Energy Policy 49 (2012) 751–758

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Embodied energy use in China's industrial sectors

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HIGHLIGHTS

- ► A hybrid IO-LCA model was employed to analyze China's energy use at sectoral level.
- ► A case study on China's sectoral energy consumption is done.
- ► Construction and service sectors are actually energy intensive from the supply chain perspectives.
- ► Upstream and downstream ectoral collaboration along the whole supply chain is necessary.
- ► Energy conservation policies should be based upon a comprehensive analysis on sectoral energy use.

ARTICLE INFO

Article history:
Received 21 January 2012
Accepted 11 July 2012
Available online 3 August 2012

Keywords:
Energy consumption
EIO model
Production and consumption

ABSTRACT

As the world's top energy consumer, China is facing a great challenge to solve its energy supply issue. In this paper energy use from all industrial sectors in China's economy of 2007 was explored by conducting an extended environmental input–output analysis. We compare the energy consumption embodied in the final demand for goods and services from 29 sectors with the energy demand required for the actual production process in each sector. Two different viewpoints for sectoral energy use have been presented: energy use is directly allocated to the producer entity, and energy use is reallocated to sector's supply chain from consumption perspective. Our results show that considerable amount of energy use is embodied in the supply chain, especially for "Construction" and "Other Service Activities" sectors, which is not detected if energy use is allocated on a production basis. When further dividing embodied energy consumption into direct energy consumption and indirect energy consumption, total indirect energy consumption is much higher than that of total direct energy consumption, accounting for 80.6% of total embodied energy consumption in 2007. Our results provide a more holistic picture on sectoral energy consumption and therefore can help decision-makers make more appropriate policies.

1. Introduction

With rapid economic development and increasingly improved living standards, China is now the world's top consumer of primary energy and CO_2 emitter (Guan et al., 2009), accounting for 20% of the global energy consumption (British Petroleum (BP), 2011). Seventy percent of China's primary energy consumption was from coal in 2009, with a total consumption of 3.02 Bt. Heavily depending on coal consumption as China's primary energy source results in many negative environmental and health effects such as climate change, respiratory diseases, acidic rain, air pollution, and solid wastes. Moreover, the Gross Domestic Product per unit energy consumption (energy efficiency) in China is just 60% of that in India, and 47% of that in Japan (international constant price) (World Bank, 2011). Since China will keep rapid economic growth in the next decades, total energy consumption will increase rapidly if energy efficiency cannot be improved simultaneously (Guan et al., 2008). Hence, it is important to control the vastly growing energy consumption by improving energy efficiency and by increasing the use of renewable energy.

To meet these challenges, the Chinese government has launched several programs to promote energy efficiency. The well-known "national energy intensity targets" were announced by the National Development and Reform Commission (NDRC) and were coupled with the national "Five-Year Social and Economic Development Plan" (Geng 2011). According to China's

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0301-4215/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2012.07.016

11th Five-Year Plan (2006–2010), energy efficiency should have been improved by 20% during the period and was actually improved by 19.1% (National Development and Reform Commission (NDRC), 2011b). Similarly, the 12th Five-Year Plan (2011–2015) has set the energy efficiency target to 16% energy intensity reduction (National Development and Reform Commission (NDRC), 2011a). Each provincial government received its own reduction target based upon its GDP level and should pursue such a target by considering its own realities. For instance, to improve the overall energy efficiency, both national and local governments had closed a large number of inefficient power plants and industrial factories and replaced them with more efficient equipment during 2005–2010. Facilities with a total production capacity of 100 Mt of iron, 55 Mt of steel, 250 Mt of cement and 50 Mt of coal-burning power generation have been shut down or replaced (Xinhuanet, 2007).

However, most of these efforts focused on traditional energy-intensive sectors such as steel and cement; little attention has been paid to the hidden drivers for such heavy industrial production. Ignorance of the conveying effect through the whole supply chain can undermine the efforts for efficiency improvement in these energy-intensive sectors. Although significant energy efficiency improvement in these energy-intensive sectors has been made, the total industrial production and energy consumption from these sectors are still increasing due to the higher demand of their products. For instance, the growth rate of cement and steel production had been higher than the rate of GDP growth (10.52%) during 2005–2010, achieving 12.28% (Kong, 2012) for cement and 11.98% (Guo and Zhang, 2012) for steel, respectively. In addition, the lack of attention to the related effects from the supply chain may even cause inefficient energy consumption. For example, the Chinese government launched an ambitious target to reduce its energy intensity by 20% during 2005–2010 in 2004 (National Development and Reform Commission (NDRC), 2007). This reduction was adjusted for each province and was implemented as a "top-down" mandatory approach. Under such conditions, several regional officials had to take actions to ration the power supply in the second half of 2010 to reach their targets. Thus, factories within these regions had to buy diesel-burning power generators to maintain their normal operation, resulting in a national diesel shortage (Qiu, 2011).

