Energy Balance in India’s International Trade: 
An Input-Output Based Analysis

Anjali Tandon* 
Shahid Ahmed* 

The energy balance due to embodied energy use may be significant for trade dependent economies. In this paper, authors estimate the balance of embodied energy in India’s international trade at aggregate and sector levels. Over time, the composite energy sector (including primary and secondary energy) is observed to have turned from energy deficit to energy surplus primarily on account of expanding petroleum sector. On the contrary, non-energy sector has become energy deficit though it had a relatively insignificant energy surplus in the initial period. This points to the importance of embodied energy, particularly coal based, in the traded goods.

JEL Classification: C67, D57, Q40

Keywords: Energy balance; Embodied energy; Trade; Input-Output; India.

1. Introduction

The changes in foreign trade of an economy can have unintended implications on energy use through transfer of energy embodied in the non-energy transactions. The growing volume of trade and energy embodied in trade is well recognized. While studies acknowledge the importance of non-energy manufactured goods (Peters et al., 2011), the growing integration of international supply chains further emphasizes

* The authors are thankful to the anonymous reviewers for very useful comments that helped to improve the paper considerably. An earlier version of the paper was presented at the 24th International Input-Output Association Conference at Yonsei University, Seoul, Korea, during 5-8 July, 2016. Authors are thankful to the conference participants for their useful comments on the paper.
* Associate Fellow, National Council of Applied Economic Research, New Delhi, Email: tandon_anjali@hotmail.com;atandon@ncaer.org
* Professor, Department of Economics, Jamia Millia Islamia (Central University), New Delhi, Email: sahmed@jmi.ac.in

© Jadavpur University.
the role of international trade in the changing energy use. Some researchers contend that energy accounts based on indicators such as CO$_2$ produced per unit of GDP or per capita could be misleading, and inappropriate for countries which are net exporters of CO$_2$ intensive items. This further underscores the need to account for energy embodied in traded goods. Many studies have acknowledged the energy imbalance from trade in non-energy goods to the currency value of gross and net flows as well as the relative energy intensities of imports and exports [Heredeen and Bullard (1976)]. Herdeeven (1978) also insisted that the energy embodied in the trade of non-energy commodities be accounted for in a country’s net energy balance.

The cross border flow of goods and service are recorded in the statement of national accounts which provide the transaction value of outflows and inflows separately at a disaggregated level. For instance, trade statistics are provided for all traded commodities and services transferred. Although the relative significance of traded sectors can be studied in a structural sense form the national accounts, the value based recording of transaction flows is often inadequate for the analysis in real terms. The specific nature of a commodity warrants a quantity based analysis. For instance, it becomes necessary to analyze quantity of energy flows from a sustainability view point. Another insisting reason for quantity based analysis of energy is the embodied nature of energy use which is well established in literature. Therefore, international trade in non-energy goods and services is additionally characterized by energy transfer in an indirect form. Although the energy accounts are available separately, they account for only the direct transactions in the form of raw materials such as raw coal and crude oil, or as final product such as the aviation turbine fuel. Therefore, an alternate and comprehensive accounting becomes necessary to account for both direct and embodied energy trade.

The significance of energy balance is due to the fact that international trade can significantly contribute and alter the energy use in an economy. The difference between production and consumption is essentially the difference between exports and imports, which constitutes the trade balance. Therefore, analysis of the changes in energy balance is important to differentiate the production-based and consumption-based energy use [Marques, Rodrigues and Domingos (2011)]. Thus,

---

1 The terms viz. sector, commodity, process, industry and production activity are used interchangeably.
energy balance due to embodied use could be significant for trade dependent economies. Also, it is difficult to predict \textit{ex ante} the direction of energy balance for countries with varied compositions of exports and imports in terms of energy intensity of the traded products. And, India is a befitting case here due to the dissimilar structure of its exports and imports. India’s energy use has further fascinated many researchers due to high growth rates which are expected to increase further given its development objectives of equity, equal opportunity and poverty reduction.

For past many years, India’s imports of direct energy products are dominated by crude oil while exports of petroleum products have strengthened in the recent years. Among the non-energy products, imports are concentrated in capital goods e.g. machinery and equipment while exports are predominantly of services. In view of the wide band of energy intensity of the non-energy products, international trade can affect the energy situation of the Indian economy. Although an earlier study by Mukhpadhyay (2004) computed energy content of imports and exports separately, the estimates are limited to non-energy sectors as users of primary energy. The inclusion of energy sectors for analysis widens the scope of analysis by facilitating to compare the energy balance between energy and non-sectors separately. The present research is a unique attempt in this direction. The creation of a separate sector representing non-thermal electricity for analysis is another key contribution of the present research. Non-thermal electricity, which essentially represents hydroelectricity, has an increasing significance in the Indian economy. Although, electricity \textit{per se} is not traded significantly in India, its embodied use across sectors of production improves the estimates of energy balance. Most existing studies exclude the electricity sector for analysis due to its predominantly thermal based generation. However, the present paper makes novel efforts to separate out the non-thermal component which is likely to expand in future given the growing emphasis on sustainable growth. The use of separate price deflators for output, export, imports and intermediate use for each of the sectors of analysis, is another highlight of the paper which is useful to obtain improved estimates. Also, the analysis has a sufficiently wide reference period which facilitates inter-temporal comparison unlike previous studies such as Mehra et al. (2011).
With the above in mind, we propose to estimate the balance of embodied energy in India’s international trade. We use the estimates to study the key research objectives for the Indian economy:

1. Are the energy balance and trade balance necessarily in same direction?
2. How has the energy balance performed over time with increasing openness of the economy?
3. What are the sector-wise contributions to energy balance?

