The empirical study on energy embodied in goods of Sino-US trade

Xiaolei Liu and Chunchao Chu
China Academy of Transportation Sciences, Beijing, China

Email: 6868915@qq.com

Abstract. The huge trade surplus of Sino-US trade is founded on large net exports of embodied energy because of the energy’s dual nature which is not only commodity and also factor input. In this paper, energy embodied in goods of Sino-US trade of 2015 is calculated quantitatively based on Input-Output analysis approach. The results show that the net export of embodied energy was 341.75 million tce (tons of coal equivalent). Due to the scarcity of energy endowments in China, over net export of embodied energy for trading interest is against sustainable development which is one of basic state policies. The author gives some advices based on empirical analysis.

1. Introduction
Since 40 years ago when Chinese reform and opening-up started, relying on the system bonus extracted by the reform and the expand of international market under opening, China’s economy has been highly increased at average rate of 8% every year, which has been ranked at the second largest economic entity in the echelon of developing countries, and worked such wonders attracts the worldwide attention. With the fast growth of economy, China’s consumption on energy also kept increasing, which as of the year of 2015, China has been the most incremental country for global primary energy consumption in 15 years for succession. China energy consumption gap kept expanding, as the picture 1 shows, energy gap in 2015 has been up to 0.68 billion tons of standard coal. Refer to the lastest global energy consumption data published by BP, in the year of 2015, energy consumption of China is 32 percentage higher than of US.
Figure 1. China’s energy gap and the increase rate of energy gap (Unit: 10 thousands of tons of standard coal, %)

In recent years, with the rapid and continuous growth of China's economy, the western countries which are led by US believe that the rapid increase China made on the demand of energy will have a major impact their “politics, strategy, economy and state security”. (Article 1837, Energy Policy Act of 2005 of America). Some US energy experts believe, China is in great and increasing demand for energy, hence causing the pressure on energy keeping going up world widely and destruction of the global political balance. To a certain extent, the two countries, China and US, will become strategic rivals and further regional and international conflicts. The point of view, as the energy version of China Threat Theory, has a profound effect in the United States, which can be seen in the case that China National Offshore Oil Corp. (CNOOC in short) acquire Unocal Corporation as early as the year of 2005. In July of 2005, CNOOC would put the acquisition of Unocal Corp. on the agenda, which arouses a thousand waves in American politics as the normal integrity and expansion for an enterprise’s developing. Finally, CNOOC announced to give up the acquisition under the intervene of US government. And the western countries such as the United States imputed the blame of the turmoil in global oil market in recent two years to the sharply increasing of China’s petrol import.

In November of 2015, Paris Climate Agreement, a new global climate agreement, went into effective formally, by which the major countries in the world undertake the due obligations of the emissions. With the principle of common but differentiated responsibilities, China undertook the emission responsibilities. The emission responsibilities are closely bounded up with energy consumption, while although China has been the import only country of energy commodity since 1997, the energy for China’s economic activities was not only consumed within the boundary of China. Considering that the energy has the characteristics of input and commodity elements, service and products are the reflect of the energy consumed during the economic operation of China, and the embodied energy will be consumed in importing countries along with the commodity exporting. With the sharply increase of China export trade, the rate of this kind of embodied energy has been increased day by day. It is found in the research of Chinese Academy of Social Sciences, exported embodied energy from China in 2002 was rated 27.6% in the whole countries energy consumption is 2002,
which is around 0.41 billion tons of standard coal. China became the export only country for embodied energy. The United States became the second largest trader partner and export market of China. China energy’s actual consumption status will be influenced by merchandise trade between China and US. It is not fair for those so-called China energy threat theory maker to use the merchandises made in China and at the same time to blame our sharpening increase of energy consumption and greenhouse gas emissions.

Therefore, the clarification of embodied energy’s import and export status between China and US can be of great help to understand the reason for the sharp increasing of China energy’s consumption. Besides, China is a country with scarce energy, and it is constantly one of the priorities of government work to save energy and reduce emissions. Thus it is more significantly practical for China to research the relationship of energy consumption and merchandise export trade between China and US, and with the research to help China to consider the energy saving from the angle of foreign trade structure as a new way.

2. Review on Relevant Literature

In 1973, Walter quantized the environmental loading in goods for the first time from the perspective of final goods to analyze the pollution in the goods of America. In 1974, the International Federation of Institutes for Advanced Studies (IFIAS) clearly put forward the concept of “embodied” for the measurement of the total quantity of a certain resource directly or indirectly consumed during the production of a certain product or service.

