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The Changing Energy Intensity in Indian Economy: A Sector-level Analysis Based on Input-Output Model

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ABSTRACT

This paper is an attempt to analyze changing energy intensities in the Indian economy. The hybrid input-output model at constant prices has been used to address the problem of homogenous pricing of energy inputs across sectors of the economy. Results reveal that the indirect rather than direct energy use is an important source of energy consumption. In such scenario, conservation measures should be pegged in upstream suppliers through technological improvements, fuel substitution or input replacements. Finally, the paper argues that improvements in energy efficiency in the production chains are likely to be more effective than changes within the production process.

Keywords: Hybrid Input-output, Energy Intensity, Constant Prices
JEL Classifications: C67, D57, Q40

1. INTRODUCTION

Energy is a basic input for all economic activities. The direct energy use is attributed to consumption of primary energy as a fuel (e.g., electricity required to operate machines and equipment in the manufacturing process) or as a material input (e.g., natural gas used as feedstock in fertilizer industry). Energy is also directly consumed as a final good for various uses such as for electrification and as transport fuel in household sector of the economy. The demand for energy also varies by change in tastes and consumption habits of the consumer which in turn gets manifested in production process of the economy.

Energy intensity, initially measured on per capita consumption basis could not well indicate the level of development and efficiency of a country. Of late, energy consumption per unit of gross domestic product (GDP) or output is a preferred indicator of energy intensity. It indicates the total energy requirement to support economic and social activities in an economy. At the global level, total output expanded faster than energy use over time (De Cian et al., 2013; Yoder). The final use of energy increased whereas energy intensity of the output declined (IEA, 2008; GTF, 2013). Energy intensity is often used a proxy for energy efficiency. The rates of efficiency improvement, however, vary at the regional and country level. The developed countries and Eastern Asia accounted for bulk of the energy savings. The savings occurred notably in China, US, EU and India. Further, these countries performed diversely in terms of sources attributing to changes in energy intensity due to technology improvement and restructuring[1].

Also at the sectoral level, it is argued that efficiency improvements largely occurred in the sectors with initially higher level of energy intensity. The industrial sector featured as an example where it was easier to enhance efficiency. The quantum and sources of energy used in the sectors of production largely influence country level trends in emissions. This in turn highlights the importance of source-wise energy intensity. It is further essential to consider source-wise intensity due to the renewable and exhaustive nature of energy sources. This is particularly important for developing

1 Intensity improvements are highest for China and almost entirely due to technical changes while structural changes are influential in lowering intensity of the US. For India, technology changes contribute to lowering of intensity though the extent of decline is not as substantial (UNIDO, 2011).

countries like India which face enormous energy challenge due to a wide non-renewable energy base.

The energy use is also affected by changes in energy intensity of the producing sectors. The amount of energy consumed directly per unit of output incorrectly measures the energy intensity of an activity. Discounting the indirect energy consumed underestimates the energy intensity. Hence, measurement of energy intensity based on total energy use, including the indirect energy, is an appropriate measure of energy intensity. The significance of indirect energy consumption is best illustrated through the example of automobile industry. The manufacture of automobile uses various inputs such as steel, paints, glass and tyres besides other inputs. Each of these inputs in turn consumes energy during their respective production process. For instance, manufacturing of steel uses energy in the form of coking coal along with iron ore in the blast furnace. Similarly, paints are chemical derivatives of petroleum products as energy source, while the glass industry uses energy in the form of natural gas during the combustion process to heat furnace for melting raw materials that form glass. The tyre industry uses energy for process, heating, ventilation and cooling. Therefore, energy requirement of a given industry is a function of the energy consumption of its input industries, i.e., the upstream suppliers (Ahmed and Tandon, 2014). The chain of raw material suppliers can be traced down to the consumption of primary energy in all supplying industries. Thus, the embodied energy requirements for all goods and services can be estimated as a sum total of direct and indirect energy requirement. This is further essential for two following reasons. First, the proportion of direct energy consumption in total energy consumption varies across sectors of the economy thus highlighting the difference in direct energy intensities for sectors. Second, extent of the proportion of indirect energy intensity in total energy intensity, as compared with direct energy intensity, is useful from a policy perspective that mandates a focus on energy conservation efforts in the energy intensive sectors with significant output proportions.

India sources its energy requirements predominantly from non-renewable energy resources particularly due to large domestic reserves of coal[2]. Nearly half of the total energy demand is coal based amounting to 283 million tonne of oil equivalent (mtoe)[3]. Although the energy use is dominated by coal, yet its share in overall energy supply declined over time. During the period 1990-1991 to 2000-2001, the energy base shifted away from coal towards oil and natural gas. However, the share of coal increased again during the period 2000-2001 to 2011-2012 due to increased imports by non-coking coal by power utilities and cement industry along with imports of coking coal imports by the steel industry. The combined share of natural gas and crude oil increased to 43% at 234 mtoe. Nuclear power expanded its base to 17 mtoe with a share of 3%.

2 Energy sources are commonly classified on their renewable nature. The renewable sources are easily replenished into the environment system. Examples include hydro electricity, tidal energy and solar power. On the other hand, non-renewable sources are available in limited quantities as they cannot be reproduced quickly. Examples include fossil fuels such as coal, natural gas and oil.

3 Includes the demand for lignite, figures correspond to the year 2011-12, Source: Government of India (2008).

Electricity is a widely used form of energy across sectors of the economy for both intermediate use and final consumption. India's electricity is substantially coal based with a share of 56% in total installed capacity[4]. The diversification to the alternate non-renewable sources is well recognized as a means to meet the supply shortfalls from increasing demand for electrification with lower environmental externality. Electricity generation from renewables such as hydro and wind is encouraged by the policy makers as cleaner sources[5]. Hydro power accounts for 19.5% of total generation capacity while wind base power accounts for 8.6% share[6]. In fact, supply of electricity from renewable sources (including generation from wind, small hydro plants, biomass, waste to energy and solar system) has increased, albeit with a small base as compared to non-renewable electricity[7]. In view of the critical significance of renewables such as hydro power, a study distinguishing electricity generated from renewable and non-renewable sources becomes increasingly relevant. This further has significance in terms of viewing the non-thermal component of electricity as a composite of hydro and nuclear power.

In view of the above, a study of the changes in energy intensity in Indian economy is undertaken with the following objectives:

a. To identify the major energy consuming sectors, and
b. To analyze the contribution of indirect energy intensity embodied in the production.

We use the hybrid (input-output [I-O]) approach at constant prices for two points of time. Remainder of the paper is organized into the following sections. Section 2 presents the review of literature. The details of the methodology and database are given in Section 3. The results are discussed in Section 4. Section 5 concludes the discussion.

2. REVIEW OF LITERATURE

India ranks fourth among the top energy consuming countries after US, China and Russia. However, India's per capita energy consumption is among the lowest. India also performs better in terms of energy intensity of GDP. During 2014, the energy intensity of India's GDP is 0.141 as compared to 0.156 for the world[8]. This is much lower than other leading consumers. The energy intensity of US, China and Russia stands at 0.153, 0.203 and 0.340, respectively[9]. India's energy intensity has been continuously declining since the 1990s despite the increase in absolute energy use (Government of India, 2013).

The role of energy intensity as a source of change in energy use in I-O framework is widely attempted in the literature. A large number

4 As on March 2012, Source: CEA (2015).

5 Data for electricity generation from other renewables such as solar, tidal and geothermal energy is not readily available on a continuous basis. This leaves hydro power a main source of renewable eelctctricty.

6 Share of wind based power is adapted from Maithani (2011).

7 Although small, the share of renewable in India's energy is comparable to that for US, Indonesia, Thailand and China (Government of India, 2013).

