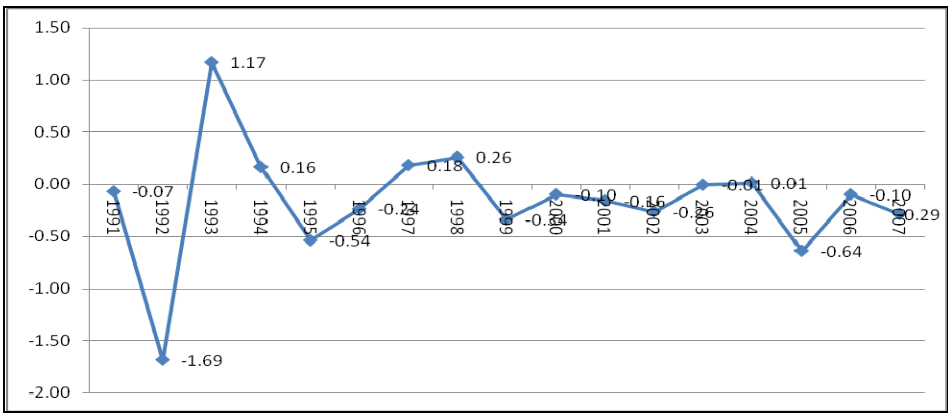

Figure-4: Output of the reseduals of decomposition analysis based on Multiplicative Laspeyres Index Approach

Here we have analyzed the different results obtained for four factors such as the total industrial intensity, intensity change due to the sectoral intensity change, intensity change due to the structural effect and the residuals. In the following discussions, we have tried to capture the factors responsible in change in the total energy intensity in Indian manufacturing. Majorly we have discussed to factors namely the sectoral energy intensity change and the structural effect with respect to the total energy intensity change. The results are given in table-4. As given in the previous discussion the residuals if tending to zero, it can be conformed that the decomposition is perfect. However, we can see that there are variations in the residuals output in the analysis and many of them are not tending to zero. Figure-4 can give a broad outline of the result obtained from the analysis. As we are considering the Generalised Parametric Divisia method approach, we will compare the results of the residuals terms to interpret the results.

Table-4: Results of the Decomposition based on the Multiplicative Laspeyres Index Approach

Year	ΔI_{tot}	ΔI_{str}	ΔI_{int}	ΔI_{res}
1991	-0.0665	0.0178	-0.0133	-0.0711
1992	-1.2689	1.7496	-1.3324	-1.6860
1993	1.4027	-1.4011	1.6369	1.1670
1994	0.2008	-0.2583	0.2957	0.1634
1995	-0.5370	0.5076	-0.5037	-0.5410
1996	-0.2348	0.2216	-0.2181	-0.2384
1997	0.1991	-0.2764	0.2943	0.1812
1998	0.2611	-0.2347	0.2385	0.2573
1999	-0.2982	0.0643	-0.0226	-0.3399
2000	-0.0916	0.1492	-0.1419	-0.0988
2001	-0.1567	0.1218	-0.1190	-0.1595
2002	-0.2629	0.2305	-0.2288	-0.2646
2003	0.0013	0.0235	-0.0157	-0.0065
2004	0.0195	0.0282	-0.0215	0.0128
2005	-0.6319	0.6684	-0.6594	-0.6409
2006	-0.0941	0.0836	-0.0787	-0.0990
2007	-0.2824	0.3040	-0.2973	-0.2891

Source: CMIE Data base accessed on 16th August, 2009 & own calculation

4.2 The General Parametric Multiplicative Divisia Method

We derive the two general parametric Divisia methods in a manner the same as that described in Liu et al., 1990. Let us define the variables as defined previously in the methodological section before in the initial paragraph of this section. Following Ang, 1994 let us aggregate energy intensity in terms of the disaggregated sectoral data as:

$$I_t = \sum_t S_{i,t} I_{i,t} \tag{0.7}$$

Where the summation is taken with respect to subscript *i* and over all the sectors at the level of disaggregation considered. Differentiating equation above with respect to *t* yields the following:

$$I_t^{'} = \sum_t I_{i,t} S_{i,t}^{'} + \sum_t I_{i,t}^{'} S_{i,t} \tag{0.8}$$

This involves the decomposition of two aggregate energy intensities. Now dividing equation 1.8 by I_T and integrating on both side from year 0 to year T, we have

$$In(I_T / I_0) = \int (\sum_i I_{i,t} S^{/}_{i,t} / I_t) dt + \int (\sum_i I^{/}_{i,t} S_{i,t} / I_t) dt \quad (0.9)$$