With the above background, it is crucial to study how different industrial sectors use energy for their operations so that appropriate national regulations and standards can be enacted to promote energy efficient production. Therefore, a comprehensive analysis of sectoral energy consumption is required, which should not only focus on the direct energy consumption activities but also consider the indirect activities potentially causing energy consumption throughout the whole supply chain, namely, the embodied energy consumption (direct plus indirect) perspective (Bullard and Herendeen, 1975; Peters, 2008; Skelton et al., 2011). One sector's embodied energy consumption includes both energy consumption caused by final demand (direct energy consumption) and energy consumption caused by other sector's activities throughout the supply chain (indirect energy consumption) (Brown and Herendeen, 1996).The embodied energy consumption provides a complete picture that does not only consider the direct energy consumption primarily due to final demand, but also identifies the drivers of the energy consumption and quantifies the amount of energy usage for which every sector is responsible (Leontief, 1970; Skelton et al., 2011). Such an analysis can facilitate policy-makers to understand how embodied energy consumption occurs along the entire supply chain so that an appropriate energy management policy for industrial sectors can be raised.

In this paper, the embodied energy consumption among China's 29 industrial sectors was estimated by conducting an extended environmental input–output analysis. First, we selectively review the method of our input–output analysis. Then, we quantify and present the embodied energy consumption for 29 industrial sectors in China's economic system. The main focus of this paper is to present our policy implications for sectoral energy conservation policy. Finally we draw our conclusions.

2. Methods and data

2.1. Selective review of environmental input–output analysis

A comprehensive analysis of energy consumption in industry supply chains requires an appropriate method that does not only focus on the energy consumption due to final demand of one single industrial sector but also consider the use of energy in intermediate production processes by other industrial sectors that are included in the supply chain. The standard Leontief input–output (I–O) model has been extended to the so-called environmental extend input–output model (EIO) to capture energy consumption flows in the economy (Leontief, 1936, 1970). EIO describes the energy consumption required to produce a unit of economic output (goods and services) driven by final demand. This tool allows the calculation of the direct energy consumption by a sector's final demand as well as all indirect energy consumption from other sectors within the same supply chain (Duchin, 1998; Hubacek et al., 2009). This "top-down" approach for assessing environmental impacts of the whole economy has been widely applied for national energy analyses after the energy crisis in the early 1970s (Leontief, 1970; Lin and Polenske, 1995; Peters and Hertwich, 2008). Interactions between economic activities, the associated direct and indirect energy consumption and related environmental impacts can be explicitly determined by the input–output relationship described by Leontief and its extension to cover environmental impacts (e.g., Duchin, 2009; Feng et al., 2009, 2010; Guan and Hubacek, 2007, 2008; Hubacek et al., 2009; Weber et al., 2008). The input–output analysis has been extended to cover interregional and international trade in multi-regional input–output models (MRIO) (Leontief, 1970; Minx et al., 2009; Peters and Hertwich, 2008; Peters et al., 2011; Wiedmann et al., 2010); this type of model has been used to analyze international embodied energy consumption and related CO_2 emissions inventories in the context of the Kyoto Protocol from the perspective of either consumers of goods and services or producers. For a single system boundary, energy consumption associated with the production process comprises the production entity (the production energy use) and the total energy consumption in its production activity (the embodied energy consumption). Several scholars have conducted their studies of embodied energy consumption in production activities in China. For example, Lin and Polenske (1995) explained energy consumption changes between 1981 and 1987 in China by analyzing effective changes in the production technologies as well as the final demand shift on the consumer side. Liu et al. (2009) conducted an energy input–output analysis in China to evaluate the indirect energy consumption of rural and urban households and studied how energy policies influenced final prices; they concluded that energy efficiency improvements did not only serve as a means to reach energy conservation goals but also have a positive impact on household income. Another example of studying the embodied energy in the supply chain of one single sector is the analysis on the environmental impacts of the coke-making process in China by using an input–output process model (Polenske and McMichael, 2002); they discovered changes in the production technology of the supplying sectors and the subsequent impacts. Similar studies were also conducted by Liang et al. (2011).