With the embodied energy in the national trade has been increasing, many scholars have calculated the embodied energy of their own nations. (Machado et al., 2001[1]; Mukhopadhyay et al.,2004[2]; Sánchez-Chóliz et al.,2004; Andrew et al.,2008[3]; Sissoko, Wachsmann et al., 2009[4]). Thomas Wiedmann (2009[5] gave a summary of the results in a very detailed way. The single-region input-output analysis method has become more and more improved during application while the multi-region input-output analysis method has been used gradually because the former cannot differentiate among the technologies at home and abroad,( Li et al.,2008[6]; Ackerman et al.,2007[7]; McGregor et al. 2008[8]; Nakano et al.,2009[9], Shimoda et al.,2008[10]; Bin Su et al.,2009; Xianbing Liu et al.,2010[11]; Ranran Yang et al.,2014[12]).

In China, the study on the relation between trade and energy starts relatively later. Using input-output model, Liu Yanpeng (2001)[13] conducted detailed calculation on the amount of cultivated land resource fully occupied (fully consumed) by China’s import and exported products. On one hand, the study reveals that China has international trade deficit in resources only from the perspective of cultivated land resource; and on the other hand, it partially indicates that China’s trade surplus in goods, to a great extent, relies on the trade deficit in land resources and the sacrifice of scarce resources. LiuRuixiang et al. (2013)[14] uses the latest data from World Import-Output Table(WIOT) to estimate the change of embodied energy in China’s export commodities since 2000 and uses the Structural Decomposition Analysis( SDA) to analyze the cause of changes. GU Alun et al. (2013)[15] indicate that the import and export processing trade plays a significant role in calculating the embodied energy and CO2 emission s in China .The export embodied energy (carbon equivalent)increased from 209 M t in 2002 t o 591 M t in 2005 in China, with its ratio to the total energy consumption increasing from 13.79 % t o 25.04 %.
To sum up, China’s export and energy consumption have drawn the concern of the academic world, who has conducted certain studies and achieved some important results. But in the calculation process, there are few calculation points and trend analysis. Studies conducted by foreign institutions often lack of latest statistics, and their research results often deviate from China’s real condition. By applying to input-output analysis method, this paper has studied and calculated the net export of embodied energy in exported goods, and according to the calculation result, this paper has conducted in-depth analysis on the structure of exported goods from the perspective of energy consumption.

3. Study Method and Sources of Data

3.1. Input-output Method

In the input-output table, part of the total output $x_i$ of No. $i$ industrial sector is intermediate products, which are invested into 13 sectors respectively as the compensation for the consumption of subject of labor. Of this, the investment into No. $j$ sector is $X_{ij}$, and the other part is final products $Y$, which is for net export, household consumption, government consumption, fixed investment and increase in stock. This equilibrium relationship can be expressed as:

$$X_i = \sum_{j=1}^{n} X_{ij} + \sum_{j=1}^{n} A_{ij} \cdot X_j + \sum_{i=1,2,\cdots,n} (i-1,2,\cdots,n; j = 1,2,\cdots,n)$$

(1)

Where, $A_{ij} = X_{ij}/x_i$, which is the direct consumption coefficient in this input-output table.

If in a matrix: $X = AX + Y$, then $X = (I - A)^{-1}Y$. Where, $(I - A)^{-1}$ is called Leontief Inverse Matrix and embodies the complete consumption, as $(B)$. Of this, $b_{ij} = (i, j=1,2,\cdots,n)$ is called Leontief Inverse Coefficient, which indicates the total demand to $(i)$ product-specific sectors when (No. $j$) sector increases one unit of final products.

Assuming that the primary energy consumption of China’s industries is $(E_{ind})$, the amount of energy consumed in (No. $i$) industrial sector is $(E_i)$, $EI$ is the direct energy consumption intensity of per unit of total output, and for (No. $i$) sector, $EI_i = E_i / X_i$, then as in the following matrix:

$$E_{ind} = EI \cdot X = EI \cdot (I - A)^{-1} \cdot Y = EEI \cdot \bar{Y}$$

$$EEI = EI \cdot (I - A)^{-1}$$

(2)

Where, $(EEI)$ is the complete energy consumption intensity of per unit of final products. It is necessary to note that the complete energy consumption intensity of per unit of final products is a very important intermediate variable in the calculation of embodied energy.