It is important to separately analyze energy balance for the direct and embodied energy trade which jointly contributes to the overall energy balance. At a more disaggregate level, the energy balance and trade balance may show different characteristics due to variations in energy intensity across sectors. In the Indian context, the non-energy exports are less energy intensive while the corresponding imports belong to the energy intensive categories [Mukhopadhyay (2004)]. This in turn points to the worsening of the overall energy balance of the country. Even though a comprehensive accounting may not necessarily change India’s energy balance from deficit to surplus at an aggregate level, the sectoral perspective is useful to identify the contribution of different sectors. Our key interest is to analyse the role played by different sectors as exports and imports of energy in the overall energy balance rather than only quantifying the numbers at an aggregate level.

Rest of the paper is structured into the following sections. Section 2 presents review of literature. The methodological details are given in Section 3 while Section 4 explains the data and compilation. This is followed by results and discussions in Section 5. The paper concludes in Section 6.

2. Review of literature

Many researchers have emphasized on the transfer of emissions from international trade of various countries and regions which constitute a large and growing proportion of global emissions.\(^2\) The intent has been to uncover the changes in

---
\(^2\)The study of energy use is ultimately linked to the related carbon emissions which are important from an environmental and sustainability perspective. Most energy studies, therefore, present the results and discussions for emissions. Due to prevalence of the emission studies and their relevance for energy use, these studies are reviewed here. However any emission based study is, in essentially, based on the energy used in different sectors of an economy. The present paper maintains a focus on
emissions owing to cross border trade. Although merely transfer of goods through the trade channel may not change the level of global emissions, except for due to the emissions during transport of goods, the variations in emissions intensity of the trading partners magnified the effect (Ahmad and Wyckoff, 2003). In fact the variations in inter-sectoral emission intensities explains energy deficit for trade surplus countries such as Italy, Japan and Sweden; while trade deficit countries such as Australia, Brazil, Russia and UK registered energy surplus due to exports of energy intensive products. In either case, changes in external sector policy can significantly impact the change in energy and hence emissions (Choliz and Durante, 2004). Therefore, the difference in emissions from trade transfers is indicative of the changes from substitution of domestic production with imports.

The emissions or in fact the energy embodied in traded goods are being used by countries to lower the use of energy in domestic production; which is only a cosmetic reduction in energy use, as the same (or similar) amount is being produced elsewhere to meet the consumption needs. Therefore, some authors have highlighted the importance of monitoring emissions transfers via international trade while also paying attention to territorial emission statistics. For instance, Peters et al. (2011) suggest the stabilization of emissions in developed countries partly due to increased imports from the developing countries. This indicates that growth in international trade may show up as emission reduction for net importers of energy while the reverse is observed for net exporting nations that face development challenges. Studies such as Huichao and Wang (2010) emphasize that developed nations like US share part responsibility for China’s rapid energy consumption and carbon emissions besides the historical responsibility.

More recently, the influence of emissions embodied in traded goods has also been acknowledged to influence international traded flows. Studies have acknowledged that trade flows lead to allocation of polluting activities, in addition to the conventional factors of production namely labour and capital. This has led to many country specific and multi-country studies. The impact of foreign trade on energy use in Brazilian economy was studied by Machado (2000). The findings suggest that trade is observed to evolve in energy as well as carbon-intensive activities with high energy use. An important reason for energy based analysis is the comparability of quantities of energy output and inputs from alternate sources. This is helpful to check the robustness of the results.
share of energy-intensive exports in non-energy-intensive commodities, while the
same measure dropped for imports. In terms of energy and carbon content of trade,
Brazil’s net energy and carbon balance is found to have narrowed though still
positive. Similarly, Pan, Phillips and Chen (2008) argue that China’s energy
consumption is high due to its economic growth which is primarily driven by
exports that are either intermediate or consumption goods to the developed countries.
In a similar attempt, Mukhopadhyay (2004) analyzed the impact of international
trade on energy in the Indian context. The results for India are contrary to those
observed by Machado (2000) for Brazil. The pollution terms of trade index for India
exhibited environmentally favourable exports as compared to imports. At the same
time, it is also felt that extreme trade balance of emissions could also be biased by
the choice of a base year that could be reflective of a sudden and temporary trade
pattern [Munksgaard and Kalus (2001), Tunk et al. (2007), and Herdeeen (1978)].
Therefore, it is useful to study the pattern of energy use over a period of time. The
study by Mukhopadhyay refers to a single time period along with simulations for a
future period. The Indian economy has increasingly integrated with the world and
therefore the structure of the economy is also influence by trade [Mukhopadhyay
(2004)]. In fact the cost advantages from cheap labour, resource abundance and low
environmental compliance can be influential factors in changing composition of
India’s trade with rest of the world. Therefore, it becomes essential to map out the
energy flows between India and rest of the world. Since aggregated results hide the
important interchanges at sector levels, a sector level analysis is recommended. The
inclusion of a separate non-thermal electricity sector is another contribution of the
present study. Although electricity, per se is not traded, energy embodied in
electricity constitutes a significant share for most countries dependent on fossil fuel
based generation [Ahmad and Wyckoff (2003)]. At the same time, electricity from
renewable resources is helpful to lower the emission intensity, emphasizing the need
for its inclusion as an explicit sector of study. The present study fills this gap.