8 Figures represent energy intensity of GDP at constant purchasing power parities (kilo of oil equivalent/$2005 prices), Source: Enerdata Information Services (2015).

9 US refers to North America.

of studies use decomposition analysis to analyze the contribution of changes in energy intensity compared to other factors such as the level of output and structural change (Park, 1992; Lin and Polenske, 1995; Mukhopadhyay and Chakraborty, 2002). However, results vary with specification of the decomposition. Some of the studies in the Indian context, viewed energy intensity as a major contributing factor for changing energy consumption (Tiwari, 1999) with the declining intensity of crude oil and electricity contributing to the lower consumption of the respective fuels while the overall increase in coal intensity contributed to higher use of coal. Similarly, energy intensity has a strong effect on lowering India's carbon mission (World Bank, 2007). Chakraborty (2007) argued that worsening of energy intensity contributed to increasing energy use. Other study noted a relatively weak intensity effect suggesting that energy reductions are purely driven by structural effect (Gupta and Roy, 2002).

Most of the studies on changing energy intensity in India have a limited sectoral profile and have been confined to the manufacturing and industrial sectors. For instance, Ray (2011) is limited to cement, aluminum, glass, fertilizer, paper, iron & steel and chemical industries. Sahu and Narayanan (2010) is a study based on data which represents a partial picture of the industry. Parikh and Gokarn (1993), using an I-O framework, estimated emissions due to energy use. The authors attributed one-third of the total direct carbon emissions from fossil fuels to the electricity sector. They also estimated highest total emission intensity of the electricity sector, followed by cement and iron & steel sector. Murthy et al. (1997) noted high coal intensity for the coal tar products, while fertilizers are oil intensive and non-ferrous metals have high intensity of electricity. In a slightly different context, Roy and Mukhopadhyay (1999) considered the electricity sector along with the primary energy sectors along with other infrastructure intermediates for different sectors of the economy. The analysis suggested the highest energy intensity of both primary energy and electricity; and for the basic metal sector comprising of iron & steel and other basic metals. The study by Tiwari (2000) found coal tar products as coal intensive, other transport services as crude oil intensive, and production of non-ferrous metal as electricity intensive process. Another study by Dash and Saxena (2000), suggested coal tar products as coal intensive, fertilizer as crude oil and gas intensive, transport as petroleum intensive and sugar as electricity intensive. In the analysis for a later period, Mukhopadhyay (2004) observed high energy intensity for the electricity, petroleum products, coal tar products, cement, fertilizer, inorganic heavy chemicals, iron & steel, non-ferrous metal and transport sectors.

Most of the studies ignored to consider electricity intensity which is important not only due to changing conversion efficiencies of the secondary energy source, but also alongside the fuel substitution during in the generation process. While Mukhopadhyay (2004) ignored to analyze the electricity intensity of sectors, Tiwari (2000) attempted to avoid double counting of coal in the electricity sector through data manipulation which again ignored to account for the electricity from non-fossil sources. Besides, the methodological framework in the study by Gupta and Roy (2002) is restricted with the estimation of the intensity in terms of money value of flows.

The present research argues that it is important to consider primary electricity due to its: (i) Substitutability, (ii) renewable nature of the hydro resources, and (iii) primarily domestic sourcing potential to save the outgo of valuable foreign exchange required for imports of other primary fossil fuels. Additionally, analysis of the electricity sector is useful to underpin the technology changes resulting from inter-fuel substitution, say between primary and secondary sources with varying distribution of use. This qualifies a case for considering primary electricity as an energy sector. The present study tries to improve upon the existing literature on energy use by disaggregating electricity into non-thermal and thermal components.

3. METHODOLOGY AND DATABASE

In the standard I-O model, the intersectoral relationships among sectors are expressed in the form of linear equations that constitute a system of simultaneous equations representing all activities of the economy (Leontief, 1936)[10]. It assumes homogeneity of output for a given sector which in turn implies identical pricing across the different using sectors (Mayer and Flachmann, 2011). However, this assumption could be unrealistic for specific commodities such as energy. For instance, fuels such as diesel or electricity could be highly subsidized for certain sectors leading thereby to significant price differentials across the users. The hybrid I-O model is useful to address the problem of homogenous pricing of energy inputs across sectors of the economy. The present paper is attempted by using the hybrid I-O formulation as given by Miller and Blair (2009).

The relationships in physical quantities are independent of prices. The quantity based I-O analysis is possible by using hybrid (or mixed) I-O model that has a suitably adapted formulation. It represents commodity flows through a combination of physical quantities for the energy sectors and money values for the remaining sectors. For a hybrid energy I-O model, the comparable matrices in hybrid (mixed) units are obtained by substituting rows corresponding to the energy sectors with the rows that have transactions in physical quantities. The resulting hybrid I-O contains flows of the energy sectors in physical quantities while all other non-energy commodity rows are maintained with monetary values. The energy rows trace the use of energy commodities in other remaining sectors of the economy. A mathematical formulation of the hybrid I-O is discussed as follows (refer Appendix A for specifications of the I-O model).

Let the hybrid I-O matrices be notated as Z^*, A^* and L^*, where the matrices are comparable to the standard I-O matrices for the commodity flows (Z), technical coefficients (A) and the Leontief inverse (L), respectively[11]. Additionally, we also define the following matrix equation:

10 The intersectoral transactions for the American economy were initially represented in physical units such as tonnes or numbers. The data on physical output is not readily available. Hence, the I-O transactions are widely presented in terms of commodity flows in money values.

11 The matrices Z and Z^* differ in the energy rows that contain money values in Z but are replaced with the corresponding quantities in Z^*. Similarly the matrices A and A^* and L and L^* differ only in the energy rows.

$$E + q = g \quad (1)$$

Where, $E = (e_{kj})$ is the energy matrix that explicitly provides the quantity of energy flows from the k^{th} energy sector to the j^{th} sector of production for intermediate consumption and has dimensions $m \times n$ in an economy with n sectors of which m correspond to the energy sectors. The column vector $q = (q_k)$ represents the energy quantities consumed as final demand and has dimensions $m \times 1$. Similarly, the column vector $g = (g_k)$ represents the total energy output and has dimensions $m \times 1$.

The comparable hybrid matrices as related to the conventional money flow matrices are follows:

$$Z^* = \left(z_{ij}^*\right) = \begin{cases} z_{ij} \text{ where } i \text{ is a non-energy sector} \\ e_{kj} \text{ where } k \text{ is an energy sector} \end{cases} \quad (2)$$

$$f^* = \left(f_i^*\right) = \begin{cases} f_i \text{ where } i \text{ is a non-energy sector} \\ q_k \text{ where } k \text{ is an energy sector} \end{cases} \quad (3)$$

$$x^* = \left(x_i^*\right) = \begin{cases} x_i \text{ where } i \text{ is a non-energy sector} \\ g_k \text{ where } k \text{ is an energy sector} \end{cases} \quad (4)$$

A diagonal matrix of the output vector in hybrid units is defined as:

$$\hat{x} = \left(x_{ij}\right) = \begin{cases} x_i \text{ where } i \text{ is a non energy sector on the diagonal} \\ g_k \text{ where } k \text{ is an energy sector on the diagonal} \\ 0 \text{ elsewhere} \end{cases} \quad (5)$$

Then the energy requirements can be specified using the following matrix equations[12].

$$A^* = Z^*\left(\hat{x}^*\right)^{-1} \quad (6)$$

$$L^* = \left(I - A^*\right)^{-1} \quad (7)$$

These equations respectively provide the direct and total energy requirement coefficients.

