Hindawi Publishing Corporation
Advances in Materials Science and Engineering
Volume 2015, Article ID 910835, 10 pages
http://dx.doi.org/10.1155/2015/910835

Research Article

Resource Distribution, Interprovincial Trade, and Embodied Energy: A Case Study of China

Sanmang Wu, Yalin Lei, and Li Li

School of Humanities and Economic Management, China University of Geosciences, Beijing 100083, China

Correspondence should be addressed to Sanmang Wu; wusanmang@sina.com

Received 25 June 2014; Accepted 20 October 2014

Academic Editor: Hanlie Hong

Based on data from 2007 input-output tables for each province, we estimated the energy embodied in China's interprovincial trade through input-output analysis. The results show that a sizable transfer of energy is embodied in China's interprovincial trade, and the transfer goes from the central and western provinces, which have higher energy endowments, to the eastern and coastal provinces, which have more developed economies. The provinces with the greatest net inflow of embodied energy via interprovincial trade were Zhejiang, Guangdong, Beijing, Shandong, and Jiangsu. The provinces with the greatest net outflow of embodied energy were Inner Mongolia, Shanxi, Shaanxi, Xinjiang, and Heilongjiang. To effectively reduce China's energy consumption, it is vital to adhere not only to the producer responsibility principle but also to the consumer responsibility principle. In particular, the economically developed provinces with substantial net inflows of embodied energy in interprovincial trade should provide support to the provinces from which the embodied energy outflows come.

1. Introduction

China's rapid economic development comes at the expense of enormous resources and environmental pollution. According to the World Energy Look 2010 of the International Energy Association [1], China's total energy consumption in 2009 was equivalent to 2.252 billion tons of crude oil, which was 4% greater than the energy consumption of the US in 2009. China is already the world's top energy consumer.

China's increasing total energy consumption has caused severe environmental pollution. China produces the most carbon emissions in the world, according to the International Energy Association [2]. In 2012, China contributed 300 million tons of carbon emissions. The Tyndall Centre for Climate Change Research [3] indicated that the top four regions producing the greatest amounts of carbon emissions in 2011 were China, US, the European Union, and India. The carbon emissions of these four regions accounted for 28%, 16%, 11%, and 7%, respectively, of the world's total emissions.

The rapid growth of China's carbon emissions has become a concern in the international community, and international pressures are increasing for emission reduction in China. In this context, China is currently strengthening its energy-saving and emission reduction measures. In 2011, the Chinese government published the Plan for Energy Saving and Emission Reduction during the 12th Five-Year Plan Period (2011–2015). This plan proposed reducing energy consumption per unit of gross domestic product (GDP) by 16% between 2010 and 2015. The total emissions of chemical oxygen demand and sulfur dioxide will be reduced by 8%, and the total emissions of ammonia nitrogen and nitrogen oxides will be reduced by 10%. To achieve these goals, the State Council issued the Plan for Greenhouse Gas Emission Control during the 12th Five-Year Plan Period in 2011. This plan specifies the targets for energy consumption and carbon dioxide emission per unit of GDP for each province (excluding Hong Kong, Macao, and Taiwan, there are 22 provinces, five autonomous regions, and four municipalities directly under the central government in China. For simplicity's sake, all of them will be called provinces) during the 12th Five-Year Plan period. However, the public disputes the fairness of the plan's assignment of the energy-saving and emission reduction targets across the provinces because the targets were formulated in accordance with the producer responsibility principle, not the consumer responsibility principle.

Some provinces may achieve energy-saving and emission reduction targets through the inflow of high-energy-consumption products (embodied energy) from other provinces, which is detrimental to the fulfillment of China's energy-saving and emission reduction goals on the whole. Thus, analysis of the embodied energy inflow and outflow via interprovincial trade in China is necessary to provide factual evidence for realizing the energy-saving and emission reduction goals in each district in China.

2. Literature Survey

After the signing of the Kyoto Protocol, countries with the task of greenhouse gas emission reduction may achieve their goals by increasing commodity imports from countries without such obligations. As a result of trade growth, carbon leakage will occur, leading to the constant growth of global greenhouse gas emissions. Embodied energy, embodied carbon emissions, and embodied pollutant emissions are topics of concern for researchers, who devote many empirical analyses to these issues. Input-output analysis, a useful analytical framework developed by Leontief [4], has been widely used to analyze the energy embodied in goods and services [5–7]. The following literature review shows that existing analyses primarily cover two major areas of interest.

One topic in existing research is the energy and carbon emissions embodied in a single country's international trade. Lenzen analyzed the primary energy and greenhouse gas contents in Australia's final consumption using input-output analysis and revealed that indirect energy consumption cannot be ignored in the commodity manufacturing process [8]. Sánchez-Chóliz and Duarte performed a sector-based calculation of carbon dioxide emissions that were associated with Spain's economic development and trade and evaluated the effect of each sector imports and exports on carbon dioxide emissions [9]. Mongelli et al. studied energy consumption in Italy's international commodity trade using input-output analysis and calculated the energy and carbon dioxide emissions embodied in Italy's commodity trade [10]. Peters and Hertwich investigated the energy and carbon emissions embodied in Norway's foreign trade [11].