This study used the most recently available input–output tables (2007) and constructed the EIO model to reveal China's sectoral embodied energy consumption; our study focuses on China's sectoral direct and indirect energy consumption and presents the related policy implications for energy conservation and efficiency in the national Five-Year plan.

2.2. EIO model development

The EIO model captures the energy consumption of each economic sector from supply chain perspectives. The total output of one economy is expressed:

$$X = Z + y = AX + y \quad (1)$$

X represents total economic output, which can be expressed as a vector; Z represents the intermediate demand matrix; y represents the final demand vector, including the components of "rural and urban households consumption", "government consumption", "gross capital formation", "export" and "others"; and A represents the economy's direct demand matrix. Matrix A describes the relationship between all sectors of the economy. Assuming that $(I-A)$ is nonsingular, then the total economic output vector X can be expressed by Eq. (2):

$$X = (I-A)^{-1}y \quad (2)$$

I represents the identity matrix, $(I-A)^{-1}$ is the Leontief inverse. Eq. (2) illustrates the gross output needed to satisfy both the final consumption "y" and the corresponding intermediate consumption "$(I-A)^{-1}$" from each economic sector.

The EIO method combines the economic IO model with sectoral environmental impacts by multiplying the total economic output by each sector's energy intensity (energy consumption per unit economic output from each sector i). The total (both direct and indirect) energy consumption can be expressed by Eq. (3):

$$E = FX = Fy + FAy + FA^2y + FA^3y + FA^4y \cdots = F(I-A)^{-1}y \quad (3)$$

E represents the matrix of the total embodied energy consumption; F represents the factor vector of the energy intensity for each sector. Fy is the direct energy consumption due to final demand, FAy is the first round of indirect energy consumption due to intermediate industrial activities. FA^2y, FA^3y, $FA^4y\cdots$ (Infinite recursive reduction series of FA^jy) are the second, third, fourth, … round indirect energy consumption of intermediate activates. F can be calculated by Eq. (4):

$$F_i = D_i/X_i \quad (4)$$

F_i represents the intensity factor of sector i; D_i represents the production energy consumption for sector i; X_i represents the total economic output from sector i.

2.3. Data sources

In this study, we adopted the most recently available input–output table, namely, the one for the year of 2007 (National Bureau of Statistics of China (NBSC), 1996–2010), covering 42 economic sectors in total. Production energy consumption data from each sector were extracted from the Chinese Energy Statistics Year Book (CESYB) (National Bureau of Statistics of China (NBSC), 1995–2010). The input–output table is available at 42 industrial sectors in details, while the energy consumption data cover 29 sectors. We aggregate the 42 economic sectors into 29 sectors to keep the two datasets consistent. Table 1 presents the

Table 1
Sectors classification for Chinese ecomony.

Group code	Group	Sectoral code	Sector name
A	Agriculture	1	Farming, forestry, animal husbandry, fishery and water conservancy
B	Mining	2	Coal mining and dressing
		3	Petroleum and natural gas extraction
		4	Ferrous metals mining and dressing
		5	Other metals mining and dressing
C	Manufacturing	6	Food processing, food production, beverage production, tobacco processing
		7	Textile
		8	Garments and other fiber production, leather, furs, feather and related production
		9	Timber processing, bamboo, cane, palm and straw production, furniture manufacturing
		10	Paper printing, educational and sports goods production
		11	Petroleum processing and coking, gas production and supply
		12	Raw chemical materials and chemical production, medical and pharmaceutical production, chemical fiber, rubber production, plastic production
		13	Nonmetal mineral production
		14	Smelting and pressing of ferrous and nonferrous metals
		15	Metal products
		16	Ordinary and special equipment
		17	Transportation equipment
		18	Electric equipment and machinery
		19	Electronic and telecommunications equipment
		20	Instruments, meters, cultural and office machinery
		21	Handicraft manufacturing and other manufacturing products
		22	Waste collection, separation, processing & treatment
D	Power and heating supply	23	Electricity power/heating supply
		24	Gaseous fuels production and supply
		25	Water treatment and supply
E	Construction	26	Construction
F	Tertiary industry (Service)	27	Transport, logistics, postal and telecommunication services
		28	Wholesale, retail trade, hotels, catering service
		29	Other service activities

Table 2
Sectoral energy mix in China.