3. Methodology

In the traditional Input-Output (I-O) model, intersectoral relationship of a sector with
other sectors is expressed in the form of linear equations that constitute a system of
simultaneous equations representing all activities of the economy. The model
assumes homogeneity of output for given sector which in turn implies identical
pricing for all using sectors [Mayer and Flachmann (2011)]. However, this
assumption could be unrealistic for energy commodities. For instance, fuels such as diesel or electricity are highly subsidized for certain sectors leading to significant price differentials across the users. As an alternate, hybrid I-O model is useful to address the problem of homogenous pricing of energy inputs across sectors of the economy. The methodology of this paper makes use of hybrid I-O as formulated by Miller and Blair (2009). The hybrid I-O represents commodity flows through a combination of energy quantities and money values (of the non-energy sectors) and is adept to account for cumulative effect of all successive rounds i.e. indirect energy requirements through energy embedded in inputs. The comparable flow matrices in hybrid (mixed) units are obtained by substituting the energy sector rows in physical quantities for the rows that contain energy flows in currency values. The resulting hybrid I-O contains rows corresponding to energy commodities in physical quantities while all other non-energy commodity rows are maintained in monetary values. The energy sector rows trace the use of energy commodities in other sectors of the economy.

3.1 Estimating energy use embodied in trade

Based on the location of the production and consumption of a commodity, products are classified into four categories as shown in Table 1 [Lin and Sun (2010)]. The products can be,

i) produced in the domestic economy and consumed within the domestic economy (quadrant I);

ii) produced in the domestic economy but consumed in rest of the world (quadrant II);

iii) produced abroad and consumed in the domestic economy either as final products or as intermittent products into the manufacturing (quadrant III);

iv) produced abroad, used domestically for some intermediate processing into a final good which is then exported to rest of the world for consumption (quadrant IV).

The Energy Embodied in Exports, EEE, is represented by the sum of energy embodied in quadrants II and IV. Similarly, Energy Embodied in Imports, EEI, is represented by the sum of energy embodied in quadrants III and IV. The difference between EEE and EEI is the Balance of Energy Embodied in Trade, BEET, for the economy (Refer Appendix 1 for computational details).
Table 1. Classification of products based on location and trade

<table>
<thead>
<tr>
<th>Consumption</th>
<th>Domestic consumption</th>
<th>External consumption</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>I</td>
<td>II</td>
<td>EEP</td>
</tr>
<tr>
<td>Domestic production</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External production</td>
<td>III</td>
<td>IV</td>
<td>EEI</td>
</tr>
<tr>
<td>Total</td>
<td>EEC</td>
<td>EEE</td>
<td></td>
</tr>
</tbody>
</table>


Balance of Energy Embodied in Trade (BEET) = EEE-EEI

Source: Adapted from Lin and Sun (2010).

3.2 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. Homogeneity amongst sub-sectors, in terms of input use and output disposition, is another key consideration for sector choice. The availability of price indices required to deflate transaction flows is another criterion. The list of sectors of analysis is presented in Table 2.

The primary energy sectors – coal & lignite; natural gas; crude petroleum, and non-thermal electricity – are distinguished separately. Data on the coal & lignite sector is consistently reported in all four Input-Output Transaction Tables (IOTTs). However, natural gas and crude petroleum sectors are not uniformly available in the four IOTTs. While natural gas & crude petroleum is available as a composite sector prior to the IOTT for 2003-04; the two are distinguished in the IOTTs from 2003-04 onwards. However the two sectors differ notably in their trade volumes as noted from India’s high and increasing import dependency on crude petroleum. Therefore,

---

3While I-O refers to the methodological framework, IOTT is generally used to refer to the matrix of inter-industry transactions.
4Refer Section 4.1 for details on time frame of the study.
it becomes relevant to consider natural gas and crude petroleum separately. We adopt the input use and supply structure from Pal et al. (2015) to separate the composite sector during the years 1993-94 and 1998-99.\(^5\)

With regard to electricity, it is necessary to consider only the primary component of electricity to rule out double counting from the simultaneous consideration of thermal electricity (which is essentially coal based) and is already accounted in coal & lignite as a primary energy sector. Thus, non-thermal electricity as a separate sector is mainly kept due to relevance of hydro power, as a source of renewable energy, which has a significant share of 26.2 per cent in total installed capacity for electricity generation. Hydroelectricity also accounts 16.7 per cent of the total generation. Using the input structure from Pal et al. (2015), the composite electricity sector is disaggregated into non-thermal (inclusive of hydro and nuclear electricity) and thermal electricity (Refer to Appendix 2 for details). The thermal electricity sector although present as a separate sector represents a using sector of the primary energy inputs such as coal & lignite. The row of composite electricity is split in the proportion of corresponding outputs. Different conversion efficiencies for each energy source – coal & lignite; natural gas; crude petroleum; hydroelectricity, and nuclear electricity – are used to estimate energy intensity.\(^6\)

The proportion of non-thermal electricity which includes primarily hydroelectricity along with a marginal share of nuclear electricity is estimated at 21.3, 16.5, 14.7 and 16.9 per cent for the four reference years, respectively. Our computations from the inclusion of non-thermal electricity sector conform to the energy conservation equations formulated by Miller and Blair (2009).