Let us define $R_{tot} = I_T / I_0$, where R_{tot} is the change in aggregate energy intensities. As we are considering the two-factor decomposition the R_{tot} is defined as the changes in the energy intensity in time T over time 0. Now equation 1.14 can be rewritten as the following expression:

$$R_{tot} = \exp\{\sum_i I_{i,t} S^{/}_{i,t} / I_t dt\} \exp\{\sum_i S_{i,t} I^{/}_{i,t} / I_t dt\} = R_{str} R_{\text{int}} \quad (0.10)$$

Where R_{str} is the estimated structural effect and R_{int} the estimated intensity effect.

The equations for the structural as well as the intensity effect are as follows:

$$R_{str} = \exp\left[\sum_i [I_{i,0} / I_0 + \beta_i (I_{i,T} / I_T - I_{i,0} / I_0)] x (S_{i,T} - S_{i,0})\right] \quad (0.11)$$

$$R_{\text{int}} = \exp\left[\sum_i [S_{i,0} / I_0 + \tau_i (S_{i,T} / I_T - S_{i,0} / I_0)] x (I_{i,T} - I_{i,0})\right] \quad (0.12)$$

Where, $0 \le \beta_i, \tau_i \le 1$

The result of the decomposition drawn using the General Parametric Multiplicative Divisia Method, is presented in table-5. It can be clearly visible from figure-5 and table-5 that the residuals are tending to one, which is following the characteristics of the multiplicative index of decomposition. As compared to the multiplicative index approach, the General Parametric Multiplicative Divisia Method has resulted, a better result in decomposition. Hence, gives us a space to interpret the results based on the General Parametric Multiplicative Divisia index and can ignore the results obtained by the multiplicative decomposition.

Table-5: Results of the Decomposition based on the General Parametric Multiplicative Divisia Method

Year	R_{tot}	R_{str}	R_{int}	R_{res}
1991	0.9872	1.0035	0.9974	0.9863
1992	0.7526	1.4534	0.7402	0.6996
1993	1.3635	0.7337	1.4242	1.3049
1994	1.0382	0.9527	1.0562	1.0317
1995	0.9017	1.1031	0.9078	0.9005
1996	0.9523	1.0472	0.9557	0.9515
1997	1.0424	0.9435	1.0627	1.0397
1998	1.0534	0.9544	1.0488	1.0524
1999	0.9421	1.0133	0.9956	0.9339
2000	0.9811	1.0313	0.9707	0.9800
2001	0.9671	1.0265	0.9750	0.9663
2002	0.9429	1.0531	0.9503	0.9422
2003	1.0003	1.0054	0.9964	0.9985
2004	1.0045	1.0065	0.9950	1.0030
2005	0.8551	1.1792	0.8488	0.8543
2006	0.9748	1.0230	0.9789	0.9734
2007	0.9223	1.0906	0.9183	0.9210