3.1. Sectors of Analysis

The energy and energy intensive sectors are identified for the analysis. In order to capture the technology coefficients precisely, sectors with similar production technology are grouped together. While forming a broader group, homogeneity amongst the sectors, in terms of input use and output disposition, is the basic criterion for sector choice. The availability of prices indices required to deflate the transaction flows is another important consideration.

The energy sectors are identified as primary and secondary. Primary energy generally represents the new energy, generally in the form of extracted resources, entering into the production system. Fossil fuels such as coal, lignite, crude oil and natural gas are examples of primary energy. On the other hand, secondary energy refers to a transformed or processed form of primary (or another secondary) energy. Examples of secondary energy include electricity obtained from the man-made transformation process of a primary energy such as coal. Further, these concepts are perfectly compatible within the I-O models that capture the impact of direct use of primary energy as well as the indirect use as input to produce secondary energy.

The renewable such as electricity from hydro, nuclear, wind and geothermal sources are classified as primary energy. The existing studies on India have conspicuously ignored electricity generated from primary sources, particularly the hydroelectricity. Further, hydroelectricity generation has a significant share of 26.2% in installed capacity[13]. India features prominently among the top 10 countries in terms of installed capacity of hydroelectricity. Hydroelectricity also accounts 16.7% of the total generation[14]. Hence, there has been a gap in the existing literature with respect to consideration of primary electricity as a source of energy.

We identify three primary energy sectors *viz*. coal &lignite; natural gas &crude petroleum, and non-thermal electricity. Data on coal &lignite sector is consistently reported in the I-O transaction tables (IOTTs). However, natural gas & crude petroleum sector is not comparable over time. Therefore, to keep the sectoral scheme comparable across the years, natural gas & crude petroleum is considered as one sector. Using the input structure from Pal et al. (2015), the composite electricity sector is further disaggregated into non-thermal and thermal electricity. The study by Pal et al. (2015) is based on the analysis for 36 sectors for the 2 years 1994-1995 and 2006-2007 and differentiates electricity into hydro, non-hydro and nuclear components. Hence, the column of composite electricity sector is spilt based on the individual input structure for each of three sources of electricity. The hydro and nuclear components are combined to represent non-thermal electricity representing primary electricity. The row of composite electricity is split in the proportion of corresponding outputs. It is important to note that electricity output is supplied as a homogenous product (irrespective of the generation source) to other sectors. Therefore, it is less important to examine output disposition separately for non-thermal and thermal electricity generation (Pradhan et al., 2014). Nevertheless, inclusion of primary electricity further helps by providing robust estimates of electricity intensity that account for the contribution of hydro power as a non-fossil resource. The mapping between present sectors of analysis and IOTT is presented in Table 1.

The present paper defines energy intensity as the quantity of energy required to produce one unit output of a given sector. For the hybrid I-O analysis, energy quantity is measured in mtoe by using availability of conversions factors from various energy forms. The conversion factor for coal, lignite, natural gas and electricity is computed separately per unit of output as 0.41, 0.2865, 0.9 and 0.086, respectively[15]. Further, the proportion of non-thermal electricity such as hydro and nuclear electricity is estimated at 21.3% and 16.9% for the years 1993-1994 and 2007-2008, respectively[16].

12 Refer Miller and Blair (2009).

13 As on March 2007, Source: CEA (2015).

14 Energy Statistics (2013; 2014).

15 Output of coal and lignite is measured in thousand tones, natural gas is measured in million cu mtrs and electricity is measured in billion kwh. Source: Energy Statistics (2011).

16 Ministry of Petroleum and Natural Gas (1993-94 and 2010-11).

Table 1: Mapping scheme with the input-output sectors - Disaggregate sectors

Sector name	Sector code	IOTT codes 1993-1994		IOTT codes 2007-2008	
Coal & lignite	col	023	(1)	027	(1)
Natural gas & crude petroleum	oil	024	(1)	028-029	(2)
Non-thermal electricity#	nte	part 100	(1)	part 107	(1)
Thermal electricity	ele	part 100	(1)	part 107	(1)
Agriculture & allied	agr	001-022	(22)	001-024, part 025*, 026	(26)
Mining	min	025-032	(8)	030-037	(8)
Food, beverages and tobacco	pfd	033-040	(8)	038-045	(8)
Paper, paper products and newsprint	ppp	052-053	(2)	057-058	(2)
Chemicals, rubber and plastics and products	crp	056-057, 060-068	(11)	061-062, 065-073	(11)
Non-metallic mineral products	nmm	069-071	(3)	074-076	(3)
Basic metal and metal products	fmp	072-074, 076-077	(5)	077-079, 081-082	(5)
Non-ferrous basic metals	nfm	075	(1)	080	(1)
Machinery and equipment	ome	078-090	(13)	083-094	(12)
Other manufacturing	omf	041-051, 054-055, 091-098, 105-115	(21)	046-056, 059-060, 095-105	(24)
Construction	cns	099	(1)	106	(1)
Transport services	tpt	103-104	(2)	109-113	(5)
Other services	svs	102,105-115	(12)	108, 114-130	(18)
Petroleum products	p_g	058, 101	(2)	063, part 025*	(1)
Coal tar products	ctp	059	(1)	064	(1)

#Includes hydro and nuclear power, *In order to maintain a consistent scheme of sector aggregations across the years, the gobar gas component of forestry and fishing sector is compiled along with the petroleum product sector that includes gasworks. Note: Figures within parenthesis are the number of sectors aggregated. Sources: Based on CSO (2000, 2012). IOTT: Input-output transaction tables

The conversion of a primary energy like coal into the secondary energy such as thermal electricity involves loss of energy during the transformation process. The use of conversion efficiencies provides the actual requirements of the primary energy into the system. This is further used to validate the energy conservation equation of the hybrid I-O model. Using the conversion efficiencies for hydro and nuclear power at 85% and 33%, respectively, the model conforms to the energy conservation equation for both the years of analysis[17, 18].

3.2. Time Frame

The analysis refers to the years 1993-1994 and 2007-2008, benchmarked to the corresponding IOTTs (CSO, 2000; 2012). The base year 1993-1994, also signifies relevance as the initial year of economic reforms. The sector specific reforms in particular were also introduced around this time. The year 2007-2008 as a terminal year points to the importance of second generation reforms in place since the early 2000s, notably the dismantling of the Administered Pricing Mechanism which directly affected the fuel pricing. This had implications on upstream and downstream industries in the economy.

3.3. Deflation Methodology

The methodology for deflating the IOTT at 1993-1994 base year prices is based on Celasun (1984). This has two advantages. First, it allows for a double deflation through deflating the inputs and outputs using separate deflators. Second, the methodology is useful to convert the nominal technology coefficients directly into real technology coefficients. The conversion process is rather demanding in terms of data requirements as it makes use of separate price indices for gross output, exports and imports which is important to improve the precision of computations. The data are available from Office of the Economic Adviser, Department of Commerce & Industry, Department of Industrial Promotion (Government of India, 2012), Reserve Bank of India (2009 and 2013) and the National Account Statistics.

17 The conversion efficiency varies across sources of generation due to variations in technology and input use. For instance, conversion efficiency for coal varies between 32% and 42%, for gas between 33% and 38%, for oil between 38% and 44%, for hydro electricity between 85% and 90% and for nuclear power between 33% and 36% (Mukherjee, 2012; Euroelectric, 2003).

18 Conversion efficiencies for coal & lignite and natural gas & crude petroleum sectors as obtained from the I-O based computations are consistent with alternate source.