---


\(^6\) The conversion efficiency varies across sources of generation due to variations in technology and input use. For instance, conversion efficiency for coal varies from 32-42%, for gas from 33-38%, for oil from 38-44%, for hydro electricity from 85-90% and for nuclear power from 33-36% [Mukherjee (2012), Honorio et al. (2003)].
Table 2. Sectors of analysis

<table>
<thead>
<tr>
<th>S.No</th>
<th>Sector name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coal &amp; lignite</td>
</tr>
<tr>
<td>2</td>
<td>Natural gas</td>
</tr>
<tr>
<td>3</td>
<td>Crude petroleum</td>
</tr>
<tr>
<td>4</td>
<td>Non-thermal electricity*</td>
</tr>
<tr>
<td>5</td>
<td>Thermal electricity</td>
</tr>
<tr>
<td>6</td>
<td>Petroleum products</td>
</tr>
<tr>
<td>7</td>
<td>Coal tar products</td>
</tr>
<tr>
<td>8</td>
<td>Agriculture &amp; allied</td>
</tr>
<tr>
<td>9</td>
<td>Mining</td>
</tr>
<tr>
<td>10</td>
<td>Food, beverages &amp; tobacco</td>
</tr>
<tr>
<td>11</td>
<td>Paper, paper products &amp; newsprint</td>
</tr>
<tr>
<td>12</td>
<td>Textile &amp; leather</td>
</tr>
<tr>
<td>13</td>
<td>Fertilizers &amp; pesticides</td>
</tr>
<tr>
<td>14</td>
<td>Chemicals, rubber &amp; plastics &amp; products</td>
</tr>
<tr>
<td>15</td>
<td>Cement</td>
</tr>
<tr>
<td>16</td>
<td>Non-metallic mineral products</td>
</tr>
<tr>
<td>17</td>
<td>Iron &amp; steel</td>
</tr>
<tr>
<td>18</td>
<td>Non-ferrous basic metals</td>
</tr>
<tr>
<td>19</td>
<td>Machinery &amp; equipment</td>
</tr>
<tr>
<td>20</td>
<td>Other manufacturing</td>
</tr>
<tr>
<td>21</td>
<td>Construction</td>
</tr>
<tr>
<td>22</td>
<td>Transport services</td>
</tr>
<tr>
<td>23</td>
<td>Other services</td>
</tr>
</tbody>
</table>

# Includes hydro and nuclear power.

Sources: Based on CSO, 2000 and 2012.

3.3 Measurement of energy

The quantity of energy is measured in million tonne of oil equivalent (mtoe) due to the availability of conversions factors from various primary energy forms. 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 which is further used to validate the energy conservation equation of the
Hybrid I-O model. The conversion efficiency varies across sources of generation due to variations in technology and input use. Conversion efficiencies for coal & lignite and natural gas sectors as obtained from the I-O based computations are consistent with alternate source. Using the conversion efficiencies for hydro and nuclear power at 85 and 33 per cent respectively, the model conforms to the energy conservation equation for the years of analysis.

4. Data

We are interested in an inter-temporal analysis for India, to analyse the changes due to increased openness of the economy.

4.1 Time frame

The analysis is based on the four successive benchmark IOTTs viz. 1993-94, 1998-99, 2003-04 and 2007-08 (Central Statistics Office (CSO) 2000, 2005, 2008 and 2012). The IOTT 1993-94, as base year, corresponds to the first generation reforms. Around this time structural and industrial reforms were introduced in the economy. The IOTT 2007-08 as a terminal year signifies the importance of second generation reforms, already in place since the early 2000s. These were mainly oriented towards distributional, equity and efficiency aspects within the economy. Notable among them are dismantling of the Administered Pricing Mechanism directly effecting the fuel pricing in India and hence the upstream and downstream sectors.

4.2 Deflation of the IOTTs

The intersectoral transaction flows are available at nominal prices. The paper converts IOTTs for 1998-99, 2003-04 and 2007-08 at the base year 1993-94 prices using the methodology suggested by Celasun (1984). While it is a common practice to deflate the values of aggregated sectors, we have computed, mapped and obtained deflators for each of the 130 sectors. This is further helpful in obtaining robust price indices in instances where the commodities within a sector have noticeably different values of the price index. For example, Wholesale Price Index (WPI) for coal is different from that of mineral oils, both of which are clubbed under the broad category of fuel & power. Therefore, considering the WPI for coal explicitly, instead
of mapping with price indices of fuel & power, has improved the precision of our computations.

The WPI and implicit GDP deflators for are sourced from the Office of the Economic Advisor and National Account Statistics, respectively. The unit value indices, separately for exports and imports, are obtained from the Reserve Bank of India.

5. Results and discussion

India’s trade deficit has widened since 1993-94 in real terms (see Figure 1). While both exports and imports increased, the latter expanded faster. Typically, India’s trade deficit is attributed to merchandise goods, particularly due to rising crude oil imports contributing more than one-third of the total imports. At a cursory level, this hints towards the deficit on account of energy imports measured in money values. However, from the sustainability perspective a quantity based analysis of energy is preferable to evaluate the balance of energy embodied in trade (i.e. BEET) in physical terms. Additionally, the BEET also takes into account the energy intensity of different sectors and is useful to recognize sector-wise contribution in the overall energy balance. In fact, sector-wise intensities are instrumental in determining the overall energy balance of a country. For instance, an earlier study for another developing country like Brazil, found net exports of embodied energy in non-energy sectors despite a corresponding net trade deficit in monetary terms (Machado et al. (2001)).

Our computations for India at the aggregate levels how an overall energy deficit through the entire reference period covered by the four IOTTs: 1993-94, 1998-99, 2003-04 and 2007-08. India’s energy deficit widened from (-)23 mtoe during 1993-94 to (-)50 mtoe during 1998-99 and further increased to (-)83 mtoe during 2003-04 before it narrowed to (-)40 mtoe during 2007-08. Thus, an overall deficit is observed in energy balance as well as the trade balance through the entire reference period.\(^8\)

\(^7\) In fact, the growth differentials between exports and imports are even sharper when compared with nominal growth rates.