Code	Coal[a]	Coke[a]	Crude oil[a]	Gasoline[a]	Kerosene[a]	Diesel[a]	Fuel oil[a]	Natural gas[b]	Electricity[c]
1	2338	82	0	247	1	1875	1	0	979
2	16518	75	0	20	3	57	6	5	610
3	343	0	1204	34	0	170	35	91	316
4	213	126	0	10	2	43	1	0	516
5	587	16	0	5	1	57	1	0	173
6	2938	16	1	36	1	86	45	3	634
7	2393	4	0	22	2	39	47	1	1142
8	299	2	0	17	1	41	22	0	201
9	386	3	0	10	1	19	3	0	181
10	3432	11	1	22	2	40	37	1	564
11	25656	98	30309	27	2	46	396	27	416
12	14281	2287	2328	90	6	187	470	227	3930
13	17105	258	15	35	3	233	606	31	1884
14	25139	26258	0	37	4	132	263	20	6153
15	265	95	0	26	2	48	17	1	688
16	812	648	0	60	6	76	15	7	687
17	742	116	0	45	8	62	12	7	424
18	139	19	0	25	1	44	15	2	347
19	126	1	0	15	1	46	32	7	487
20	20	3	0	5	1	8	0	0	62
21	451	4	0	6	1	11	3	0	294
22	6	3	0	0	0	1	1	0	11
23	131923	7	8	21	0	267	604	71	4642
24	1471	32	0	3	0	9	6	9	46
25	31	0	0	4	0	2	0	0	224
26	565	18	0	199	0	434	16	2	309
27	685	1	164	2763	1130	6794	1390	17	532
28	868	71	0	352	5	604	25	17	930
29	811	7	0	950	43	858	12	16	1709

[a] Unit: 10^4 t.
[b] Unit: 10^8 m^3.
[c] Unit: 10^8 kW h (kilo-watts-hours).

29 sectors classification and more aggregated 6 sector groups. This classification principle has been widely used in IO-based energy and carbon footprint research in China (Chang et al., 2010; Chen and Zhang, 2010; Zhang, 2010). Based on equation 5, A is a matrix with 29×29 elements, $\hat{Y}$ is a diagonal matrix with the values of final energy demand along its diagonal, F is a column vector with energy intensity data of 29 sectors.

The mix of energy consumption from each sector was listed in Table 2. There are 9 types of energy sources: raw coal, coke, crude oil, gasoline, kerosene, diesel, fuel oil, natural gas and electricity. It should be noted that the final electricity consumption was counted as the energy consumption from electricity sector, instead of the primary energy consumption for power generation. The total amount of energy consumption from each sector can be converted into the Standard Coal Equivalent (SCE), based on the calorific value of various energy types.

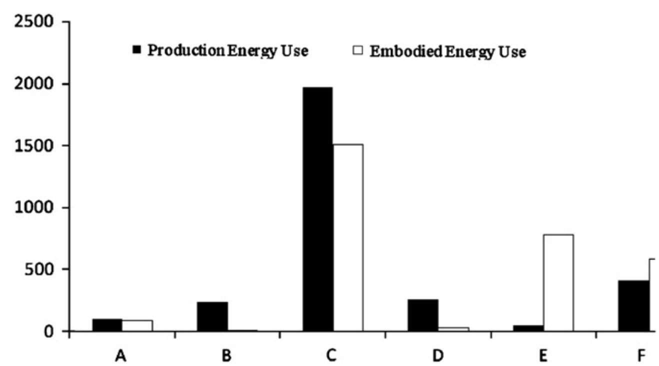

Fig. 1. Production energy use (extracted from the CESYB) vs. embodied energy consumption(calculated by the EIO model) for 6 sector groups. (Units: Mt SCE).

3. Results

3.1. Pattern of embodied energy consumption

Fig. 1 depicts the comparison results between production energy use and embodied energy consumption for 6 industrial groups, and Fig. 2 depicts the comparison results for 29 economic sectors.