4. RESULTS AND DISCUSSION

4.1. Direct Energy Intensity

Direct energy intensity of all 19 sectors of the Indian economy is shown for the reference years by energy types in the Tables 2 and 3, respectively. The findings for intensity of primary energy sectors are indeed consistent with findings with Mukhopadhyay (2004) for the year 1993-94. Highest total energy intensity is observed for the composite electricity sector with comparable magnitude of estimates. The estimates of total energy intensity of the coal & lignite and natural gas & crude oil sectors match closely except that our estimates exceed by unity. This is attributed to the accounting of coal used for thermal electricity, within the coal sector itself in the present analysis. In other words, the accounting of thermal electricity based on primary fossil fuels such as coal and natural gas results in higher energy intensity. The present study improves upon the earlier research by exclusively accounting for non-thermal electricity over a longer time horizon.

The changes in direct energy intensity are observed by comparing corresponding columns in the tables. The following discussion maintains a focus on the changes observed between the two periods. Total direct energy intensity of a sector is the aggregate of direct energy intensity of each of the three energy forms *viz.* coal & lignite; natural gas & crude petroleum, and non-thermal

Table 2: Direct energy coefficients, 1993-1994

Sector name	Coal & lignite		Natural gas & crude petroleum		Non-thermal electricity		Total energy	
Coal & lignite	0.007334	(3)	0.000000	(16)	0.001119	(3)	0.008452	(3)
Natural gas & crude petroleum	0.000000	(19)	0.002491	(2)	0.000183	(4)	0.002674	(4)
Non-thermal electricity	0.297773	(2)	0.000000	(16)	0.065587	(1)	0.363360	(2)
Thermal electricity	1.877182	(1)	0.691556	(1)	0.042861	(2)	2.611599	(1)
Agriculture & allied	0.000000	(18)	0.000000	(14)	0.000000	(17)	0.000000	(19)
Mining	0.000000	(17)	0.000000	(16)	0.000000	(11)	0.000000	(17)
Food, beverages and tobacco	0.000003	(11)	0.000001	(9)	0.000000	(18)	0.000004	(13)
Paper, paper products and newsprint	0.000024	(7)	0.000000	(12)	0.000001	(9)	0.000025	(9)
Chemicals, rubber and plastics and products	0.000008	(9)	0.000013	(5)	0.000001	(8)	0.000022	(10)
Non-metallic mineral products	0.000054	(5)	0.000000	(16)	0.000001	(6)	0.000055	(7)
Basic metal and metal products	0.000030	(6)	0.000001	(8)	0.000001	(10)	0.000031	(8)
Non-ferrous basic metals	0.000013	(8)	0.000001	(7)	0.000001	(5)	0.000015	(11)
Machinery and equipment	0.000001	(13)	0.000001	(6)	0.000000	(13)	0.000002	(15)
Other manufacturing	0.000002	(12)	0.000001	(10)	0.000000	(12)	0.000003	(14)
Construction	0.000000	(16)	0.000000	(13)	0.000000	(15)	0.000000	(18)
Transport services	0.000004	(10)	0.000000	(15)	0.000001	(7)	0.000005	(12)
Other services	0.000001	(14)	0.000001	(11)	0.000000	(16)	0.000002	(16)
Petroleum products	0.000000	(15)	0.000345	(3)	0.000000	(19)	0.000345	(5)
Coal tar products	0.000190	(4)	0.000090	(4)	0.000000	(14)	0.000279	(6)

Figures in parenthesis show the sector ranks, Energy intensity of energy sectors (1-4) measured in mtoe per mtoe; for remaining sectors (5-19) in mtoe per mrs (million rupees).
Source: Computations based on CSO (2000)

Table 3: Direct energy coefficients, 2007-2008

Sector name	Coal & lignite		Natural gas & crude petroleum		Non-thermal electricity		Total energy	
Coal & lignite	0.017612	(2)	0.000000	(16)	0.000555	(4)	0.018167	(2)
Natural gas & crude petroleum	0.000001	(11)	0.001925	(2)	0.000890	(3)	0.002815	(3)
Non-thermal electricity	0.000000	(19)	0.000000	(16)	0.002294	(2)	0.002294	(4)
Thermal electricity	0.821331	(1)	0.057890	(1)	0.031642	(1)	0.910864	(1)
Agriculture & allied	0.000000	(18)	0.000000	(16)	0.000000	(18)	0.000000	(19)
Mining	0.000000	(13)	0.000000	(15)	0.000000	(12)	0.000000	(15)
Food, beverages and tobacco	0.000000	(12)	0.000000	(11)	0.000000	(11)	0.000001	(14)
Paper, paper products and newsprint	0.000008	(7)	0.000000	(14)	0.000000	(9)	0.000008	(10)
Chemicals, rubber and plastics and products	0.000002	(8)	0.000005	(5)	0.000000	(10)	0.000007	(11)
Non-metallic mineral products	0.000027	(6)	0.000003	(7)	0.000000	(6)	0.000030	(9)
Basic metal and metal products	0.000051	(5)	0.000003	(6)	0.000000	(8)	0.000055	(8)
Non-ferrous basic metals	0.000100	(4)	0.000001	(8)	0.000000	(7)	0.000102	(7)
Machinery and equipment	0.000002	(9)	0.000000	(9)	0.000000	(17)	0.000002	(12)
Other manufacturing	0.000001	(10)	0.000000	(10)	0.000000	(13)	0.000001	(13)
Construction	0.000000	(17)	0.000000	(13)	0.000000	(15)	0.000000	(17)
Transport services	0.000000	(15)	0.000000	(16)	0.000000	(14)	0.000000	(16)
Other services	0.000000	(16)	0.000000	(12)	0.000000	(19)	0.000000	(18)
Petroleum products	0.000000	(14)	0.000227	(3)	0.000000	(16)	0.000227	(6)
Coal tar products	0.000225	(3)	0.000138	(4)	0.000001	(5)	0.000363	(5)

Figures in parenthesis show the sector ranks, Energy intensity of energy sectors (1-4) measured in mtoe per mtoe; for remaining sectors (5-19) in mtoe per mrs (million rupees).
Source: Computations based on CSO (2012)

electricity. It is seen that energy sectors have been the most intensive consumers of energy in each of the years. These include all three primary energy sectors – coal & lignite; natural gas & crude petroleum, and non-thermal electricity; and the secondary energy sectors – thermal electricity, petroleum products and coal tar products. A slight change is observed in the rank hierarchy of total direct energy intensity of the energy sectors. The thermal electricity sector maintains a top position. Both coal & lignite and natural gas & crude petroleum sectors moved up by one rank each while on the other hand, direct intensity of non-thermal electricity declined during the period[19]. At the same time, during 2007-2008, coal tar products moved up at the fifth position due to an increase in direct energy intensity as compared with the year 1993-1994. The petroleum product sector slipped to the sixth position due to an improvement in direct energy intensity in 2007-2008.

During 1993-1994, highest direct energy intensity of 2.611599 for the thermal electricity sector implied that one mtoe of thermal electricity generation required direct energy inputs of 2.611599 mtoe due to a very high intensity of coal use at 1.877182 mtoe, followed by 0.691556 mtoe of natural gas & crude petroleum and

19 An improvement in direct energy intensity of a sector means lower requirement of energy to produce one unit of output of the sector. Thus, decreasing energy intensity is considered as improvement in energy intensity. Similarly, increasing energy intensity is considered as worsening of energy intensity.