\(^8\) Xu and Dietzenbacher (2014) also studied the changes in EEE and EEI, for 40 countries including India, with a very distinctive decomposition formulation and observed a positive emission balance for the developing countries as a group as well as China and a negative balance for the group of developed countries. However, explicit information on the direction of India’s energy balance is not discussed.
Despite a higher value of energy embodied in overall imports (EEI) compared to energy embodied in overall exports (EEE), the corresponding growth rates provide an interesting insight. First, even though EEI grew faster than EEE during the initial sub-period between 1993-94 and 1998-99, the trend reversed in the following years. Consequently, during the overall period from 1993-94 to 2007-08, the EEE expanded faster than the EEI. This points to increasing energy embodied in exports which in turn points to greater exports of embodied energy whether in intermediate or final use form. The contribution of intermediate exports in increasing India’s EEE is also validated from the findings of Xu and Dietzenbacher (2014) attributing 48 per cent of increase in India’s EEE to increasing intermediate use in rest of the world. This also shows increasing integration of Indian exports in the world economy through global supply chains. At the same time, another 66 per cent and 44 per cent increase is on account of changes in structure and level of final demand from rest of the world, respectively. This in turn shows that India’s export expansion has been driven by demand in external markets as a reflection of increasing competiveness. Second, the trend in growth of EEE and EEI fluctuated over time. This is contrary to the
prevalent notion on India’s accelerated imports of energy and is perhaps the result of improving energy intensity of the Indian manufacturing sector [Goldar (2010)].

The analysis attempts to answer the above dilemma on changing energy balance due to exports and imports by cutting across the overall energy balance into broad categories of energy and non-energy products. The overall energy balance is the composite of (direct) energy and non-energy sectors. Between 1993-94 and 2007-08, the non-energy and energy sectors (including primary and secondary energy) swapped positions in the overall BEET (Figure 2). It is observed that over time, the energy sector turned from an energy deficit to an energy surplus category. This is primarily on account of India’s expanding petroleum sector which registered growing exports. Exports of petroleum products increased notably during the later period from merely 2.7 million tonne in 1990-91 to 40.8 million tonne in 2007-08 and further to 63.41 million tonne in 2012-13, as a result of private sector participation and increased refining capacity (CSO, 2011 and 2014). The growing overseas demand for petroleum products is reflected in the increasing exports from private majors such as Reliance and Essar which jointly constitute 80-90 per cent of exports while public sector accounts for the rest [Toms (2010)]. From a net importing sector, the petroleum product sector has transformed to a leading export product leaving behind the traditionally high valued added exports from the gems and jewllery sector [Francis (2015)]. India exports a wide variety of petroleum products ranging from gasoline, ATF, HSD, and fuel oils. Private participation in the exploration and refining increased after the New Exploration License Policy, 1999. Deregulation in the refining and production segment attracted major companies for investment in the refining business with a technologically advanced setup resulting in operational capacity exceeding 100 per cent for exceptional cases. However, distribution and marketing continued to be government controlled. The domestic price was regulated to insulate the consumer from price shocks in international markets. The public sector companies found it profitable to sell in the domestic market due to government subsidies for under recoveries, a benefit deprived to the private refiners. Though, private companies generated surplus output but could not find a suitable domestic market with fair prices, making it impossible to get internationally comparable price for the product. For instance, Cairn Energy could not strike a fair deal with Indian Oil Corporation for its new found energy sources in Barmer, Rajasthan in 2000. At the same time, prices in the international markets
were remunerative. For instance, the refinery transfer price of products such as petrol and diesel were lower than the price in international market (Ministry of Petroleum and Natural Gas, 2015). The additional costs on account of excise duty, BS IV premium, marketing margins, etc. further increased the costs for the domestic producers. In addition, the newer private refineries had the geographical advantage from their coastal location, which reduced transportations costs. Thus, export became a profitable option for private refiners. While efficient refineries such as the Jamnagar refinery have contributed towards India’s becoming a refining hub, the presence of large demanding countries such as Japan, South Korea and China within the neighborhood have also contributed to rise in exports of petroleum products. In fact, strengthening of the exports of petroleum products has resulted in increasing concentration among India’s merchandise exports. On the other hand, the aggregate non-energy sector turned energy deficit though it had a relatively insignificant

Note: Figures represent the embodied energy measured in million tonne of oil equivalent (mtoe).
Source: Authors’ computations.

---

9 Based on computations from the press release ((Ministry of Petroleum and Natural Gas, 2015).
energy surplus during the initial period. This points to the importance of embodied energy in traded goods. Imports of energy intensive products or large imports of the relatively less intensive products are the reasons behind this finding. Therefore, it becomes necessary to analyse the sector-wise EEE, EEI and BEET.

The sector-wise results are shown in Table 3. The total EEE increased by more than four times from 41 mtoe during 1993-94 to as much as 130 mtoe during 2007-08. Energy embodied in exports increased for all exports with non-metallic mineral sector as the only exception. In addition, some major distributional changes are also observed among the other sectors. While transport services accounted for highest embodied energy during 1993-94, the petroleum product sector took over by 2007-08. Other important exporting sectors include other manufacturing; other services; iron & steel; transportation services, and chemicals, rubber & plastic & products. Similarly, EEI also increased from 63 mtoe to 170 mtoe. Likewise EEE, the EEI increased for all sectors with the exception of secondary energy sectors, viz. petroleum products and coal tar products. Lower EEI in the petroleum product sector is due to lesser imports of petroleum products as discussed earlier. The important importing sectors with regard to embodied energy included non-ferrous basic metals, machinery & equipment, other manufacturing; iron & steel, petroleum products, and chemicals, rubber & plastics & products.