In this study, a system boundary was set up according to China's territorial boundary, and energy embodied in imports was not included (excluded in the final demand Y), thus the sum of all sector's production energy use and the sum of their embodied energy consumption are equal. The embodied energy consumption for each sector was the energy consumption reallocated through this sector's supply chain, thus significant differences exist between production energy use and embodied energy consumption for 6 groups and 29 sectors. From Fig. 1, it is very clear that "Manufacturing" (Group C) industry was the main contributor to total production energy use, while "Manufacturing" (Group C), "Construction" (Group E) and "Service Industry" (Group F) were the three main contributors to total embodied energy consumption. Particularly, "Manufacturing" (Group C) industry dominated both production energy use and embodied energy consumption, accounting for 65.8% of the total amount of production energy use and 50.4% of total amount of embodied energy consumption.

With respect to the 29 economic sectors (Fig. 2), sectors of "Petroleum Processing and Coking, Gas Production and Supply" (No. 11), "Raw Chemical Materials and Chemical Production, Medical and Pharmaceutical Production, Chemical Fiber, Rubber Production, Plastic Production" (No. 12),"Nonmetal Mineral Production" (No. 13), "Smelting and Pressing of Ferrous and Nonferrous Metals" (No. 14), "Electricity Power/Heating Supply" (No. 23) and "Transport, Logistics, Postal and Telecommunications Services" (No. 27) are the greatest contributors to the total production energy use, accounting for 70% of the total production energy use. Each of these sectors accounts for 5.8%, 15.3%, 7.55, 25.0%, 7.9% and 8.0% of total production energy use, respectively. Meanwhile, sector of "Construction" (No. 26) is the largest contributor of the total embodied energy consumption (26.1%), followed by "Other Service Activities" (No. 29) (12.4%), "Ordinary and Special Equipment" (No. 16) (7.5%), "Electronic and Telecommunications Equipment" (No. 19) (6.4%), "Transportation Equipment" (No. 17) (6.0%) and "Electric Equipment and Machinery" (No. 18) (5.4%).

3.2. Direct energy consumption versus indirect energy consumption

By using Eq. (3), embodied energy consumption from 29 sectors was further decomposed into direct energy consumption and indirect energy consumption (Fig. 3).

The results indicated that indirect energy consumption accounts for 80% of the total embodied energy consumption. Particularly, "Construction" sector has the largest amount of embodied energy consumption, with approximately 95% of its embodied energy consumption allocated into indirect energy consumption.

To further explore the energy consumption features of typical economic sectors, three sectors were chosen for a more detailed analysis of their embodied energy consumption. Based on Eq. (3), embodied energy consumptions of "Construction" sector (No. 26), "Other Service Activities" sector (No.29) and "Ordinary and Special Equipment" sector (No.16) have been presented in Figs. 4–6, respectively.

The results showed that indirect energy consumptions from these three sectors were mainly caused by energy consumptions from their upstream/downstream sectors, especially from sectors of "Raw Chemical Materials and Chemical Production, Medical and Pharmaceutical Production, Chemical Fiber, Rubber Production, Plastic Production" (No. 12), "Nonmetal Mineral Production" (No. 13), "Smelting and Pressing of Ferrous and Nonferrous Metals" (No. 14), "Electricity Power/Heating Supply" (No. 23) and "Transport, Logistics, Postal and Telecommunications Services" (No. 27). Because sectors of No. 12, No. 13 and No. 14 are typical heavy industrial and energy-intensive sectors, the higher proportion of embodied energy consumption in "Construction" and "Other Service Activities" can be explained by the intermediate activities' energy consumption from those energy-intensive sectors.

4. Discussion

By employing the EIO method, our study results provided an innovate perspective for explaining the rapid growth of "energy-intensive" sectors in China. While heavy industries, such as smelting and pressing of metals, are typical energy-intensive sectors and have higher level of production energy use, sectors, such as "Construction" (No. 26), have relatively higher embodied energy consumptions and should be considered energy-intensive sectors from a supply chain perspective.

By uncovering the supply chain energy consumption for a single sector (Figs. 4–6), our results illustrated that those heavy industrial sectors and the relevant energy supply sectors along upstream/downstream supply chains are the main contributors of the high embodied energy consumption for sectors such as "Construction". Consequently, the supply chain energy consumptions contribute to higher values of the embodied energy consumption of certain sectors.