0.042861 mtoe due to input of non-thermal electricity (Table 2). Even during the latter year, 2007-2008, thermal electricity continues to lead in direct energy intensity although the magnitude of total direct intensity has reduced. Much of the lowering in direct energy intensity is attributed to reduction in direct coal intensity followed by reductions in intensity of natural gas & crude petroleum and non-thermal electricity, in that order. The reduction in direct coal intensity of thermal electricity generation is explained due to adoption of cleaner technologies such as coal beneficiation that refers to the process of coal washing to reduce the ash content. Coal washing in India became mandatory after the Ministry of Environment and Forests notified that power stations beyond 1000 km radius form the coal sources and located in sensitive, residential and urban areas must use coal with ash content not in access of 34% (TERI, 2010). This improved the efficiency of the coal circuits that now receive washed pulverized coal which has much higher rates of oxidation. Improvements in efficiency of coal use have resulted in lower coal intensity of the power generation process. The lower intensity of crude oil and natural gas is explained due to savings from transportation of coal that has lower ash content thus leading to savings on the transportation of unwanted material. Also, more thermal plants are now located closer to the pitheads. A decline in own use of electricity is result of the improvement in coal efficiencies of thermal plants. Total direct energy intensity of thermal electricity sector declined by 65.1% over the period.

Unlike thermal electricity, total direct energy intensity of the coal & lignite sector worsened registering an increase of 114.9%. This is attributed to the high ash content of coal. As much as up to 45% of run-of-mine adds to wastage and increases the amount of crude ore required in producing one unit output (Indian Chamber of Commerce, 2012). Changes in the non-thermal electricity intensity of the coal & lignite sector contributed to lower total energy intensity of the coal sector as the same reduced by 50.4%. This improvement can be attributed to the technology improvements through the use of boilers that burn the high ash content and heavy earth moving machinery such as the electricity based power shovels (Chikkatur and Sagar, 2007). However, this was insufficient to counter the increase in direct intensity of own use as a raw material that had a net increasing effect on total direct energy intensity of the coal sector. Despite the improvement due to non-thermal electricity, the coal & lignite continues to rank the second most intense user of direct energy inputs. Direct energy intensity of the natural gas & crude oil sector increased over time with mixed changes in intensity of self consumption and the non-thermal electricity use. The direct intensity of non-thermal electricity increased drastically while direct intensity of own use improved over the period. The improvement in own use intensity is accounted by the energy conservation measures implement by the oil refineries. This included replacement of the less efficient boilers and furnaces and other operational improvements[20,21]. The worsening of electricity efficiency can be attributed to non-commensurate drilling results. The direct intensity of non-thermal electricity improved by 99.4% with similar improvement in each of the primary energy sources due to renovations of the existing plants and recent capacity additions that have better performance efficiency (World Energy Council, 2013).

Among the remaining secondary energy sectors, the direct energy intensity of coal tar products increased by 29.9% due to increased intensities of each of the three energy inputs namely coal & lignite; natural gas & crude petroleum, and electricity. However, the magnitude of these changes was lower than observed for the former three energy sectors. Lower efficiencies are attributed to below normal levels of performance. The technological status of foundries varies widely (Bhagat, 2002). Further, composition of the products varies with differences in the quality o coal used. For instance, as much as 20.7% of the volume is lost during preparation of light oil (Ganguly et al., 1933)[22]. The petroleum product sector registered a decline in total direct energy intensity by 34.3% primarily due to the improved intensity of crude oil. A marginal worsening is observed for non-thermal electricity intensity. The magnitude of change in the direct intensity is much smaller when compared with the changes observed for total direct intensity of coal, crude oil and the electricity sectors.

Among the non-energy sectors, changes are observed both in terms of ranks as well as the magnitude of total direct energy intensity. The non-ferrous basic metal sector has emerged as the most intensive user of direct energy. During 1993-1994 it was the 11th most intensive user of direct energy. Its rank changed to 7th during 2007-2008[23]. The change is attributed to the notable increase in direct coal intensity that increased by a factor of eight. This is attributed to inefficient generation in the coal based captive power plants such as those in the aluminum sector[24]. The increase outweighed savings in energy intensity due to lower non-thermal electricity use. Although basic metal and metal products maintained their 8th, the intensity increased due to coal intensity that worsened over time. Even though traditional methods in the iron and steel industry have been replaced with newer methods of direct reduced iron, the low quality of coal feedstock seems to have affected the direct intensity. Also, the relatively low share of steel production from scrap explains higher energy intensity[25]. A decline in direct energy intensity is observed for the non-metallic mineral product sector at the 9th position in 2007-08 compared with its 7th rank during 1993-94. This is due to lower direct intensity of coal use as indicated by a lower consumption of average thermal in the dry process plants that reduced from 780 kcal/kg clinker in 1995-96 to 750 kcal/kg clinker in 2000-01 (Government of India, 2002). Also, the weighted consumption of electrical energy reduced from 104 kwh/tonne cement to 90 kwh/tonne cement over the same period (India Brand Equity Foundation, 2013a). The total direct energy intensity of the paper, paper products and newsprint declined and the sector ranked 10th during 2007-08. The lowering of energy requirement is attributed to integrated mills that make

20 http://envfor.nic.in/sites/default/files/cc/cop8/moefbk/use.pdf.

21 http://www.beeindia.in/awards_and_painting_competition/document/EC_Award/2009/AwardBooklet2009/18-Refinery.pdf.

22 Other prominent coal tar products include naphthalene, pitch oil and anthracene.

23 A higher rank indicates increased direct intensity.

24 http://www.cseindia.org/userfiles/57-66%20Aluminium%281%29.pdf.

25 Steel production from scrap is less energy intensive as compared with that from the raw material. In India, the share of scrap based steel production has been at 18% as compared with 33% in the world during 2007 (Trudeau, et. al., 2011).

Table 4: Direct energy coefficient as proportion of total energy coefficient (%)

Sector name	1993-1994				2007-2008			
	Coal & lignite	Natural gas & crude petroleum	Non-thermal electricity	Total	Coal & lignite	Natural gas & crude petroleum	Non-thermal electricity	Total
Coal & lignite	0.7	0.0	59.2	0.8	1.7	0.0	66.8	1.8
Natural gas & crude petroleum	0.0	0.2	36.2	0.3	0.0	0.2	52.1	0.3
Non-thermal electricity	28.4	0.0	6.0	14.3	0.0	0.0	0.2	0.2
Thermal electricity	77.7	67.2	66.8	74.4	77.1	20.9	77.5	65.9
Agriculture & allied	0.1	0.0	40.1	1.5	0.1	0.0	47.1	2.2
Mining	0.3	0.0	60.3	2.2	7.7	0.1	62.3	5.8
Food, beverages and tobacco	26.6	7.2	22.7	17.1	8.5	0.6	41.0	6.1
Paper, paper products and newsprint	50.9	0.4	37.7	38.7	42.3	0.0	38.2	27.5
Chemicals, rubber and plastics and products	29.7	40.5	38.1	35.5	19.8	27.5	38.1	25.0
Non-metallic mineral products	73.4	0.0	48.6	55.8	69.7	13.9	53.8	51.4
Basic metal and metal products	43.4	3.8	31.8	33.9	54.5	22.0	39.1	49.8
Non-ferrous basic metals	27.2	4.9	44.7	20.9	66.8	6.3	38.1	61.4
Machinery and equipment	3.5	6.6	28.1	5.4	6.5	2.6	28.3	6.1
Other manufacturing	9.5	4.7	36.0	8.4	7.0	1.9	34.3	6.0
Construction	0.7	0.3	21.0	1.0	0.1	0.0	25.3	0.5
Transport services	22.1	0.0	56.2	7.7	1.2	0.0	41.4	0.8
Other services	12.7	12.4	40.9	13.6	2.3	1.2	49.7	3.7
Petroleum products	4.6	96.9	17.5	95.4	2.2	92.0	25.7	88.7
Coal tar products	92.0	82.3	19.7	88.4	89.9	79.4	33.6	85.4

Source: Computations based on CSO (2000, 2012)

use of recovered heat from the production process in ancillary activities such a drying of paper (Central Pulp and Paper Research Institute). The decline in total direct energy intensity of the chemicals, rubber and plastics and their products at 11th position is on account of lower intensities of both coal & lignite and natural gas & crude petroleum use. This can be explained due to change in feedstock from coal based naphtha to the natural gas for production of ammonia in the fertilizer industry (Integrated Research and Action for Development, 2007). The decrease in total direct energy intensity of the machinery and equipment, at 12th position, has been observed due to mixed behavior of intensity of various energy inputs (Sahu and Narayanan, 2010). The position of the other manufacturing sector improved to 13th primarily due to lower intensity of coal use. This sector includes various production activities such as the textile and wearing apparel industry that have upgraded technology due to modernization and investment promotion. The government initiatives for technology improvements include the National Textile Policy and the Technology Upgradation Fund Scheme (India Brand Equity Foundation, 2013b and Mukherjee and Mukherjee, 2012).