A second topic of research interest is the embodiment of energy and carbon emissions in multilateral trade. Przybylinski analyzed the effect of bilateral trade between Poland and Germany on the two countries' environments and measured the total effect of bilateral trade between the two countries through input-output analysis [12]. Hayami and Nakamura used the input-output tables of Japan and Canada and bilateral trade data to calculate the carbon dioxide emissions in the trade between the two countries [13]. They found that greenhouse gas emissions could be reduced in both countries by redistributing technologies between the two countries. Lenzen and Munksgaard expanded the single-district model and proposed a multidistrict input-output model, which was used to calculate the energy and greenhouse gas emissions embodied in final consumer products in Denmark [14]. Rhee and Chung studied the carbon dioxide transfer through international trade between Japan and Korea. Despite Korea's trade deficit with Japan, the carbon dioxide emissions embodied in the goods exported from Korea to Japan exceeded the emissions embodied in the goods exported from Japan to Korea. Thus, there was a carbon dioxide transfer from Korea to Japan through international trade [15].

For China, energy consumption has been investigated in a number of analyses [16–18]. Shui and Harriss performed an estimation of emissions embodied in US-China trade using input-output analysis [19]. The carbon dioxide export from China to the US rose from 213 tons in 1997 to 497 tons in 2003. However, there is very little carbon dioxide exported from the US to China. Shen estimated the effects of China's goods exports and imports on energy consumption from 2002 to 2005 using an input-output model [20]. Pan et al. calculated the energy and carbon emissions embodied in China's exported goods in 2002 using input-output analysis [21]. They calculated the complete energy use intensity for each industrial sector in China and the sector-based energy embodiment in China's imports and exports for 2002. Li and Hewitt used input-output analysis in analyzing the carbon emissions embodied in China's exports to the UK. With the import of industrial goods from China, UK had an 11% reduction of carbon emissions in 2004 compared with years in which there were no imports from China. However, Sino-UK trade resulted in a 117-ton increase in the world's carbon dioxide emissions in 2004 [22]. Lin and Sun used an input-output table to estimate China's carbon emissions in 2005 that were associated with consumption and production. The difference between the carbon dioxide export and import was as high as 1.024 billion tons, which means that carbon leakage occurred [23].

As the literature review demonstrates, input-output analysis is the tool most frequently used in estimating the energy and carbon emissions embodied in international trade. However, there have been few studies on the energy and carbon emissions embodied in trade between different regions within one country. China is territorially vast and shows a considerable gap in economic development across its regions. The provinces differ greatly in terms of economic development stages, industrial structures, and resource endowments. The embodied energy inflows and outflows occur in enormous quantities through interprovincial trade. Estimating the energy embodied in China's interprovincial trade is of great importance to scientifically formulate energy-saving and emission reduction targets for each district in China. Therefore, this study also adopted input-output analysis to estimate embodied energy inflows and outflows in China's interprovincial trade.

3. Research Methods and Data Sources

3.1. Research Methods. According to the following balance equation for the input-output table,

$$X_{11} + X_{12} + \cdots + X_{1n} + Y_1 = X_1,$$

$$X_{21} + X_{22} + \cdots + X_{2n} + Y_2 = X_2,$$
$$X_{31} + X_{32} + \cdots + X_{3n} + Y_3 = X_3,$$
$$\vdots$$
$$X_{n1} + X_{n2} + \cdots + X_{nn} + Y_n = X_n, \tag{1}$$

formula (1) is simplified as follows:

$$\sum_{j=1}^{n} X_{ij} + Y_i = X_i \quad (i = 1, 2, \ldots, n). \tag{2}$$

Formula (2) is simplified as follows:

$$\sum_{j=1}^{n} a_{ij} X_{ij} + Y_i = X_i \quad (i = 1, 2, \ldots, n), \tag{3}$$

where a_{ij} is the direct consumption coefficient.

Formula (3) is simplified as follows:

$$AX + Y = X, \tag{4}$$

where

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}, \qquad X = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix}, \qquad Y = \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{bmatrix}. \tag{5}$$

Through a matrix operation, formula (4) becomes

$$X = (I - A)^{-1} Y. \tag{6}$$

In formula (6), X is the final output vector for each sector in a district. Some of the output is used in final consumption and some reenters the production sphere as raw material. There are some output outflows from production through trade. The outflowing output is expressed as E_x. By substituting Y with E_x in formula (6), the right side of the equation becomes the outflowing output from the district. The total product value input is expressed as X_e. Thus,

$$X_e = (I - A)^{-1} E_x. \tag{7}$$

Using the energy consumption data at hand, the sector-based energy consumption coefficients for each district were calculated (i.e., the energy consumed per unit of output value, denoted by e). The product of e and the X_e value of total products input to produce the outflowing goods is the energy consumption embodied in the outflowing goods, which is the embodied energy defined in this paper and denoted by E in the following equation:

$$E = e * \left[(I - A)^{-1} E_x \right]. \tag{8}$$

Based on formula (8), as long as the sector-based trade data between any two regions are available, the energy embodied in the goods (including services) traded between two regions can be calculated. Suppose the two regions are a and b, and the value of products flowing from a to b is $E_{x_{(a,b)}}$, which is the column vector of $n \times 1$ (where n is the number of sectors, as below). e_a is the unit energy consumption vector for each sector in a; A_a is the direct energy consumption coefficient matrix for the input-output table in a; $E_{a,b}$ is the energy embodied in all products flowing from a to b. Thus,

$$E_{a,b} = e_a * \left[(I - A_a)^{-1} Ex_{a,b} \right]. \tag{9}$$

Formula (9) is the core formula for calculating the energy embodied in trades between provinces. Using formula (9), the energy embodied in interprovincial trade can be calculated. The calculation that results from formula (9) is a figure. By substituting $E_{x_{(a,b)}}$ with the $n \times m$ matrix composed of the column vectors of the value of products flowing from a to other regions (where m is the number of regions), the calculation result becomes a row vector, indicating the embodied energy flowing from a to other regions. Using this method, the matrix of embodied energy flowing from one district to other regions can be obtained (i.e., the $m \times m$ matrix).