Given the above information, it is necessary to find appropriate explanations for such phenomena. First, China's soaring economy has been primarily driven by infrastructure construction and

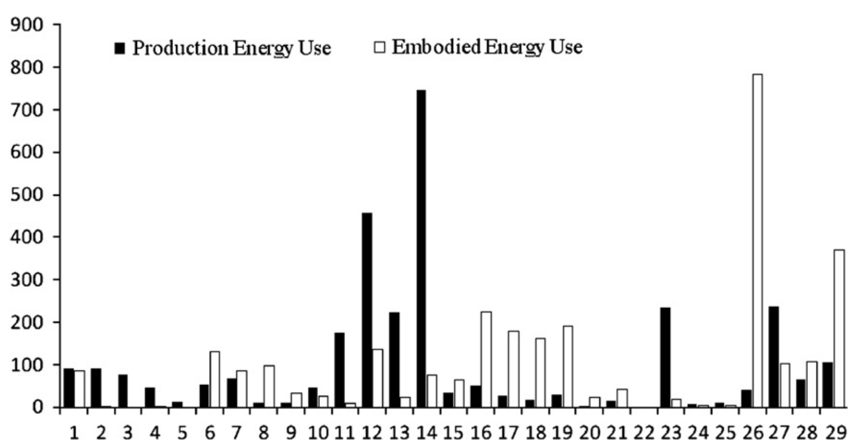

Fig. 2. Production energy use vs. embodied energy consumption for 29 economic sectors (Units: Mt SCE).

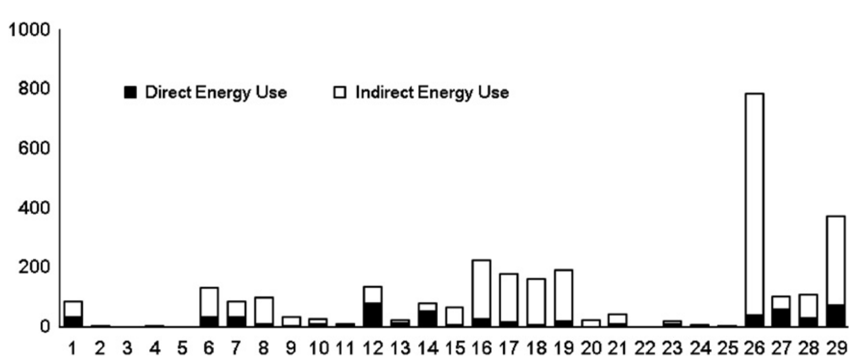

Fig. 3. Direct and indirect energy consumption for 29 sectors (Units: Mt SCE).

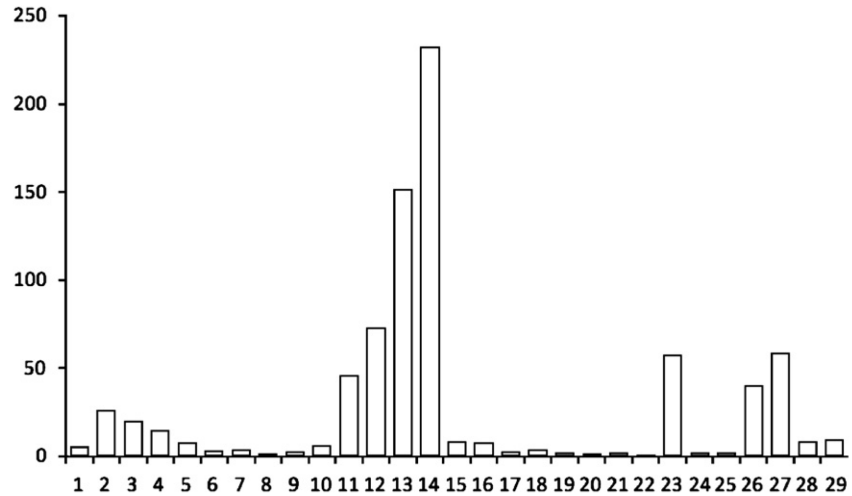

Fig. 4. Embodied energy consumption for ''Construction'' sector (Units: Mt SCE).