Changes in the BEET are importantly recognised in the key sectors contributing to energy deficit as well as energy surplus. The four major energy deficit sectors include non-ferrous basic metals, machinery & equipment, other manufacturing, and crude petroleum. The energy surplus sectors include petroleum products, textile & leather, and other services. Although the energy surplus generated form the petroleum product sector is notable, it is insufficient to offset the high energy deficits in the core manufacturing sectors viz. non-ferrous basic metals, machinery & equipment, and other manufacturing. The imports of non-ferrous metals mainly include aluminium products for the downstream industries such as electrical and

---

10 Also, the I-O analysis is useful for a long term analysis and therefore consecutive IOTTs are not necessarily helpful to study the impact of reforms. A long time horizon e.g 1993-94 to 2007-08 is helpful to study the cumulative effect of reforms. For brevity the discussion henceforth maintains a focus on the longer reference period in order to assess the cumulative effect over the longer term.

11 Although insignificant in magnitude, the EEI also declined for mining and paper, paper products & newsprint sectors.
Table 3. Sector-wise energy embodied in trade (mtoe)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coal &amp; lignite</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Natural gas</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Crude petroleum</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>8</td>
<td>-1</td>
</tr>
<tr>
<td>4</td>
<td>Non-thermal electricity</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Thermal electricity</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Petroleum products</td>
<td>3</td>
<td>38</td>
<td>23</td>
<td>16</td>
<td>-20</td>
</tr>
<tr>
<td>7</td>
<td>Coal tar products</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>3</td>
<td>-5</td>
</tr>
<tr>
<td>8</td>
<td>Agriculture &amp; allied</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>Mining</td>
<td>-</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>10</td>
<td>Food, beverages &amp; tobacco</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>11</td>
<td>Paper, paper products &amp; newsprint</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>12</td>
<td>Textile &amp; leather</td>
<td>5</td>
<td>9</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>13</td>
<td>Fertilizers &amp; pesticides</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>-2</td>
</tr>
<tr>
<td>14</td>
<td>Chemicals, rubber &amp; plastics &amp; products</td>
<td>4</td>
<td>11</td>
<td>5</td>
<td>10</td>
<td>-1</td>
</tr>
<tr>
<td>15</td>
<td>Cement</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>16</td>
<td>Non-metallic mineral products</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>17</td>
<td>Iron &amp; steel</td>
<td>2</td>
<td>14</td>
<td>4</td>
<td>13</td>
<td>-2</td>
</tr>
<tr>
<td>18</td>
<td>Non-ferrous basic metals</td>
<td>-</td>
<td>3</td>
<td>2</td>
<td>32</td>
<td>-2</td>
</tr>
<tr>
<td>19</td>
<td>Machinery &amp; equipment</td>
<td>2</td>
<td>7</td>
<td>7</td>
<td>32</td>
<td>-4</td>
</tr>
<tr>
<td>20</td>
<td>Other manufacturing</td>
<td>5</td>
<td>17</td>
<td>7</td>
<td>31</td>
<td>-2</td>
</tr>
<tr>
<td>21</td>
<td>Construction</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-1</td>
<td>-</td>
</tr>
<tr>
<td>22</td>
<td>Transport services</td>
<td>6</td>
<td>14</td>
<td>1</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>23</td>
<td>Other services</td>
<td>3</td>
<td>10</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>41</td>
<td>130</td>
<td>63</td>
<td>170</td>
<td>-23</td>
</tr>
</tbody>
</table>

Notes: 1. mtoe: million tonne of oil equivalent.
2. - insignificant.
Source: Authors’ computations.
electronics; automobile industry; construction; packaging consumer durables, and other applications including defence. The demand for aluminium products are mainly in the form of – wire rods primarily driven by power transmission and distribution networks; castings for automobile sector; rolled products for foil stock; applications in heavy transport equipment such as bus, truck and coaches; roofing &siding, figures; consumer durables such as pressure cookers, fans and fixtures; foil for pharmaceutical; food and non-food packaging; and extrusions such as curtain walls, windows and doors. etc. [Goplaiksrishana (2013)]. Despite the availability of good grade bauxite, the low quality of aluminium products drives the imports [Majid (2011)].

The energy deficit of the machinery & equipment sector is due to imports of engineering and non-electrical machinery. Engineering machinery includes generation machinery such as turbines and generators, and distribution machinery such as switch gear and control gears (India Brand Equity Foundation, 2008). There is a significant gap in domestic capacity of electric furnaces which are imported. Mechanical appliances and nuclear reactors are also imported under this category in addition to the imports of electrical machinery including sound and television recorders, etc. Imports of other manufacturing include transport equipment for rail, road, air and water transport services. Limited manufacturing capacity (e.g for wagons) and the high cost due to low technology penetration contribute to import dependency for transport equipment (Chandra and Jain, 2007). The imports of crude petroleum are due to domestic shortages.