The direct energy intensity of the processed food sector, transport services and other services declined over time. The decline in direct coal intensity of the food processing sector is explained by the greater use of refinement equipment such as driers that use agricultural residue, by-products and solar energy (Kachru)[26]. The use of energy efficient furnances in the sugary processing industry has also contributed to lower direct energy requirements of the food processing sector. For instance, the steam consumption has declined from 60-70% to 35-40% in the sugar processing industry (Rao)[27]. The lower direct energy intensity of the mining sector is primarily due to lower electricity intensity that is the result of use of efficient heavy earth moving machinery such as power shovels for improved drilling precision in extractions of ores (Jayanthu et al., 2014). In the transport sector, lower direct intensities of coal and non-thermal electricity have contributed to decline in total direct energy intensity. This is due to fuel substitution towards CNG and increasing use of diesel consumers that benefit from cross subsidization (European Business and Technology Centre, 2013). Also, lower intensity of coal is a result of increasing electrification and dieselization of Indian railways. The improved direct energy intensity of the service sector is a result of energy saving measures and technology improvement that increase profitability of the business (Leroi et al., 2013 and SIDBI)[28]. The changes in mining, construction and agriculture sectors have been relatively insignificant.

4.2. Total Energy Intensity

A comparison of direct energy *viz*. total energy requirements shows wide variations across sectors. For 11 sectors the direct intensity is <10% of the total energy intensity in 2007-2008 (Table 4). These include sectors namely coal & lignite; natural gas & crude petroleum; non-thermal electricity; agriculture & allied; mining; food, beverages and tobacco; machinery and equipment; other manufacturing; construction, transport services, and other services. During 2007-2008, the proportion was close to 50% for two sectors namely – non-ferrous basic metals, and basic metal and metal products. In two more sectors, *viz*. petroleum products and coal tar products, the contribution of direct energy intensity in total energy

26 http://www.panelamonitor.org/media/docrepo/document/files/agro-processing-industries-in-india-growth-status-and-prospects.pdf.

27 http://www.staionline.org/pdf/latest%203rd%20India%20Sugar%20Expo%20Presentations.pdf.

28 http://www.sidbi.com/?q=financing-schemes-sustainable-development-including-energy-efficiency-and-cleaner-production-msmes.

Table 5: Indirect energy intensity to direct energy intensity (ratio)

Sector name	1993-94				2007-08			
	Coal & lignite	Natural gas & crude petroleum	Non-thermal electricity	Total	Coal & lignite	Natural gas & crude petroleum	Non-thermal electricity	Total
Coal & lignite	138.9	-	0.7	122.9	57.2	-	0.5	55.9
Natural gas & crude petroleum	-	406.8	1.8	382.1	53124.2	532.3	0.9	374.1
Non-thermal electricity	2.5	-	15.7	6.0	-	-	436.3	453.4
Thermal electricity	0.3	0.5	0.5	0.3	0.3	3.8	0.3	0.5
Agriculture & allied	1122.2	6399.6	1.5	66.0	1017.6	-	1.1	43.8
Mining	386.6	-	0.7	44.0	11.9	1926.6	0.6	16.1
Food, beverages and tobacco	2.8	12.8	3.4	4.9	10.8	153.1	1.4	15.5
Paper, paper products and newsprint	1.0	243.8	1.7	1.6	1.4	3682.6	1.6	2.6
Chemicals, rubber and plastics and products	2.4	1.5	1.6	1.8	4.0	2.6	1.6	3.0
Non-metallic mineral products	0.4	-	1.1	0.8	0.4	6.2	0.9	0.9
Basic metal and metal products	1.3	25.4	2.1	2.0	0.8	3.5	1.6	1.0
Non-ferrous basic metals	2.7	19.3	1.2	3.8	0.5	15.0	1.6	0.6
Machinery and equipment	27.9	14.3	2.6	17.5	14.3	37.5	2.5	15.3
Other manufacturing	9.5	20.2	1.8	10.9	13.3	53.0	1.9	15.7
Construction	140.6	313.2	3.8	96.0	678.3	4302.8	2.9	183.9
Transport services	3.5	-	0.8	12.0	80.3	-	1.4	125.1
Other services	6.9	7.0	1.4	6.4	42.8	80.4	1.0	26.0
Petroleum products	20.7	0.0	4.7	0.0	45.2	0.1	2.9	0.1
Coal tar products	0.1	0.2	4.1	0.1	0.1	0.3	2.0	0.2

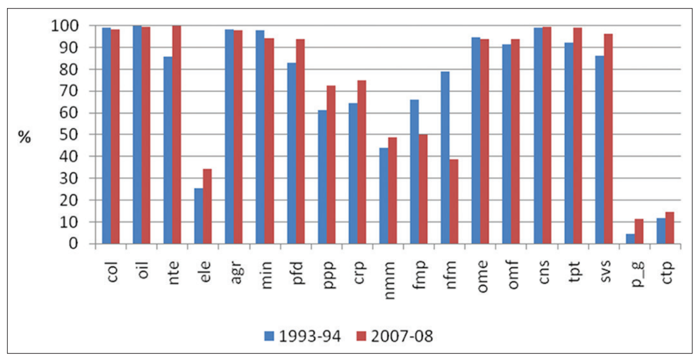
-: Insignificant values of direct intensity coefficients. Source: Computations based on CSO (2000; 2012)

intensity was higher than 80%. A low share of direct energy in total energy intensity highlights the importance of indirect energy use, particularly in the construction and transport services.

The ratio of indirect energy intensity to direct energy intensity has been high for most sectors. The ratio is below unity only for four sectors namely non-metallic mineral products; non-ferrous basic metals; petroleum products and coal tar products (Table 5). For remaining 15 sectors, the ratio not only exceeds unity but also acquires significant values for sectors such as coal & lignite; natural gas & crude petroleum; non-thermal electricity; construction and transport services. The findings suggest that indirect consumption can be important source of energy use. In such cases, efforts to save energy or improve energy efficiency may not be fruitful if focused through attempts to lower direct energy consumption. Instead, the policy orientation toward lowering consumption of embodied energy would be more effective. Such measures should appropriately be pegged in upstream suppliers through technological improvements, fuel substitution or input replacements. Therefore, energy improvement in the production chains are likely to be more effective than energy changes within the production process of the industry itself.