3.2. The Calculation of Exported Embodied Energy

If a country exports to its trade partners, and the export volume of (No. $i$) sector to its trade partner is $(EX_i)$, then the total energy embodied in exported goods can be shown to be equal to the following matrix:

$$EXEE = EEI \cdot EX = EI \cdot (I - A)^{-1} \cdot EX$$

(3)
In the n industrial sectors, only part of them carry out trade in goods; some sectors, such as construction, water supply, transportation, storage, catering, wholesale, and retail, only provide service for domestic consumption or belong to service trade, so they can be excluded. When calculating the export of embodied energy, the impact of imported intermediate products should be taken into consideration. Viewing from the perspective of production, one part of the domestic investment in the production process is of the imported intermediate products; the other part is from domestic investment. In the above mentioned formula, the direct energy consumption coefficient matrix A includes the contribution of intermediate products. In order to eliminate the impact of intermediate products, we assume that the proportion of invested imported products in all sectors is in consistence, and the proportion of imported intermediate products equals to the proportion of imported final products to products produced domestically.

Assuming that (M) is the import coefficient, and (D=I-M) is localization coefficient. Based on the above hypothesis, (M) is a diagonal matrix, which is used to measure the dependence on import of (No. i) sector. Of this, m, a factor of this diagonal matrix, can be calculated with a classical calculation method in input-output analysis on trade issues; the formula is as following:

\[ m_{ij} = IM_i / (X_i + IM_i - EX_i) \]  

Thus, eliminating the impact of imported intermediate products, the exported embodied energy is:

\[ \text{EXE}_i' = EEI_1 \cdot \text{EX} = EI_1 \cdot [I - (I - M)A]^{1} \cdot \text{EX} \]  

3.3. The Calculation of Net Export of Embodied Energy

Compared with the calculation of the absolute value of energy embodied in exported goods, the analysis on the net value of embodied energy in exported goods can interpret the influence of imported and exported goods as a whole of a country to its energy consumption. Therefore, it is more significant to the analysis on policy implications. In order to calculate the net value of exported embodied energy, it is necessary to define and calculate the imported embodied energy.

The imported intermediate products also embody energy consumption. Importing products of a certain sector can correspondingly reduce the output scale of the very sector, and reduce the energy consumption of the very sector; therefore, it can be calculated according to the complete energy consumption of domestic final products. Most existing literature uses the “direct substitution effect” method, i.e. using the complete energy consumption intensity of domestic industrial sectors to calculate the imported embodied energy. But this method has an underlying assumption that the technical level of source countries is equivalent to that of one’s own country, and the same value of imported products is used to substitute the same value of domestic products of the same sector. If the technical level of two countries varies a lot and the level of energy consumption of two countries is quiet different, accordingly, the “direct substitution effect” method, calculating according to the value of products, will overestimate or underestimate the energy embodied in imported products. Viewing from the perspective of exporting countries, another method views the
result of exported embodied energy calculated with localization coefficient as a net value, as in formula (5), which is adopted by this paper.

3.4. Sources of Data
The calculation of energy embodied in exported goods needs the statistical data of sector-specific energy consumption, the input-output (I-O) data that can reflect the relations between different sectors, and the statistical data of international trade of China. They are respectively from: China Statistical Yearbook(2016, China’s Input-output Tables2015) \((42 \times 42 \text{ sectors})\) compiled by the State Statistical Bureau, and China Foreign Economic Statistical Yearbook(2016) and United Nations’ trade statistics website.

The level of detail of different data varies. The sector-specific data of energy consumption include the data of 43 industrial sectors plus household consumption; the extended input-output table involves the data of 42 sectors; the exported and imported goods are categorized according to the Harmonized System (HS). When calculating the energy embodied in exported goods, in order to match the classification standard of the previous three kinds of data, it is necessary to merge the 42 sectors into 27 sectors, 21 of which have international trade in goods. Then the statistical data of foreign trade in goods of these 21 sectors are categorized.