5.1 Sector-wise embodied energy

Further, the sector-wise computations of the BEET, EEE and EEI for each of the four primary energy sources show a worsening energy deficit on account of coal & lignite as opposed to energy surplus from crude petroleum (Figure 3).12 This is surprising given India’s large domestic coal reserves and the increasing domestic shortage of crude petroleum. The crude petroleum based EEE increased notably by more than four times followed by 3.6 times increase in natural gas based EEE and a relatively small expansion in the coal based EEE which increased by 2.4 times. The primary electricity based EEE remained relatively low. However, the EEI expanded

---

12The energy balance of primary electricity is relatively insignificant.
most strongly due to coal & lignite based embodied energy which increased by 3.8 times, followed by 3.6 times increase in natural gas based EEI while crude petroleum based EEI increased by 1.6 times. Clearly, this is associated with the energy embodied in the products in an indirect form which are being imported. Despite domestically available coal reserves, the imports of coal & lignite in embedded forms highlights the weaknesses in domestic production/ capacities for various reasons including constraints on foreign investment, rigidity in labour markets, market failure in the form of fuel or capital subsidies or cross subsidization and infrastructural bottlenecks among others.

Figure 3: Source-wise energy embodied in exports, imports and trade balance (mtoe)

![Bar chart showing energy embodiment in trade](chart.png)

Notes: 1. mtoe: million tonne of oil equivalent.
Source: Authors’ computations.

6. Conclusions

In the present research, we study the changes in energy embodied in India’s trade using information on structure of the economy as available from the four consecutive
IOTTs for the year: 1993-94, 1998-99, 2003-04 and 2007-08. We argue that the energy balance as determined from the difference of energy embodied in exports and imports can be significant for trade dependent countries. Given the different energy intensities of the traded products and also the varying compositions of exports and imports, it is difficult to predict *ex-ante* the direction of energy balance. A study of energy embodied in trade is particularly important for a developing country, like India, due to high growth rates, development objectives and increasing openness of the economy, so as to assess the changes in energy use from a sectoral perspective. Therefore, our key interest is to analyze the role played by different sectors as exports and imports of energy in the overall energy balance rather than only quantifying the numbers at an aggregate level.

The results show energy deficit for the Indian economy during the entire reference period. An overall deficit is observed in energy balance as well as the trade balance. During the longer term, energy embodied in exports expanded faster than the energy embodied in imports. The energy content in exports increased, this could be due to various reasons such as improved cost competitiveness from better energy efficiency or changing composition of the export basket towards more energy intensive profile. While a structural decomposition analysis is required to precisely quantify the contributions of such factors, the present analysis perhaps hints towards both. The composition of exports undoubtedly changed from the traditionally low value added resource based products to more energy intensive petroleum products which constitute around 15 per cent of total exports. The energy efficiency also improved with better environmental compliance such as the Euro norms for fuels which required the lower sulphur contents. Despite increasing energy embodied in imports, the slowdown in growth of energy embodied in imports as compared to energy embodied in exports, mainly due to accelerated exports of petroleum products, is rather new found in an economy-wide framework. Interestingly, the overall energy sector turned from an energy deficit to energy surplus category benefitting from the global demand for petroleum products particularly in the Asian neighborhood countries such as China and Japan. At the same time, the aggregate non-energy sector turned into an energy deficit though it had a relatively insignificant energy surplus in the initial period. This points out to the importance of embodied energy in traded goods, particularly for India. Sector-wise changes in energy balance show

13 A decomposition analysis is beyond the scope of the present study.
non-ferrous basic metals, machinery & equipment, other manufacturing, and crude petroleum as the key energy deficit sectors, while important energy surplus sectors include petroleum products; other services, and textile & leather industries.

With regard to the energy deficit sectors such as non-ferrous basic metal products, the demand pressure is expected to further increase due to trends in populations, rural electrification, urbanisation; and also infrastructural development in the form of construction of highways, rails & waterways. Presently, domestic production of specific metals such as aluminium is constrained due to perverse policy settings such as inverted duty structure [Metalworld (2016)]. There is also need for duty correction measures for some important raw materials [Sathpathy and Mohan (2016)]. The existing shortfalls in domestic production of machinery & equipment and transport equipment need to be bridged through adoption of advanced technology. The problem of rising imports of crude petroleum can be addressed through exploring possibilities of inter-fuel substitution.

Among the energy surplus sector, the increasing energy exports embodied in petroleum products which also have high value added components, provide avenues for employment and income generation. Therefore, the sector needs policy attention for continued growth. At the same time, the caveats in the form of externalities from import leakages (of crude petroleum as a raw material) and the political implications of import dependency should be born in mind. The textile sector provides visible opportunities for strengthening exports in relatively less energy intensive manufacturing. The sector has also recorded improved energy efficiency in the past. Thus, textile exports can be helpful to partly balance the overall energy deficit alongside their traditional cost advantage, employment potential and abundantly available domestic resources. Incidentally, other services which include IT, ITES, business and financial services, have a high export share in the basket of total exports. The service sector is another area for strengthening exports in less energy intensive sectors of the economy.

A balance policy approach is required so as to encourage domestic manufacturing by exploiting domestically available resources; while also ensuring efficiency of the production process through continuous adoption of improved technology.
The findings are important for formulation of sector-specific policies. For instance, the imports under non-ferrous basic metals are further expected to increase in future with newer applications such as formwork & scaffolding which drive the demand for aluminum in the construction sector. Also, India’s automobile industry is further expected to develop into an international hub in view of the make in India initiative of the government. This in turn will pose greater demand for non-basic metals.

Further, India’s commitment to lower emission intensity by 2022 through increased presence of solar energy is expected to increase the demand for solar panel frames & supports made from non-basic metals. The increasing emphasis on high quality extrusions will further require imports of better quality products. Clearly, this is associated with the energy embodied in the products in an indirect form which are being imported. Despite domestically available coal reserves, the imports of coal & lignite in embedded forms highlight the weaknesses in domestic production/capacities for various reasons including constraints on foreign investment, rigidity in labour markets, market failure in the form of fuel or capital subsidies or cross subsidization and infrastructural bottlenecks among others.