From Figure 1, it is clear that indirect intensity constitutes substantial percentage of total energy intensity in most sectors of the economy. Given the significant proportion of indirect energy consumption, it is important to study changes in the ranks of sectors based on total energy intensity. The total energy intensity of all 19 sectors is presented in Tables 6 and 7 corresponding to the 2 years, respectively. The six energy sectors are most intensive users of energy inputs as observed from their highest total energy intensities. Total energy intensity of the thermal electricity sector is highest at 1.382745 mtoe per mote of final

Figure 1: Indirect energy intensity as % of total energy intensity



Source: Same as Table 4

demand including both direct requirements of 0.910864 mote and indirect requirements of 0.47188 mtoe (Table 7)[29]. It is interesting to note that the crude oil and coal sectors switch their ranks based on direct energy intensity. While the coal & lignite, and crude oil sectors rank second and third respectively in terms of direct energy intensity, their respective ranks in total energy are interchanged. This underscores the importance of indirect energy consumption in raising the total energy intensity of a sector. The non-thermal electricity has a fourth position.

Certain sectors gain importance upon considering the indirect energy required. For instance during 2007-2008, the natural gas & crude petroleum sector is the third most important sector in terms of direct energy intensity but it is even more significant at second position in terms of the total energy intensity (2,3)[30]. The coal &

29 The indirect energy requirements are obtained as difference between the total and direct energy intensity of the given sector.

30 Figures in parenthesis represent the total energy intensity rank and the direct energy intensity ranks in the year 2007-2008. For example (2,3)

Table 6: Total energy coefficients, 1993-1994

Sector name	Coal & lignite		Natural gas & crude petroleum		Non-thermal electricity		Total energy	
Coal & lignite	1.025811	(3)	0.019769	(4)	0.001889	(3)	1.047469	(3)
Natural gas & crude petroleum	0.008093	(4)	1.015893	(2)	0.000504	(4)	1.024490	(4)
Non-thermal electricity	1.049129	(2)	0.404281	(3)	1.093141	(1)	2.546551	(2)
Thermal electricity	2.414490	(1)	1.029541	(1)	0.064164	(2)	3.508195	(1)
Agriculture & allied	0.000004	(19)	0.000006	(18)	0.000000	(17)	0.000011	(19)
Mining	0.000008	(16)	0.000013	(16)	0.000001	(15)	0.000022	(17)
Food, beverages and tobacco	0.000011	(15)	0.000011	(17)	0.000001	(16)	0.000023	(16)
Paper, paper products and newsprint	0.000048	(8)	0.000015	(13)	0.000002	(8)	0.000064	(10)
Chemicals, rubber and plastics and products	0.000028	(10)	0.000032	(8)	0.000002	(9)	0.000061	(11)
Non-metallic mineral products	0.000074	(6)	0.000023	(9)	0.000002	(6)	0.000099	(7)
Basic metal and metal products	0.000068	(7)	0.000022	(11)	0.000002	(7)	0.000092	(8)
Non-ferrous basic metals	0.000046	(9)	0.000022	(10)	0.000002	(5)	0.000071	(9)
Machinery and equipment	0.000025	(11)	0.000017	(12)	0.000001	(11)	0.000043	(13)
Other manufacturing	0.000019	(13)	0.000015	(14)	0.000001	(12)	0.000034	(15)
Construction	0.000025	(12)	0.000014	(15)	0.000001	(14)	0.000040	(14)
Transport services	0.000017	(14)	0.000041	(7)	0.000001	(10)	0.000059	(12)
Other services	0.000006	(17)	0.000005	(19)	0.000000	(18)	0.000011	(18)
Petroleum products	0.000006	(18)	0.000356	(5)	0.000000	(19)	0.000362	(5)
Coal tar products	0.000206	(5)	0.000109	(6)	0.000001	(13)	0.000316	(6)

Figures in parenthesis show the sector ranks, Energy intensity of energy sectors (1-4) measured in mtoe per mtoe; for remaining sectors (5-19) in mtoe per mrs (million rupees).
Source: Computations based on CSO (2000)

Table 7: Total energy coefficients, 2007-2008

Sector name	Coal & lignite		Natural gas & crude petroleum		Non-thermal electricity		Total energy	
Coal & lignite	1.024993	(2)	0.007826	(4)	0.000831	(4)	1.033650	(4)
Natural gas & crude petroleum	0.027722	(4)	1.026588	(1)	0.001707	(3)	1.056017	(2)
Non-thermal electricity	0.027936	(3)	0.011239	(3)	1.003254	(1)	1.042429	(3)
Thermal electricity	1.064809	(1)	0.277118	(2)	0.040818	(2)	1.382745	(1)
Agriculture & allied	0.000002	(19)	0.000004	(18)	0.000000	(18)	0.000006	(18)
Mining	0.000004	(17)	0.000004	(17)	0.000000	(17)	0.000008	(17)
Food, beverages and tobacco	0.000005	(16)	0.000006	(16)	0.000001	(13)	0.000012	(16)
Paper, paper products and newsprint	0.000019	(11)	0.000011	(13)	0.000001	(9)	0.000030	(13)
Chemicals, rubber and plastics and products	0.000010	(13)	0.000017	(9)	0.000001	(11)	0.000028	(14)
Non-metallic mineral products	0.000039	(8)	0.000019	(8)	0.000001	(8)	0.000059	(9)
Basic metal and metal products	0.000094	(7)	0.000015	(10)	0.000001	(7)	0.000110	(8)
Non-ferrous basic metals	0.000150	(6)	0.000014	(11)	0.000001	(6)	0.000166	(7)
Machinery and equipment	0.000025	(10)	0.000006	(15)	0.000001	(15)	0.000032	(12)
Other manufacturing	0.000013	(12)	0.000007	(14)	0.000001	(14)	0.000021	(15)
Construction	0.000030	(9)	0.000014	(12)	0.000001	(10)	0.000044	(10)
Transport services	0.000006	(15)	0.000027	(7)	0.000000	(16)	0.000034	(11)
Other services	0.000003	(18)	0.000003	(19)	0.000000	(19)	0.000006	(19)
Petroleum products	0.000009	(14)	0.000247	(5)	0.000001	(12)	0.000256	(6)
Coal tar products	0.000250	(5)	0.000174	(6)	0.000002	(5)	0.000425	(5)

Figures in parenthesis show the sector ranks, Energy intensity of energy sectors (1-4) measured in mtoe per mtoe; for remaining sectors (5-19) in mtoe per mrs (million rupees).
Source: Computations based on CSO (2012)

lignite sector ranks third based on total energy intensity through it ranked higher, at the second position, in terms of direct intensity (3,2). The coal tar products and petroleum products rank fourth (4,4) and fifth (5,5), respectively.

The non-energy sectors that lead in total energy intensity include non-ferrous basic metals (7,7), basic metal and metal products (8,8), and chemicals, rubber and plastics and products (8,8). However, the construction sector emerges as a significant user of energy due to high indirect energy consumption and ranks 10th in terms of total energy intensity while it ranks 17th due to its low direct energy consumption (10,17). Similarly, total energy intensity rank of the transport service sector moves up substantially due to high indirect energy consumption (11,16). This again emphasizes the importance of indirect energy inputs. The remaining sectors – machinery and equipment (12,12); paper, paper products and newsprint (3,10); chemicals, rubber and plastics and products (14,10); other manufacturing (15,13); food, beverages and tobacco (16,14); mining; (17,15); agriculture & allied (18,19); and other services (19,18) – follow in that order of total energy intensity.