4. The Calculation Result of Energy Embodied in Sino-US Exported Goods of China and the Analysis on the Result
In light of the 21 sectors that are involved with energy embodied in exported goods, using the above mentioned formula (2), formula (4) and formula (5), inputting relevant data and applying to the localization coefficient, we can work out the complete energy consumption intensity of all industrial sectors and the net value of energy embodied of Sino-US exported goods.

| Industrial Sector                      | Complete energy consumption intensity (tce/ten thousand Yuan) | Complete energy consumption intensity with localization coefficient (tce/ten thousand Yuan) | Export of embodied energy | Net export of embodied energy |
|----------------------------------------|---------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------|-------------------------------|
| Agriculture                            | 0.5839                                                        | 0.4688                                                                              | 156.3287                 | 125.4965                      |
| Coal mining and processing industry    | 1.6529                                                        | 1.4348                                                                              | 2.6710                   | 2.3185                        |
| Mining industry of petroleum and natural gas | 1.0020                                                        | 0.8747                                                                              | 68.7719                  | 60.0365                       |
| Mining and processing industry of minerals | 1.2978                                                        | 1.0006                                                                              | 236.9628                 | 182.7028                      |
| Food manufacturing and                 | 0.7058                                                        | 0.5626                                                                              | 273.8391                 | 218.2770                      |
| Industry of Textile products | complete energy consumption intensity | localization coefficient | embodied energy | complete embodied energy |
|-----------------------------|--------------------------------------|--------------------------|----------------|-------------------------|
| Tobacco processing industry | 1.1679                               | 0.8903                   | 1316.8796      | 1003.7909               |
| Industry of clothing, leather and down feather products | 0.8171                               | 0.5735                   | 1991.2588      | 1397.6328               |
| Wood processing and furniture manufacturing industry | 1.0128                               | 0.7505                   | 1966.5596      | 1457.2934               |
| Manufacturing and printing industry of paper and stationery | 1.2901                               | 0.9788                   | 248.4440       | 188.5055                |
| Processing industry of petroleum, coking and nuclear fuel | 1.8468                               | 1.5674                   | 205.5168       | 174.4267                |
| Chemical industry | 1.7967                               | 1.4202                   | 3286.3120      | 2597.5672               |
| Industry of non-metallic mineral products | 2.2012                               | 1.9098                   | 782.5711       | 678.9477                |
| Industry of metal smelting and rolling processing | 2.7988                               | 2.3613                   | 1175.4515      | 991.7345                |
| Industry of metal products | 1.7926                               | 1.3669                   | 2615.2346      | 1994.0806               |
| Manufacturing industry of general and special equipment | 1.4821                               | 1.0607                   | 8957.2864      | 6410.4336               |
| Manufacturing industry of transport equipment | 1.3453                               | 0.9425                   | 1485.9463      | 1041.0273               |
| Manufacturing industry of electrical machinery and equipment | 1.1100                               | 0.5409                   | 6744.4781      | 3286.2559               |
| Communication equipment, computers and other electronic equipment | 1.2022                               | 0.6954                   | 2362.7360      | 1366.7768               |
| Industry of instruments and Meters, Culture and Office Machinery | 0.9639                               | 0.7504                   | 298.6717       | 232.5392                |
| Other manufacturing industries | 1.6736                               | 1.3929                   | 0.0000         | 0.0000                  |
| Total | - | - | 34215.92 | 23409.84 |

Calculated according to the complete energy consumption intensity and the statistical data on foreign trade export, in 2015 China’s aggregate energy embodied in Sino-US exported goods is 341.75 million tce. The net export of embodied energy is 234.09 million tce in 2015. But only viewing from the absolute value of amount is not enough to interpret the energy utilization efficiency and the rationality of export of all sectors. Re-ranking the 21 sectors’ complete energy consumption intensity with localization coefficient, we can see the energy consumption intensity of industry of communication equipment, computers and other electronic equipment
other electronic equipment is very low; the energy utilization efficiency of this sector ranks the third in the 21 sectors, and the export trade volume of this sector is far higher than that of other sectors. In 2015, China has been still the largest trading partner of the United States, with a total trade volume of US $ 578.59 billion, accounting for 16.21% of the total trade volume of the United States. Based on Complete energy consumption intensity in 2015, we can estimate the export of embodied energy of Sino-US is 331.292 million tce.

5. Conclusion and Policy Suggestions

The reason for the sharp increasing on China’s energy consumption is not only the domestic demand and the huge investment of fix assets, foreign trade also one of the important element. It is apparently not fair for the United States to consume a great quantity of made-in-China products while at the same time publish the theory of China energy threat. With the continuously increasing of favorable balance of trade from China to US, the trade loss such as the loss of job opportunity in the US has been converged into a very strong sense of anti-Chinese by trade within the US, frequent trade friction between China and US, and the confrontation as one falls another rises. According to the statistics of China's Ministry of Commerce, there were totally 119 cases of trade remedies investigations originated by 27 countries and regions for China to encountered in the year of 2016, among which were 91 anti-dumping cases, and the United States prosecuted China for most of the anti-dumping cases in the world as of now. The theory of China energy threat is the derivative product of anti-Chinese by trade.