References


Appendix 1: Estimating energy embodied in trade

In an economy 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). The elements of Z, i.e., $X_{ij}$ represent the flows from sector $i$ to the sector $j$. Inter-sectoral relations in the economy are represented through the technical coefficient matrix, $A$ ($n \times n$) 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 direct coefficient matrix $A$
is defined as: \( A = [a_{ij}] \) with \( a_{ij} = \frac{X_{ij}}{x_j} \). Further, the total requirement matrix \( L \) is defined as \( L = (I - A)^{-1} = [r_{ij}] \). The coefficients \( r_{ij} \) are inclusive of the indirect effects which occur due to multiple and nested rounds of inter-relationship among sectors.

Based on the Lin and Sun (2010), direct energy content of a good is determined using the direct energy intensity which is expressed as quantity of energy required per unit of output values i.e. mtoe per million rupees, \( c^d_j \). We define the row vector (1 X n), of energy intensities as

\[
c^d = \begin{bmatrix} c^d_1 & c^d_2 & \ldots & c^d_n \end{bmatrix}
\]

which represents the domestic energy content of all sectors of the economy. Using the I-O nomenclature, energy embodied in domestic output can be expressed as:

\[
C^d = c^d X
\]  
(A.2)

which using \( Y = (1 - A)X \) can be written as,

\[
C^d = c^d (1 - A)^{-1} Y
\]

\[
= \begin{bmatrix} E^d_1 & E^d_2 & \ldots & E^d_n \end{bmatrix} \begin{bmatrix} Y_1 \\ \vdots \\ Y_n \end{bmatrix}
\]

(A.3)

where, \( E^d_j = c^d_1 r_{1j} + c^d_2 r_{2j} + \ldots + c^d_n r_{nj}, \) \( j = 1, 2, \ldots, n \), represents the direct and indirect energy embodied in the production chain which delivers one unit of final demand of sector \( j \). In the above transformation \( E^d_j \) gives the direct energy intensity of the output of sector \( j \) while \( E^d_{Yj} \) gives the embodied energy in final demand of sector \( j \).
Further, the import matrix $A^m$ is required to assess the energy embodied in imported goods. Total imports, $X^m$ constitute the imports used as intermediates in the manufacturing process and the imports consumed directly by the final consumer ($Y^m$). This is expressed mathematically in the I-O notation as follows:

$$X^m = A^m X + Y^m$$

where $A^m (I - A)^{-1} Y + Y^m$ (A.4)

The processed form of intermediate imports, which is a final output, can further be consumed domestically, $I^d$ or re-exported to rest of the world, $I^e$. Under the assumption that energy content (i.e. intensity) of the exporting countries is same as those of the domestic sectors, we compute total energy embodied in imports as follows:

$$E^d X^m = E^m A^m X + E^d Y^m = E^d (I^d + Y^m)$$

Energy embodied in imported inputs is given by:

$$E^m A^m = E^d A^m (1 - A)^{-1} Y = E^m Y$$

where, the row vector $E^m$ represents imported intermediate energy per unit of final demand.

Thus, energy embodied in re-exports is given as:

$$E^m Z = E^d A^m (1 - A)^{-1} Z = E^d YA^m XZ = E^d I^e$$

where, $Z$ is the vector of exports.

Using nomenclature explained earlier in Table 1, the mathematical formulation of EEE and EEI is as follows:
Appendix 2: Primary electricity sector

The electricity sector, as given in the IOCT, includes generation from both thermal and non-thermal sources, and is inclusive of the non-utility generation. Thermal electricity is generated from fossil fuel sources such as coal, lignite and natural gas. Non-thermal electricity is generated from non-fossil sources that include hydro, wind, nuclear and renewable power. The United Nations (UN) manual recognizes electricity from hydro, nuclear, wind and geothermal sources as primary energy. Further, the concept is perfectly compatible within the I-O models which capture the impact of direct use of primary energy as well as the indirect use as input to produce secondary energy. Many existing studies, particularly on India, have conspicuously ignored electricity generated from primary sources, particularly the hydroelectricity in view of the high share of secondary electricity against the primary electricity. The present research contributes by providing methodological improvements required to assess the impact by inclusion of the primary electricity in form of hydroelectricity, with the help of conversion factors. This not only widens the coverage of energy sources but also improves the precision of computations used to evaluate changes in energy intensity which is extremely important to study the changes in coefficients due to electricity, reflecting the technological change and inter-fuel substitution from coal to gas.
This requires the introduction of a separate primary electricity sector. At the same time, it is necessary to consider only the primary component of electricity to rule out double counting from the simultaneous consideration of thermal electricity (essentially coal based) which is already accounted in coal & lignite as a primary energy 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 two years 1994-95 and 2006-07 and differentiates electricity into hydro, non-hydro and nuclear components. Hence, the column of composite electricity sector is split 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 which account for the contribution of hydro power as a non-fossil resource. Since data on electricity supply to various using sectors does not distinguish by the generation source, the supply is assumed proportionate to the output shares of thermal and non-thermal electricity, which varies with time.

Another possibility of double counting arises from simultaneously considering thermal electricity and feedstock consumption in the coal using sectors which produce electricity for self-consumption, e.g. iron & steel. This situation is avoided by discounting thermal electricity generated by the non-utilities (i.e. captive power) from the gross thermal generation which is also inclusive of electricity production by the utilities. The electricity generation for self-consumption by non-utilities, which is essentially coal based, is accounted in the sector-wise consumption of raw coal for sector such as iron & steel, etc.