A comparison of the Tables 6 and 7 highlights the changes in total energy consumption at the sector level over time. Between

implies that the sector ranks second in terms of total energy intensity but ranks third in terms of direct energy intensity.

the periods 1993-1994 and 2007-2008, total energy intensity of the most energy intensive sector, thermal electricity, declined by 60.6% with most significant contribution being from the reduction in total coal intensity of the thermal electricity sector. A reduction in total energy intensity is also observed for the coal & lignite sector due to the declining intensities of natural gas & crude petroleum and non-thermal electricity. The total energy intensity of petroleum products declined despite a small increase in intensity of coal and non-thermal electricity intensity of the sector. Among the non-energy sectors, non-metallic mineral products; paper, paper products and newsprint; chemicals, rubber and plastics and products; transport services; other manufacturing; mining; machinery and equipment; food, beverages and tobacco; other services, and agriculture sector recorded lower total energy intensities during 2007-2008 when compared with 1993-1994[31]. The behaviour of individual energy intensities has been uniform in all these sectors except for the marginal increase of coal and non-thermal electricity intensity of the petroleum sector.

At the same time, total energy intensity increased for certain sectors. Prominent among these is the natural gas & crude petroleum sector with an increase in total energy intensity. The total intensity of each of the three energy inputs increased. Similarly, total intensity of coal tar products increased due to increased intensity of coal and crude oil inputs. The increase in total energy intensity of non-ferrous basic metals; basic metal and metal products, and construction has been due to increase in total coal intensity of the sectors.

Besides changing importance in magnitude of total energy intensity, certain sectors also gained importance through higher ranks based on the total energy intensity. Prominent among these is the construction sector (10,14)[32]. Minor changes in ranks are also noted for natural gas & crude petroleum (2,4); agriculture & allied (18,19); non-ferrous basic metals (7,9); transport services (11,12) and coal tar products (5,6).

Indirect consumption of energy can be on the account of consumption of material inputs that are energy intensive or due to the use of transport services that are used by all input industries at various stages. For instance, the energy used in transportation of raw material such as the iron ores gets accounted into the total energy used in steel manufacture, which further gets added to the total energy used for transportation services in the construction sector. Thus, the effect of energy intensity gets cascaded successively in the supply chain before it is finally accounted in the sector of ultimate consumption. This has notable impact on the changing intensity of the natural gas & crude petroleum. The analysis of total energy intensities shows a decline in intensity of natural gas & crude petroleum for as many as 17 of the 19 sectors. This is heartening as natural gas & crude petroleum is the main input for the transportation fuel. A lower total intensity for many sectors is advantageous as it not only reduces the cost of transportation and increases the profitability of business, but is also environmentally favorable through lower consumption of a non-renewable energy resource.

31 The sectors are mentioned in the declining order of magnitude of reduction.

32 Figures in parenthesis represent the sector rank in total energy intensity during the years 2007-08 and 1993-94, respectively.

5. CONCLUSIONS AND POLICY IMPLICATIONS

Energy consumption in a given sector is a function of energy required for all inputs used by the sector. The embodied energy requirements, for goods and services, are estimated as a sum total of the energy requirements of all inputs in the production chain. The sector-wise energy requirements are compared based on the corresponding energy intensities. An improvement in energy intensity not only lowers the cost of production but also increases profitability of the business. It also helps the ecology through lower emissions and can be considered as a community social responsibility of the producer as well as the consumer.

In this paper, the hybrid I-O based analysis of changes in sector-wise energy intensity shows a low share of direct energy in total energy intensity. The results highlight the importance of indirect energy use due to consumption of energy intensive material inputs or due to the use of transport services in turn used by all input industries at different stages. The analysis of total energy intensities confirms a decline in the intensity of natural gas & crude petroleum for most sectors. This is heartening as natural gas & crude petroleum is the main input for the transportation fuel. A lower total intensity for many sectors is advantageous as it reduces the cost of transportation and increases the profitability of business, but is also favorable to the environment through lower consumption of a non-renewable resource.

The findings emphasize that indirect consumption can be important source of energy use. In such cases, efforts to save energy or improve energy efficiency may not be fruitful if focused through attempts to lower direct energy consumption alone. Instead, the policy orientation toward lowering consumption of embodied energy would be more effective. Such measures should appropriately be pegged in the upstream suppliers through technological improvements, fuel substitution or input replacements. Therefore, energy improvements in the production chains are likely to be more effective than energy changes within the production process of the industry itself. At the industry level, important measures such as – standards & labelling mandating the display on the product, certification of energy managers and energy auditing of firms are effective under the Energy Conservation Act (ECA), 2002. The act also provides instructional arrangements such as the Bureau of Energy Efficiency that have the objective to lower energy intensity in the economy. As many as 15 industries have been identified as energy intensive industries for designated consumers. The Energy Conservation Building Code envisages lower intensity in the commercial building sector by setting lower minimum energy efficiency standards for design and constructions including the building envelop, lighting, service, hot water, pumping and electrical power.

Eventually, the goods and services are consumed by the ultimate user. Therefore, consumer awareness acquires utmost importance in controlling or lowering the energy embodied in the product. Improved awareness of the user, through energy labelling and certification, will be effective through the changing consumer preferences for specific products and brands. Consumer as a major stakeholder can play a defining role energy intensity. Therefore, increasing awareness about the benefits of using standard and labeled products is important. This can be done through consumer education and benefits in the form of partial exemption of taxes. While the total energy intensity is important to identify sectors that guzzle huge amounts of energy, it is also important to consider the output significance of the corresponding sectors. A relatively less energy intensive sector with a significant output proportion is more important for conservation efforts as compared with an intensive sector with an insignificant output proportion. This further accentuates the present study on sector-wise energy intensities.

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APPENDIX A

Input-Output Model

Input-output models are static models that represent demand flows of goods as intermediates and final consumption in value terms. In an economy with n sectors, the output of each sector (X) is either consumed as an intermediate good (Z) in the production process of another sector, or is consumed as a final good (Y). Intersectoral relations are represented through the technical coefficient matrix, A whose ij^{th} element shows the amount of input from the i^{th} sector required to produce one unit output of the j^{th} sector.

The value flows are represented in a matrix, Z ($n \times n$ for an economy with n sectors) such that:

$$Z = (X_{ij})$$

Where, $i, j = 1,\ldots,n$

The elements of Z, i.e., X_{ij} are the flows from sector i to the sector j, measured in money values. The corresponding technical coefficient matrix, A ($n \times n$), is defined such that:

$$A = \left(x_{ij}\right) \ni: x_{ij} = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}}$$

Where, $i, j = 1,\ldots,n$

The matrix notation of I-O is as follows:

$$A{*}X + Y = X \qquad \text{(A.1)}$$

Where, X - Output vector, Y final demand vector, A is the technical coefficient matrix. The elements of A are referred to as $[a_{ij}]$, where $i, j = 1,\ldots n$. The integer n represents number of sectors in the economy.

Equation (1) is transformed to get:

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

The matrix $L = (I-A)^{-1}$ is called inter-industry matrix and equation (2) is used to determine the impact of change in final demand on overall economy. Its elements are referred to as $[r_{ij}]$, where $i, j = 1,\ldots,n$.

Any production activity in economy is undertaken eventually to serve into final demand of certain sector. Energy consumption is a feature of any production process, therefore energy use is associated with all sectors. Energy consumption can be either direct if the production process is consuming energy itself or can be indirect if it is absorbing energy through an intermediate consumption of another production activity. While the former refer to the consumption in the production process of a given sector, the latter accounts for the consumption due to use of inputs that might have contributed their own direct emissions. In other words, indirect energy consumption occurs on account of consumption of non-energy products and has an associated (implicit) flow of energy goods. Effect of change in energy demand percolates down the entire production chain that comprises of the sector itself and the sectors that feed into the given sector. This necessitates assessment of direct as well as indirect linkage so as to avoid any underestimation of energy requirements.