3.2. Data Sources. Estimating the energy embodied in China's interprovincial trade requires the input-output tables for each province, sector-based trade data, and final energy consumption coefficients. The latest available input-output tables are from 2007. Therefore, this study calculated the energy embodied in interprovincial trade for 2007. The specific data sources are listed in the subsections below.

3.2.1. Input-Output Tables for Each Province in 2007. This study's data are from the Input-Output Tables of China (2007) published by the Department of National Accounts, National Bureau of Statistics of China. Data from the Tibet Autonomous Region are not included in the input-output tables. Therefore, the energy embodied in interprovincial trade among 30 provinces (including 22 provinces, 4 autonomous regions, and 4 municipalities directly under the central government) was estimated.

3.2.2. Sector-Based Trade Data between Provinces in 2007. The sector-based interprovincial trade data in 2007 was obtained from the multiregional input-output (MRIO) table for 2007. In 1990, with the financial support of the United Nations Center for Regional Development, the National Bureau of Statistics of China, the Development Research Center of the State Council, and Tsinghua University jointly developed China's interregional input-output tables for nine sectors in seven regions for 1987, with Professors Ichimura and Wang Huijiong acting as the responsible parties. The Development Research Center of the State Council cooperated with the National Bureau of Statistics of China, Peking University, and other collaborators several times to develop China's MRIO tables for 2007. The Institute of Geographic Sciences and Natural Resources Research of the Chinese Academy of Sciences developed regional input-output tables

Table 1: The interprovincial trade matrix of a good (service).

	Beijing	Tianjin	Hebei	⋯	Qinghai	Ningxia	Xinjiang	Total
Beijing	$A_{1,2}$	$A_{1,3}$	$A_{1,4}$		$A_{1,28}$	$A_{1,29}$	$A_{1,30}$	RS_1
Tianjin	$A_{2,2}$	$A_{2,3}$	$A_{2,4}$		$A_{2,28}$	$A_{2,29}$	$A_{2,30}$	RS_2
Hebei	$A_{3,2}$	$A_{3,3}$	$A_{3,4}$		$A_{3,28}$	$A_{3,29}$	$A_{3,30}$	RS_3
⋮								⋮
Qinghai	$A_{28,2}$	$A_{28,3}$	$A_{28,4}$		$A_{28,28}$	$A_{28,29}$	$A_{28,30}$	RS_{28}
Ningxia	$A_{29,2}$	$A_{29,3}$	$A_{29,4}$		$A_{29,28}$	$A_{29,29}$	$A_{29,30}$	RS_{29}
Xinjiang	$A_{30,2}$	$A_{30,3}$	$A_{30,4}$		$A_{30,28}$	$A_{30,29}$	$A_{30,30}$	RS_{30}
Total	CS_1	CS_2	CS_3	⋯	CS_{28}	CS_{29}	CS_{30}	

for 30 provinces in 2007 [24], and the Fictitious Economy and Data Science Research Center of the Chinese Academy of Sciences also developed MRIO tables in 2007 [25].

This study used China's MRIO tables for 2007, which were jointly developed by the Development Research Center of the State Council and the National Bureau of Statistics of China. The MRIO table for 2007 is the most recent MRIO table for China. These MRIO tables cover 30 provinces and 42 sectors for each region (no input-output tables are available for Tibet, so Tibet was not included).

The estimation method for interprovincial trade is shown in Table 1. In Table 1, $A_{i,j}$ is the flow of a commodity (service) from region i to region j via interprovincial trade. The sum of rows (RS_i) represents the total value of the interprovincial exporting goods (services) in region i. The sum of columns (CS_1) represents the total value of the interprovincial importing goods (services) in region j. First, they estimated the RS_i and CS_1. Second, they estimated interprovincial trade using data (e.g., rail transportation) based on each province's input-output tables, and they got the initial matrix of trade $\overline{A}_{i,j}$. Last, they got the final trade matrix by using cross entropy. To facilitate the study, the 42 sectors were combined into 28 sectors.

3.2.3. Sector-Based Data for Each Province's Final Energy Consumption Coefficient in 2007. The sector-based data for each province's final energy consumption coefficient in 2007 were obtained by dividing the sector-based final total energy consumption for each province by the sector-based total output in the corresponding input-output table. The sector-based data for each province's final total energy consumption were from the Statistical Yearbook of 2008; however, relevant data were only available for 22 provinces. Moreover, there was a discrepancy in the sector classifications among the provinces. According to the classification of the 28 sectors listed in Table 1, there was uniform treatment for the provinces' sector-based final energy consumption data. The final total energy consumption data could not be determined from the Statistical Yearbook for eight provinces (Shanghai, Jiangsu, Zhejiang, Hebei, Shandong, Sichuan, Guangxi, and Heilongjiang). For these provinces, the following accommodation was made.

First, the final total energy consumption data for several sectors (agriculture, construction, transportation, warehousing/posts/communication, wholesale/retail trade/catering, and other industries) were taken from the 2007 energy balance tables for Shanghai, Jiangsu, and Zhejiang. The final total industrial energy consumption data were also taken from the 2007 energy balance tables. Each sector's final total energy consumption data for 2007 were obtained by the following accommodation for these provinces: the sector-based final consumption data were collected for 2010. Assuming that these provinces' industrial energy consumption structure in 2007 was the same as in 2010, the final total energy consumption in the 2007 energy balance tables was assigned according to the energy consumption structure for the industrial sectors in 2010. In this way, the sector-based final total energy consumption data for these three provinces were obtained for 2007. The final energy consumption data for the five sectors (agriculture/forestry/husbandry/fishing, construction, transportation, warehousing/posts/communications, wholesale/retail trade/catering, and other industries) from these three provinces' energy balance tables were used. Thus, the sector-based data for the 28 sectors' final total energy consumption were obtained for Shanghai, Jiangsu, and Zhejiang in 2007.