Source: CMIE Data base accessed on 16th August, 2009 & own calculation

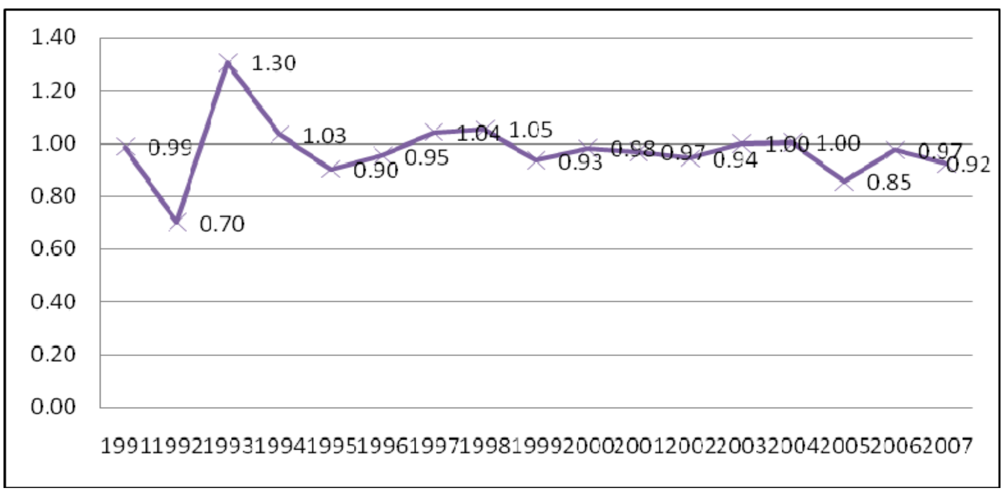

Figure-5 : Output of the residual term in decomposition analysis based on General Parametric Multiplicative Divisia Method

Table-6: Percent changes in Energy Intensity due to Structural Change and Sectoral Energy Intensity from the General Parametric Multiplicative Divisia Method

Year	**% change in** R_{tot}	**% Change in** R_{str}	**% Change in** R_{int}
1992	-23.46	44.99	-25.73
1993	61.09	-71.97	68.40
1994	-32.53	21.90	-36.80
1995	-13.65	15.04	-14.84
1996	5.06	-5.58	4.79
1997	9.01	-10.38	10.70
1998	1.10	1.10	-1.40
1999	-11.13	5.88	-5.32
2000	3.90	1.81	-2.49
2001	-1.40	-0.49	0.43
2002	-2.42	2.66	-2.47
2003	5.74	-4.77	4.61
2004	0.42	0.11	-0.13
2005	-14.93	17.27	-14.62
2006	11.96	-15.62	13.01
2007	-5.24	6.77	-6.07

Source: CMIE Data base accessed on 16th August, 2009 & own calculation

We can see from the table-6 that the changes in energy intensity is driven by the change in the structural change and changes in the sectoral change in energy intensity. In case of the year 1992, we can see that the negative change of -23.46 percent in the energy intensity as compared to the 1991 is driven by 44.99% change in structural change in the output, and -25.73% change in sectoral energy intensity. The change in the energy intensity is not consistence from 1991 to 2007, so as the case with both sectoral energy intensity change and the structural effect. Figure-6 explains this phenomenon using a diagram.

We can observe the variation in the total energy intensity, sectoral energy intensity and the change in energy intensity due to the structural effect from figure-6. It can be clearly noticed from the figure that the energy intensity change in Indian manufacturing in mainly due to the change in the structural change and has a negative relation between them. Once there a negative change in the sectoral share of output the energy intensity of the industries are rising and vice versa. However, the sectoral energy intensity has a positive relationship with the energy intensity of the Indian manufacturing. The changes in the sectoral energy intensity are following the changes in the total energy intensity of the industries. Hence, they are adding more in the energy intensity of the Indian manufacturing.