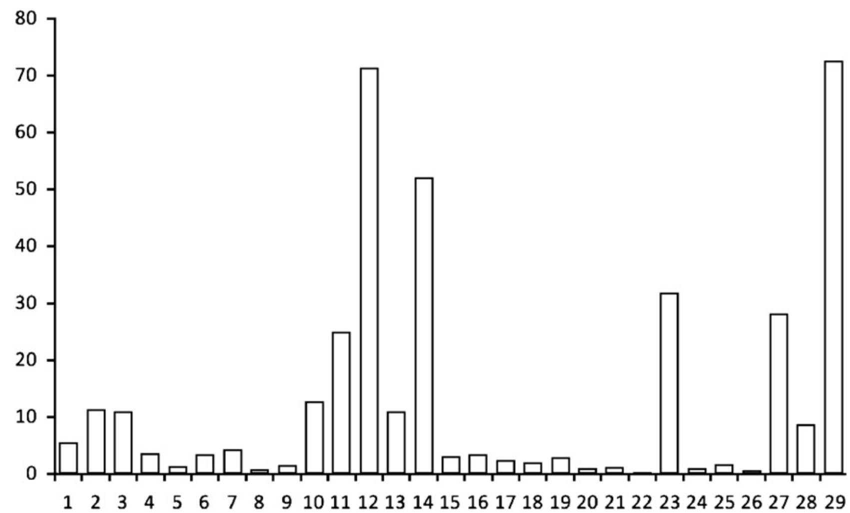

Fig. 5. Embodied energy consumption for ''Other Service Activities'' sector (Units: Mt SCE).

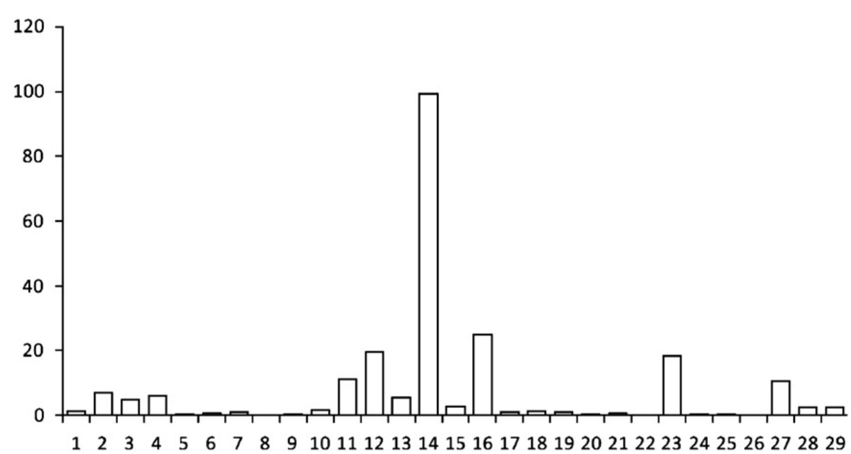

Fig. 6. Embodied energy consumption for ''Ordinary and Special Equipment'' sector (Units: Mt SCE).

capital investment (Minx et al., 2011; Peters et al., 2010). Such a strategy has been effective in maintaining China's rapid GDP growth even during the global economic recession (Guan and Barker, 2012). Based on the Chinese official statistics (National Bureau of Statistics, 2010), capital investment had contributed to 45% of the annual GDP growth during 2000–2007, whereas household consumption and exports had contributed to 30% and 25%, respectively. Capital investment creates market demand for the large-scale production expansion of cement, steel and other highly energy-intensive materials, as well as demand for the associated electricity generation to support such production (Chen et al., 2011; Minx et al., 2011; Peters et al., 2007). For example, the average annual growth rate of cement output was 10.7% from 1985 to 2010. In 2010, China's cement output was 1.87 Bmt, accounting for 56% of the world's total cement production (International Cement Review, 2011). Similarly, China's steel production had increased from 152 Mt in 2001 to 695.5 Mt in 2011, accounting for 45.5% of the world's total steel production (Guo and Zhang, 2012). Most of the cement and steel were consumed by "Construction" sector, resulting in this sector being the most intensive sector for embodied energy consumption. Thus, the supply chain demand of such sectors caused very large amounts of production activity in heavy industries; in other words, these sectors are also "energy-intensive", but energy consumption is concentrated in supply activity rather than their direct production for final demand.