Second, for five provinces (Hebei, Shandong, Sichuan, Guangxi, and Heilongjiang), the final energy consumption data for these sectors (agriculture/forestry/husbandry/fishing, construction, transportation, warehousing/posts/communications, wholesale/retail trade/catering, and other industries) came from the corresponding energy balance tables for 2007. The sector-based data for these five provinces' final energy consumption were obtained by the following method for 2007: the regions with industrial structures similar to these five provinces were identified (Table 2). For example, the industrial structures of Hebei and Liaoning were similar. Second, by referring to similar industrial energy structures in other districts, the final total industrial energy consumption for the five provinces was decomposed. Thus, the sector-based final energy consumption data for the five provinces were obtained. Third, the final energy consumption data for these sectors (agriculture/forestry/husbandry/fishing, construction, transportation, warehousing/posts/communications, wholesale/retail trade/catering, and other industries) from the energy balance tables of the five provinces were used. The final total energy consumption data of the 28 sectors for these five provinces were thus obtained for 2007.

Table 2: Provinces for which sector-based data were adjusted for 2007.

Provinces for which sector-based data were adjusted	Reference provinces
Hebei	Liaoning
Shandong	Liaoning
Hainan	Guangdong
Sichuan	Chongqing
Guangxi	Guizhou
Heilongjiang	Jilin

4. Results and Discussion

Based on these data, the energy embodied in China's interprovincial trade in 2007 was estimated using formula (9).

4.1. Total Outflow and Unit Outflow of Embodied Energy in Interprovincial Trade

4.1.1. Total Embodied Energy Outflow in Interprovincial Trade. Table 2 reflects the total embodied energy outflow in interprovincial trade between 30 provinces in 2007. As shown in Table 3, there were significant differences in the outflows of embodied energy via interprovincial trade. For example, there was an outflow of embodied energy via interprovincial trade equivalent to 77.23 million tons of standard coal from Hebei in 2007. For Hainan, the total outflow of embodied energy was 2.60 million tons of standard coal.

The five provinces with the greatest outflows of embodied energy via interprovincial trade in 2007 were Hebei, Inner Mongolia, Liaoning, Shanxi, and Heilongjiang. The total outflows were 77.23 million, 65.88 million, 58.95 million, 49.15 million, and 43.83 million tons of standard coal, respectively. Hebei and Liaoning had the greatest outflows of embodied energy via interprovincial trade. The high-energy-consumption sectors occupy a large proportion of these provinces' industrial structures, and the high-energy-consumption products are the major products traded. Hebei is China's major site of iron and steel production and the province where Handan Iron and Steel Group and Tangshan Iron and Steel Group Company Limited are headquartered. Since 2002, Hebei has ranked first nationwide in outputs of iron, steel, and steel products. Liaoning is China's important industrial base, with a proportion of heavy industry as high as 80% in 2012.

Inner Mongolia, Shanxi, and Heilongjiang also have high outflows of embodied energy via interprovincial trade because they are China's major sites of energy production (Table 4). Inner Mongolia and Shanxi are China's two largest sites of coal production. In 2013, their coal outputs were 994 million and 960 million tons, respectively. Heilongjiang is the most important oil production base, and coal and oil production consumes huge amounts of energy in the exploitation process. These regions' industries are developing with coal as their primary energy source. For example, the gross output values of coal, coking, smelting, and electric power made up approximately 80% of the gross output industrial value in Shanxi. Along with the outflow of energy products, there is a massive outflow of energy-intensive products.

The destinations of the embodied energy outflows from the top five provinces were analyzed. The three provinces with the greatest inflows of embodied energy are listed in Table 5. The destinations of embodied energy outflows from the top five provinces were in the eastern region: Zhejiang, Guangdong, Beijing, Jiangsu, and Shandong (the eastern region includes Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan; the central region includes Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan; the western region includes Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shann'xi, Gansu, Qinghai, Ningxia, and Xinjiang; and the northeastern region includes Liaoning, Jilin, and Heilongjiang).

In 2007, the five provinces with the smallest outflows of embodied energy via interprovincial trade were Hainan, Qinghai, Fujian, Ningxia, and Yunnan. These provinces are not major energy producers. Moreover, Hainan, Qinghai, Ningxia, and Yunnan are economically underdeveloped regions. Their low level of industrial development means that there will be no outflow of energy embodied in interprovincial trade products. Fujian has a more developed economy, but its industrial structure is dominated by the light industry, which has low energy intensity. Therefore, the embodied energy outflow via interprovincial trade was not substantial.

4.1.2. Unit Outflow of Embodied Energy in Interprovincial Trade. Each province's total embodied energy outflow via interprovincial trade was estimated in the previous section. There are two major reasons for the provinces' substantial total embodied energy outflows via interprovincial trade: the large proportion of high-energy-consumption industries and the large scale of the economy (although the regional industrial structure may be cleaner in terms of emissions). To reveal the source discrepancies in each province's embodied energy outflow, we further estimated the unit outflow of embodied energy via interprovincial trade. The unit outflow of embodied energy refers to the energy embodied in the unit value of commodity and service. It is calculated by dividing the total embodied energy outflow by the total value of outflowing commodities and services.