And from the point of view of China, as a country with comparative scarce energy per capita, the energy per capita in China is less than half of world average level. It is also contrary to the basic policy of sustainable development for China to exchange for the trading benefit by keeping on sacrificing the energy benefits. It is beneficial to save the energy and reduce the consumption by reducing Sino-US trade surplus properly, encouraging the export of products consumed less energy and restricting the export of products consumed more energy through proper trade policy. Take the regulation of export tax rebate for example, investment scale can be controlled by the utilization of tax rebate lever, to constrain the export for products which are high pollution, high energy consumption and resource-oriented, to narrow down the scale of the tax rebate rate of high pollution, high energy consumption and resource-oriented products or eliminate their export tax rebate, etc.

Besides, we should also develop new energy, improve the skill levels of utilizing energy, and reduce the energy consumption of exporting products. China has lower utilization rate of the energy than US, take the year of 2014 for example, each ton of oil equivalent can produce the GDP value of 5848.7 US dollars for the United States, while each ton of oil equivalent can produce the GDP value of 1760.3 US dollars for China, where lays the wide gap. The fundamental way to solve excessive embodied energy is to improve the skill levels of utilizing energy and to narrow the gap with the developed countries.

Notes:

1. Embodied energy or embedded energy refers to the total energy consumed in the whole process of upstream processing, manufacturing and transportation.
2. Available at: www.bp.corn.cn.
As for the intermediate flows matrix of EI, if the data are missing, it can be performed with “import proportionality assumption”. See: THEOECD INPUT—OUTPUT DATABASE, PP, 12.

References
[1] Machado G., Schaeffer R., Worrell E. 2001, “Energy and carbon embodied in the international trade of Brazil: An input-output approach”. Ecological Economics 39(3):409-424.
[2] Munksgaard et al., 2009, Models for national CO2 accounting. In: Suh, S. (Ed.), Handbook of Input–Output Economics in Industrial Ecology. Series: Eco-Efficiency in Industry and Science, Vol. 23:533–558.
[3] Serrano and Roca, 2007, “Trade and environment in Spain: an input–output approach”, 16th International Input–Output Conference of the International Input–Output Association (IIOA), 2–6 July 2007, Istanbul, Turkey.
[4] Andrew and Forgie, 2008, “A three-perspective view of greenhouse gas emission responsibilities in New Zealand”, Ecological Economics 68 (1–2):194–204.
[5] Friot et al., 2007, “Tracking environmental impacts of consumption : an economic–ecological model linking OECD and developing countries, 16th International Input–Output Conference of the International Input–Output Association (IIOA)”, 2–6 July 2007, Istanbul, Turkey.
[6] Li and Hewitt, 2008, “The effect of trade between China and the UK on national and global carbon dioxide emissions”, Energy Policy 36(6):1907–1914.
[7] Ackerman et al., 2007, “The carbon content of Japan–US trade”, Energy Policy 35 (9):4455–4462.
[8] McGregor et al., The CO2 ‘trade balance’ between Scotland and the rest of the UK: performing a multi-region environmental input–output analysis with limited data, Ecological Economics 66 (4):662–673.
[9] Nakano et al., 2009, “The measurement of CO2 embodiments in international trade: evidence from the harmonised input–output and bilateral trade database”, STI Working Paper 2009/3 (DSTI/DOC(2009)3), 6 February 2009, Organisation for Economic Co-operation and Development (OECD), Paris, France (2009).
[10] Shui.B., Harriss.R.C., 2006, “The role of CO2 embodiment in US-China trade.”. Energy Policy, 34:4063-4068.
[11] Liu Yanpeng: Study on Complete Utilization of Arable Land Resources for China’s Import-Export Products, Resources Science, 2001, Vol. 2.
[12] LiuRuixiang, Cause Analysis on the Change of Embodied Energy in Post-industrial China's, Export Commodities:Base on the Data of World Input-Output Table, Journal of Nanjing, Audit University, 2015, Vol. 3.
[13] Gu Alun, He Jiankun, Zhou Lingling, YAO Lan, LIU Bin, Analysis of embodied energy and transfer emissions of China’s import and export trade, Journal of Tsinghua University, 2010, Vol. 3.
[14] Fredrich Kahrl, David Roland-Holst Energy and Exports in China [J].2008,19:649-658
[15] Ma Chunbo, Stern D, China’s changing energy intensity trend: A decomposition analysis [J]. Energy Economics 2008 30:1037-1053.