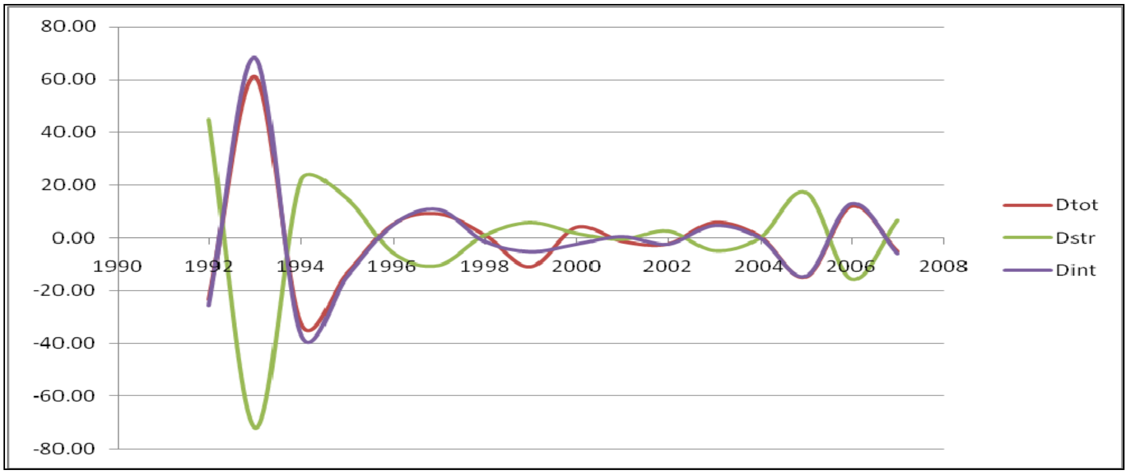

Figure-6: Percent changes in Structural Change and Sectoral Energy Intensity

Table-7: Period-wise aggregate and factorized energy coefficients for Indian manufacturing

Year	Rtot	Rstr	Rint	Rres
1990-1994	0.742	0.027	0.147	-0.446
1995-1999	1.354	0.055	-0.047	0.349
2000-2004	0.737	0.141	-0.128	-0.249
2005-2008	0.635	0.222	-0.215	-0.316

Source: CMIE Data base accessed on 16th August, 2009 & own calculation

However, the computed yearly coefficient tends to be unstable and can vary greatly from one year to next. Hence, to partly overcome the instability problem, period-wise coefficient may be calculated using the data for the beginning and ending years of a time period. The important consideration would be a significant growth in industrial production in the time period considered. Table-7 gives the period-wise decomposition of the industrial energy intensity using the general parametric divisia index.

4 Summary and Conclusion

In this study we have compared to decomposition methods and a period-wise decomposition. We can see from the results that the general parametric divisia index approach has resulted a better output as compared to the multiplicative Lespeyres decomposition index. Since decomposition can be done using either, the energy consumption approach or the energy intensity approach, the analyst is faced with the problem if making a choice between the two.

For a specific decomposition method, such as any one of the two we have considered the conclusion reached are most probably the same irrespective of the method is adopted. However the period wise decomposition gives a stable output as compared to the time series decomposition for the each year. The methods used in this paper provide a framework for method formulation for decomposition study of energy consumption in the industrial sector of any economy.

From the descriptive and the trend analysis we found that there is fluctuation in the annual growth rate of the energy consumption in the aggregate manufacturing as well as in the sub-industries. The changes are also not following the same direction. In case of few industries the changes in the growth rate is much higher than that of the total manufacturing industries. Again when we looked at the percentage share of the output to the aggregate manufacturing industries we observed that the share of the output are declining for few of the sub industries as well as increasing for few. The discussion on the energy consumption gave a picture of the energy consumption of the aggregate manufacturing, which is rising in the absolute terms, however the energy intensity of the Indian manufacturing is declining from 1990-2000. The energy intensity change in Indian manufacturing in mainly due to the change in the structural change and has a negative relation between them. Once there is a negative change in the sectoral share of output, the energy intensity of the industries are rising and vice versa. However, the sectoral energy intensity has a positive relationship with the energy intensity of the Indian manufacturing. As the changes in the sectoral energy intensity are unidirectional to the changes in the aggregate energy intensity of the industries, they are driving the changes in the aggregate energy intensity of the Indian manufacturing.

APPENDIX

Table-1A: Energy Equivalent Conversions

	Million Btu (British thermal units)	Giga (10^9) Joules	TOE (Metric Tons of Oil Equivalent)	TCE (Metric Tons of Coal Equivalent)
Million Btu (British Thermal units)	1.00000	0.94782	39.68320	27.77824
Giga (10^9) Joules	1.05506	1.00000	41.86800	29.30760
TOE (Metric Tons of Oil Equivalent)	0.02520	0.02388	1.00000	0.70000
TCE (Metric Tons of Coal Equivalent)	0.03600	0.03412	1.42857	1.00000

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