Figure 1 shows the unit outflow of embodied energy via interprovincial trade for 30 provinces in 2007. As shown in Figure 1, among the provinces, there were substantial differences in the unit outflows of embodied energy in interprovincial trade. The five provinces with the greatest unit outflows of embodied energy were Inner Mongolia, Shanxi, Guizhou, Ningxia, and Shanxi, with unit outflows of embodied energy of 53.444 thousand, 33.035 thousand, 32.544 thousand, 26.597 thousand, and 18.85 thousand tons of standard coal/10,000 RMB, respectively.

These provinces were the major producers of high-energy-consumption product outflows to other regions. The

Table 3: Outflows of embodied energy via China's interprovincial trade (in millions of tons of standard coal).

District	Embodied energy total outflow	District	Embodied energy total outflow	District	Embodied energy total outflow
Hebei	77.23	Xinjiang	35.73	Guangxi	22.10
Inner Mongolia	65.88	Jiangsu	35.57	Tianjin	20.36
Liaoning	58.95	Hunan	34.76	Sichuan	13.72
Shanxi	49.15	Shandong	34.09	Jiangxi	12.59
Heilongjiang	43.83	Guizhou	28.24	Gansu	12.00
Zhejiang	41.79	Chongqing	28.12	Yunnan	11.23
Henan	40.80	Hubei	25.35	Ningxia	8.04
Shaanxi	40.49	Shanghai	25.14	Fujian	7.73
Anhui	39.04	Guangdong	24.86	Qinghai	3.88
Jilin	36.78	Beijing	24.60	Hainan	2.60

Table 4: China's major sites of energy distribution.

Types of energy	Reserves	Major provinces of distribution	Total proportion (%)
Coal	Prospective reserves	Xinjiang, Inner Mongolia, Shaanxi, Shanxi	94.9
	Proven reserves	Shanxi, Inner Mongolia, Shaanxi, Xinjiang	80.5
Oil	Prospective reserves	Xinjiang, Heilongjiang, Shandong, Liaoning	85
	Proven reserves	Heilongjiang, Shandong, Liaoning, Hebei	70

Data source: Chinese mineral resources report, 2014 [26].

Table 5: Destinations of embodied energy outflows from the top five provinces.

Provinces with the greatest embodied energy outflows	Provinces with the greatest embodied energy inflows
Hebei	Shandong, Zhejiang, Beijing
Inner Mongolia	Beijing, Zhejiang, Guangdong
Liaoning	Hebei, Zhejiang, Shandong
Shanxi	Guangdong, Jiangsu, Shanghai
Heilongjiang	Hebei, Zhejiang, Jiangsu

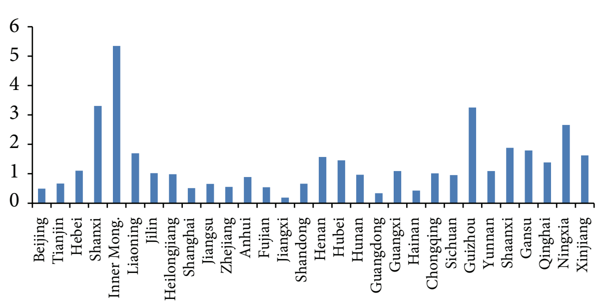

Figure 1: Unit outflow of embodied energy for each province in 2007 (in tons of standard coal/10,000 RMB).

high-energy-consumption sectors occupied a large proportion of the industrial structure. There was a considerable inconsistency in the top five provinces in terms of the unit outflows of embodied energy and the total embodied energy outflows, which indicated that the provinces with substantial total embodied energy outflows might have had low unit outflows of embodied energy.

Zhejiang is China's major manufacturer with a developed economy. In 2007, the total outflow of Zhejiang's embodied energy via interprovincial trade ranked fourth in the country, but its unit outflow of embodied energy was very small. The reason for Zhejiang's substantial embodied energy outflow was the high value of the outflowing products. Zhejiang's industrial structure was not dominated by high-energy-consumption sectors.

In 2007, the five provinces with the smallest unit outflows of embodied energy via interprovincial trade were Jiangxi, Guangdong, Hainan, Beijing, and Shanghai, with unit outflows of 1.921 thousand, 3.381 thousand, 4.267 thousand, 4.963 thousand, and 5.103 thousand tons of standard coal/10,000 RMB, respectively. These values indicated that these provinces' outflowing products consumed less energy in the production process. These provinces' industrial structures were characterized by low energy consumption.

4.2. Total Inflow and Unit Inflow of Embodied Energy in Interprovincial Trade

4.2.1. Total Embodied Energy Inflow in Interprovincial Trade. Table 6 shows the total embodied energy inflow in interprovincial trade for China's 30 provinces in 2007. As shown in Table 6, there were substantial differences in the provinces' total embodied energy inflows. For example, Hebei's embodied energy inflow via interprovincial trade is 88.69 million tons of standard coal. Qinghai's inflow is only 4.44 million tons of standard coal.

Table 6: Total embodied energy inflows via interprovincial trade for each province in 2007 (in millions of tons of standard coal).

District	Total embodied energy inflow	District	Total embodied energy inflow	District	Total embodied energy inflow
Zhejiang	88.69	Chongqing	31.02	Shaanxi	14.62
Hebei	66.19	Tianjin	25.24	Yunnan	12.46
Guangdong	65.43	Henan	24.86	Xinjiang	10.33
Shandong	55.75	Hubei	21.42	Gansu	10.20
Beijing	53.70	Guangxi	21.38	Inner Mongolia	8.82
Jiangsu	48.63	Hunan	20.23	Guizhou	7.16
Liaoning	40.79	Heilongjiang	20.14	Hainan	6.94
Jilin	39.05	Fujian	16.28	Shanxi	6.70
Shanghai	37.42	Jiangxi	15.72	Ningxia	5.61
Anhui	36.28	Sichuan	15.00	Qinghai	4.44

In 2007, the five provinces with the greatest energy inflows via interprovincial trade were Zhejiang, Hebei, Guangdong, Shandong, and Beijing. The inflows were 88.69 million, 66.19 million, 65.43 million, 55.75 million, and 53.70 million tons of standard coal, respectively. Zhejiang and Guangdong had substantial embodied energy inflows via interprovincial trade because both are major provinces in terms of manufacturing trade with strong economies. However, these two provinces are deficient in energy resources. The development of manufacturing trade requires substantial inflows of energy and non-energy-related and energy-intensive products from other regions. As a result, there will be significant embodied energy inflows.