Second, a sector's classification limited the analysis of the energy consumption in the supply chain. Because of the mismatch between sectoral classifications in China's IO tables and the classifications in sectoral energy consumption, we merged similar sectors in this study for consistency between the sectors in IO and the sectors in the energy consumption data; the aggregated sectoral classification contains 29 sectors. Thus, several subsectors may be merged together and some sectors may contain too many sectoral activities, especially "Other Service Activities", for which activities that do not belong to other sectors are all contained within it. Such classifications of energy consumption sectors have been already widely used for IO-related research in China. For example, a classification of 24 sectors was proposed by Chang and his colleagues (Chang et al., 2010), 26 sectors were proposed by Chen and Zhang (2010) and 29 sectors were proposed by Zhang (2010); the sectoral aggregation and disaggregation was also discussed by Kahrl and Roland-Holst (2008) as well as by Chen and Zhang (2010). Given the scale and proportion of the embodied energy consumption from these sectors, the uncertainty brought by such simplification cannot negate the result that China's construction and service sectors are actually energy-intensive when considering their embodied energy consumption. However, such uncertainty cannot be ignored, especially when the EIO model is coupled with life-cycle analysis (Hendrickson et al., 2006). Because the CESYB is the only official and open published data source which contains China's sectoral detailed energy consumption, it is impossible to directly improve the data quality based on current statistics system; thus, we encourage any efforts of further disaggregation of sectoral energy consumption and improvement in the data quality of China's energy statistics from different sources in the future.

5. Policy implications

Generally, current Chinese energy conservation policies focus on production energy use, thus, heavy industries received a lot of attention for their energy saving efforts. For example, during the 11th Five-Year Plan (2006–2010), energy-saving targets for China's 1000 highest energy consuming enterprises were arranged by the NDRC, aiming to save approximately 2.9 EJ of energy consumption during 2006–2010 (Price et al., 2010). In 2010, factories with production capacities of 10 MkW h of power generation, 6 million tons of steel and 25 Mt of iron were closed (National Development and Reform Commission (NDRC), 2011b; Xinhuanet, 2007). Additionally, more ambitious plans have been prepared to improve energy efficiency of 17 heavy industrial sectors (such as cement, iron and steel) during the 12th Five-Year Plan (2011–2015). However, current policy overlooks the supply chain of those heavy industries. The continuous expansion of those industries would result in multiple increase of energy demand by their upstream suppliers. This would further lead to higher energy consumption for the whole economy (Lenzen et al., 2008). Thus, energy saving measures and efficiency improvement policies should not only consider the traditional heavy industries but also pay attention to the relevant sectors along their supply chains. An integrated policy approach should be employed instead of only addressing energy efficiency issues in several individual sectors. Such integrity requires that policy makers integrate energy supply management, energy demand management, energy efficiency management, and energy-related emission management throughout the whole supply chain. Moreover, policy makers should seek new economic growth strategies, rather than only relying on infrastructure construction and capital investment. For instance, increasing investment in education service and technological innovation aspects could be helpful for long-term economic growth and the adjustment of the whole economic structure.

With respect to the "bottom-up" implementation of such energy saving and efficiency improvement policies, different strategies should be adopted based on a certain sector's energy consumption features. For those heavy industries, such as thermal power generation and smelting metal, efforts should focus on the improvement of their efficiency through cleaner production, energy audits, technology updates, compulsory phase-out/shutdown of inefficient and backward manufacturing facilities, capacity-building programs on energy saving awareness, etc. For those sectors with higher embodied energy consumptions, such as construction sector, efforts should focus on addressing their supply chain energy consumption, such as greening their supply chain and controlling the irrational final demand. Market-based instruments, such as sectoral financial subsidies, preferable tax rates and low interest bank loans, should be employed so that the energy consumption along the supply chain can be adjusted according to their final demand and consumption.

6. Conclusions

The aim of this study is to uncover the whole picture of China's sectoral embodied energy consumption. Through the use of an economic input–output assessment (EIO) model, patterns of embodied energy consumption were analyzed for 29 sectors. Our results indicate that some sectors that are not traditionally regarded as "energy-intensive" are actually the sectors with higher embodied energy consumption, such as construction sector. Therefore, energy conservation policies should be revised based upon such realities so that the rational consideration can be given to these key sectors. Policy implications from this paper can be used for those decision-makers to reconsider their energy management targets and regulations by considering sectoral realities.

Acknowledgements

This study was supported by Natural Science Foundation of China (71033004, 31100346, 41101126), Chinese Academy of Sciences (2008-318), the Shenyang Scientific Research Foundation (F10-238-6-00), and Ministry of Science and Technology (2011BAJ06B01).

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