As mentioned above, Hebei is China's major iron producer, and a large amount of coal is consumed in the manufacturing of iron products. In recent years, Hebei still needed a coal inflow from other provinces and regions. However, Hebei's coal products do not have the highest energy embodiment. Through the inflow of coal as the primary energy source, there was also a substantial embodied energy inflow.

Shandong's situation is similar to that of Hebei. Shandong is China's major iron product producer, and its crude steel production reached 59 billion tons in 2012, ranking third in the country. The reason for Beijing's substantial embodied energy inflow via interprovincial trade is that Beijing is not rich in energy resources. Given the high population intensity and economic output, as the capital of China, Beijing needs an energy inflow from other regions and an inflow of non-energy-intensive products.

The provinces with the greatest embodied energy inflows via interprovincial trade were analyzed. The top three provinces in terms of embodied energy inflow are listed in Table 6. As shown in Table 7, the embodied energy inflows to Zhejiang, Guangdong, Hebei, Shandong, and Beijing mainly came from Inner Mongolia, Hebei, Liaoning, and Hebei, respectively.

In 2007, the five provinces with the smallest embodied energy inflows via interprovincial trade were Qinghai, Ningxia, Shanxi, Hainan, and Guizhou. These provinces fall into two categories: provinces with small populations and less developed industry and coal producing provinces. In Qinghai, Ningxia, and Hainan, the population does not exceed 10 million, and there is less demand for products with high energy embodiments. In the provinces that are coal producers, such as Guizhou and Shanxi, there is less need for the inflow of direct energy products and energy-intensive products, which reduces the embodied energy inflow via interprovincial trade.

Table 7: Sources of embodied energy inflows into the top five provinces.

Five provinces with the greatest embodied energy inflows	Provinces with the greatest embodied energy outflows
Zhejiang	Hebei, Liaoning, Inner Mongolia
Guangdong	Zhejiang, Hebei, Inner Mongolia
Hebei	Liaoning, Shanxi, Inner Mongolia
Shandong	Hebei, Liaoning, Hunan
Beijing	Inner Mongolia, Hebei, Tianjin

4.2.2. Unit Inflow of Embodied Energy via Interprovincial Trade. The unit inflow of embodied energy was further estimated for each province. The unit inflow of embodied energy refers to the energy embodied in the unit value of commodities and services. It is calculated by dividing the total embodied energy inflow by the total value of outflowing commodities and services. The unit inflow of embodied energy via interprovincial trade measures the average energy consumption level of inflowing products for the corresponding province.

Figure 2 shows each province's unit inflow of embodied energy via interprovincial trade in 2007. As indicated in Figure 2, there was a much less substantial difference in terms of each province's unit inflow of embodied energy compared with the unit outflow of embodied energy. The unit inflows of embodied energy for Guizhou, Shanxi, and Fujian were less than 8,000 tons/10,000 RMB. For all other provinces, the unit inflows of embodied energy ranged from 8,000 to 12,000 tons/10,000 RMB because each province maintained

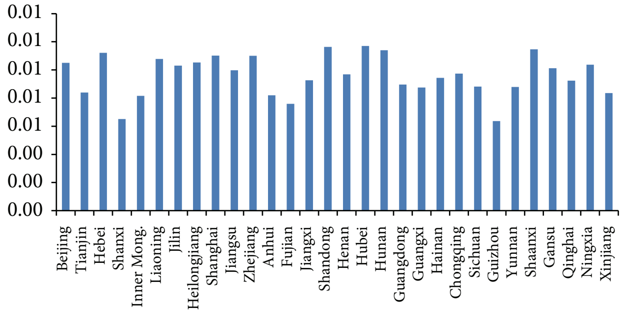

Figure 2: Unit inflow of embodied energy via interprovincial trade for each province in 2007 (in tons of standard coal/10,000 RMB).

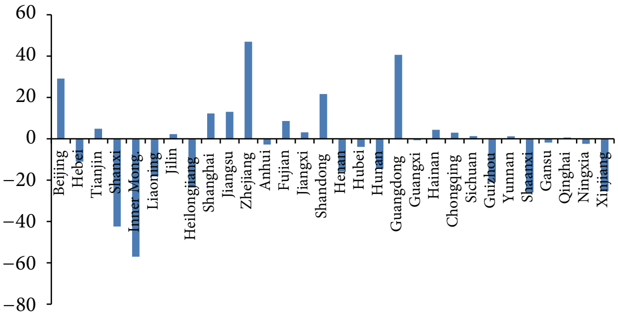

Figure 3: Net embodied energy inflow via interprovincial trade for each province in 2007 (in millions of tons of standard coal).

a trading relationship with all other provinces. The diversity of the inflowing product sources ensured that there were no extremely large or small unit inflows of embodied energy.

The provinces' unit inflows and unit outflows of embodied energy were compared in 2007. The results show that the unit outflow of embodied energy for some provinces (e.g., Inner Mongolia, Shanxi, Guizhou, and Ningxia) exceeded the unit inflow of embodied energy. The unit outflow of embodied energy via interprovincial trade was 53.444 thousand tons of standard coal/10,000 RMB in Inner Mongolia. However, Inner Mongolia's unit inflow was only 8.163 thousand tons of standard coal/10,000 RMB.

In these provinces, the average energy consumption of the outflowing products was significantly higher than the average energy consumption of the inflowing products. These provinces' industrial structures were characterized by high energy consumption. For Jiangxi, Shanghai, Guangdong, and Beijing, the unit outflow of embodied energy via interprovincial trade was significantly smaller than the unit inflow. In Shanghai, the unit outflow of embodied energy was 5.103 tons of standard coal/10,000 RMB, whereas the unit inflow was 11.017 tons of standard coal/10,000 RMB. In these provinces, the average energy consumption of the inflowing products was much higher than the average energy consumption of the outflowing products. The industrial structures also tended to be cleaner.

4.3. Net Embodied Energy Inflow. To more comprehensively reflect the embodied energy inflow and outflow for each province, the net embodied energy inflow in 2007 was estimated (the total embodied energy inflow minus the total embodied energy outflow). The specific results are shown in Figure 3, which shows that the five provinces with the greatest net embodied energy inflow via interprovincial trade in 2007 were Zhejiang, Guangdong, Beijing, Shandong, and Jiangsu. The net inflows were 46.9 million, 40.57 million, 29.1 million, 21.66 million, and 13.06 million tons of standard coal, respectively. These provinces are strong economies in China's eastern coastal areas. According to data released by the National Bureau of Statistics, Guangdong, Jiangsu, Shandong, and Zhejiang were the top four provinces in terms of GDP in 2013. Beijing's economic output also ranked among the highest of the provinces. Except for Shandong, these provinces' energy productions were low. In these regions, the direct energy products and energy-intensive products were needed in large quantities via interprovincial trade to sustain development.

In 2007, the net embodied energy inflow via interprovincial trade was negative for some provinces. The embodied energy outflows exceeded the embodied energy inflows in these provinces, which were the provinces with net embodied energy outflows. The five provinces with the greatest net embodied energy outflows were Inner Mongolia, Shanxi, Shaanxi, Xinjiang, and Heilongjiang, all of which are located in central and western China. The net outflows were 57.06 million, 42.45 million, 25.87 million, 25.4 million, and 23.69 million tons of standard coal, respectively. These provinces are all major energy producers. Inner Mongolia, Shanxi, Shaanxi, and Xinjiang are rich in coal resources, whereas Heilongjiang is a major site of oil production in China (Table 4).

5. Conclusions and Policy Implications

5.1. Conclusions. This study used input-output analysis to estimate the embodied energy in China's interprovincial trade for 2007. The following conclusions were obtained through analysis of the measurement results.

First, the eastern coastal provinces with developed economies (e.g., Zhejiang, Hebei, Guangdong, Shandong, and Beijing) had higher embodied energy inflows. The inflows were 88.69 million, 66.19 million, 65.43 million, 55.75 million, and 53.70 million tons of standard coal, respectively.

Second, the provinces with substantial embodied energy outflows via interprovincial trade were major producers of energy and iron and steel products. In 2007, the two provinces with the greatest embodied energy outflows via interprovincial trade were Hebei and Liaoning. The high-energy-consumption sectors occupy a large proportion of these provinces' industrial structures, and the high-energy-consumption products are the major products traded.

Third, the provinces with substantial net embodied energy inflows via interprovincial trade were Zhejiang, Guangdong, Beijing, Shandong, and Jiangsu. The net inflow was 46.9 million, 40.57 million, 29.1 million, 21.66 million, and 13.06 million tons of standard coal, respectively. These provinces' common features include developed economies, low resource endowments, and the ability to produce products with high energy intensities. The embodied energy inflows via interprovincial trade were remarkably lower than the outflows in Inner Mongolia, Shanxi, Shaanxi, Xinjiang, and Heilongjiang.

Fourth, due to the diversity of trade partners, there were small differences in unit inflows of embodied energy among the provinces. However, the unit outflows of embodied energy were considerably different among the provinces. For example, Inner Mongolia, Shanxi, Guizhou, and Ningxia, which are rich in energy resources, had much higher unit outflows of embodied energy compared with those of other regions. These provinces' industrial structures are characterized by high energy consumption. The unit outflows of embodied energy via interprovincial trade were substantially lower than the unit inflows in Jiangxi, Shanghai, Guangdong, and Beijing. These provinces' industrial structures are cleaner.

5.2. Policy Implications. In summary, there is generally an embodied energy outflow via China's interprovincial trade from central and western provinces, where the energy resources are richer, to the provinces in coastal eastern region, where the economy is more developed. Thus, with the development of interprovincial trade, the embodied energy is transferred from central and western provinces to eastern provinces. If energy-saving and emission reduction goals can be formulated according to the producer responsibility principle, it will be difficult to save energy and reduce emissions for the provinces in central and western region. Transferring energy-intensive products from the central and western regions to the eastern region will relieve the pressures of energy saving and emission reduction.

In fact, the economically developed provinces in China's eastern coastal region are situated upstream in the industrial chain. Transferring the high-energy-consumption products (together with the embodied energy) from the less developed provinces in the central and western regions elevates their industrial structures and realizes the energy-saving and emission reduction requirements. The intensified dependency of provinces with high embodied energy outflows on the high-energy-consumption industries aggravates the pressures of energy saving and consumption reduction, which brings greater pressure to bear on overall energy saving and emission reduction in China.

The consumer responsibility principle should be introduced when formulating energy-saving and emission reduction goals. The economically developed provinces with substantial net embodied energy inflows should take responsibility for supporting the provinces with net embodied energy outflows. Outputs of advanced technologies, knowledge, and talents from the eastern region to the central and western regions should be encouraged. By introducing capital and advanced clean production technologies, the central and western regions can improve energy efficiency and industrial output and better meet energy-saving and energy consumption reduction targets, crucial for finally realizing China's overall energy-saving and emission reduction goals.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgment

The authors are grateful for the support from the National Natural Science Foundation of China under Grant nos. 71003066, 71173200, and 71133003.

References

[1] International Energy Association, World Energy Outlook, 2010.

[2] International Energy Association, World Energy Outlook, 2013.

[3] The Tyndall Centre for Climate Change Research, *Global Carbon Emissions Reach Record 10 Billion Tons—Threatening 2 Degree Target*, Nature Climate Change, 2012.

[4] W. Leontief, "Composite commodities and the problem of index numbers," *Econometrica*, vol. 4, no. 1, pp. 39–59, 1936.

[5] D. Hawdon and P. Pearson, "Input-output simulations of energy, environment, economy interactions in the UK," *Energy Economics*, vol. 17, no. 1, pp. 73–86, 1995.

[6] Y. Kondo, Y. Moriguchi, and H. Shimizu, "CO_2 emissions in Japan: influences of imports and exports," *Applied Energy*, vol. 59, no. 2-3, pp. 163–174, 1998.

[7] G. Machado, R. Schaeffer, and E. Worrell, "Energy and carbon embodied in the international trade of Brazil: an input-output approach," *Ecological Economics*, vol. 39, no. 3, pp. 409–424, 2001.

[8] M. Lenzen, "Primary energy and greenhouse gases embodied in Australian final consumption: an input-output analysis," *Energy Policy*, vol. 26, no. 6, pp. 495–506, 1998.

[9] J. Sánchez-Chóliz and R. Duarte, "CO_2 emissions embodied in international trade: evidence for Spain," *Energy Policy*, vol. 32, no. 18, pp. 1999–2005, 2004.

[10] I. Mongelli, G. Tassielli, and B. Notarnicola, "Global warming agreements, international trade and energy/carbon embodiments: an input-output approach to the Italian case," *Energy Policy*, vol. 34, no. 1, pp. 88–100, 2006.

[11] G. P. Peters and E. G. Hertwich, "Pollution embodied in trade: the Norwegian case," *Global Environmental Change*, vol. 16, no. 4, pp. 379–387, 2006.

[12] M. Przybylinski, "Pollution flows between Poland and Germany," in *Proceedings of the 14th International Conference on Input-Output Techniques*, Montreal, Canada, 2002.

[13] H. Hayami and M. Nakamura, "CO_2 emission of an alternative technology and bilateral trade between Japan and Canada: relocating production and an implication for joint implementation," in *Proceedings of the 14th International Conference on Input-Output Techniques*, Montréal, Canada, 2002.

[14] M. Lenzen and J. Munksgaard, "Energy and CO_2 life-cycle analyses of wind turbines-review and applications," *Renewable Energy*, vol. 26, no. 3, pp. 339–362, 2002.

[15] H.-C. Rhee and H.-S. Chung, "Change in CO_2 emission and its transmissions between Korea and Japan using international input-output analysis," *Ecological Economics*, vol. 58, no. 4, pp. 788–800, 2006.

[16] K. Fisher-Vanden, G. H. Jefferson, H. Liu, and Q. Tao, "What is driving China's decline in energy intensity?" *Resource and Energy Economics*, vol. 26, no. 1, pp. 77–97, 2004.

[17] L. Hong, Z. P. Dong, and H. Chunyu, "Evaluating the effects of embodied energy in international trade on ecological footprint in China," *Ecological Economics*, vol. 62, no. 1, pp. 136–148, 2007.

[18] G. P. Peters, C. L. Weber, D. Guan, and K. Hubacek, "China's growing CO_2 emissions—a race between increasing consumption and efficiency gains," *Environmental Science and Technology*, vol. 41, no. 17, pp. 5939–5944, 2007.

[19] B. Shui and R. C. Harriss, "The role of CO_2 embodiment in US-China trade," *Energy Policy*, vol. 34, no. 18, pp. 4063–4068, 2006.

[20] L. S. Shen, "The change of China's foreign trade structure is not favorable to energy-saving and emission reduction," *Management World*, vol. 45, pp. 167–186, 2007 (Chinese).

[21] J. Pan, J. Phillips, and Y. Chen, "China's balance of emissions embodied in trade: approaches to measurement and allocating international responsibility," *Oxford Review of Economic Policy*, vol. 24, no. 2, pp. 354–376, 2008.

[22] Y. Li and C. N. Hewitt, "The effect of trade between China and the UK on national and global carbon dioxide emissions," *Energy Policy*, vol. 36, no. 6, pp. 1907–1914, 2008.

[23] B. Lin and C. Sun, "Evaluating carbon dioxide emissions in international trade of China," *Energy Policy*, vol. 38, no. 1, pp. 613–621, 2010.

[24] W. Liu, J. Chen, and Z. Tang, *Theories and Practices of Development of China's Interregional Input-Output Tables of 30 Provinces/Cities in 2007*, China Statistics Press, 2012, (Chinese).

[25] S. Minjun and Z. Zhuoying, *China's Interregional Input-Output Model and Regional Economic Connections*, Science Press, Beijing, China, 2012.

[26] Ministry of Land and Resources of the People's Republic of China, *Chinese Mineral Resources Report*, 2014.