Article

Energy Consumption Linkages of the Chinese Construction Sector

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Abstract: The purpose of this paper is to explore the relationships between the construction sector and the rest of the Chinese economy in the energy consumption as it is crucial in energy consumption of the whole economy. Therefore, this paper uses the Modified Hypothetical Extraction Method (MHEM) to quantify the linkages of energy consumption in 2002, 2005, 2007, 2010, 2012, 2015, 2017 and 2018, providing a new perspective for energy consumption linkage studies in China. In this paper we discover the volumes and paths of energy consumption net flows from other blocks to the construction sector and identify the key energy suppliers of the construction sector. The empirical findings show that the indirect energy consumption exceeded the direct energy consumption between 2002 and 2018, representing more than 90% of total (direct plus indirect) energy consumption of the construction sector. Between 2002 and 2018, the indirect energy consumption of the construction sector increased from 27,579 to $111,760 \times 10^4$ tons of coal equivalent (tce). We further find that the construction sector has the largest inflows of energy consumption to obtain its own demand than other sectors from 2002 to 2018. The average annual energy consumption net flows from other seven sectors to the construction sector were 1477, 687, 47,998, 6067, 1483, 7362 and 1923×10^4 tce in 2002–2018, respectively. Moreover, we find that the Manufacturing sector is the largest energy supplier of the construction sector between 2002 and 2018.

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Keywords: energy consumption; the construction sector; linkage; modified hypothetical extraction method

1. Introduction

With increasingly serious global warming, the issue of energy consumption cannot be ignored. Energy consumption of construction sector has become a crucial part in global energy consumption [1–6]. Construction sector as the one of the highest energy consumption sectors in China, is the core sector of Chinese energy consumption [7]. According to statistics by National Bureau of Statistics of China, the energy consumption of construction sector in China has increased from 5533 to 9142×10^4 tce (1 tce = 29.3 GJ) during the period between 2010 and 2019, with the average annual growth rate of 6.5%. It is observed that the energy consumption of Chinese construction sector still experiences a growing trend. Besides, with the continuous increase of China's construction scale, the energy consumption of China's construction sector will continue rising [8–10].

In order to solve the problem of global warming, countries around the world are confronted with the common goal of CO₂ emission reduction [11–17]. In recent decades, Chinese rapid economic development has been accompanied by a relatively large amount of energy consumption [18,19]. Chinese government not only introduces energy conservation and emission reduction as the basic state policy [20], but also establish the target to peak its CO₂ emissions before 2030 in the Paris Agreement. It is admitted that the construction sector plays a crucial part in global energy conservation and emission reduction across sectors [21–23]. Similarly, the construction sector is equally key to realize the target of energy conservation and emission reduction in China [7,24,25]. Therefore, energy consumption of

the Chinese construction sector has attracted significant attention in academia for many years [18,26–29].

The common practice is to use direct consumption to evaluate energy consumption, whereas it is not systematic to merely emphasize direct energy consumption [30]. In a national economy, the output of one sector is probably other sectors' input, which means the interdependence among different sectors rather than independence [31]. Theoretically, the production processes in which one sector is interdependent with other sectors is defined as linkages [32]. The linkages among different sectors can introduce three energy consumption situations as follows. Firstly, there are direct and indirect energy consumption in actual commodity production and service activities [29,30,33,34]. Secondly, as the basic input–output relationship illustrates, products of a sector requires products from other sectors as the intermediate input and goods produced by this sector can further become other sectors' intermediate input, because all of these products of the sectors need energy as input, energy consumption of sectors has linkage effect [35]. Thirdly, input and output of commodities or service among different sectors means energy flow among different sectors [30,36]. It is worthy stressing that the construction sector as the pillar of economy in China is critical to national economic development and it closely interacts with other sectors in the economic system [24,31,37]. Therefore, quantitative analysis of the indirect consumption, linkage of energy consumption and energy flow of China's construction sector would assist in achieving the goal of energy conservation and emission reduction.

From a methodological viewpoint, input–output analysis has become an approach that is widely applied in the field of energy [38–42]. In compliance with input–output analysis, Schultz [43] analyzed linkages among 20 standard sectors for the first time using hypothetical extraction method (HEM), this method suppose that a sector is eliminated and then compare total output changes in the economic system before and after the removal of this sector, aiming to measure the importance of this sector in the whole economic system and quantitatively analyze impacts on other sectors. HEM is generally applied to research the economic effect of a sector [42–48], and identification of a key sector to formulate targeted policies based on the analysis results [49–52], even extended to resource consumption and carbon emission research fields to analyze the linkages of resources consumption and carbon emission of different countries or regions [53–58]. On the foundation of HEM, Duarte et al. [59] pointed out that modified hypothetical extraction method (MHEM) calculates the vertically integrated consumption and divide linkage effect into four components which aims to analyze the linkage of water use in Spain. In addition to the studies of linkage of water use [60], MEHM is also involved in researches of CO₂ emission [61–65]. Although an increasingly number of scholars have used MHEM, there are few studies that focus on the linkage of energy consumption between a single sector and the rest of the Chinese economic system.

Different from previous studies, this research is expected to apply MHEM to the linkage of energy consumption, concentrating on the linkage of energy consumption between Chinese construction sector and the rest of the economic sectors. Then, we calculate indirect energy consumption of Chinese construction sector using the national input–output table and energy consumption by sector from China (National Bureau of Statistics of China, 2002, 2005, 2007, 2010, 2012, 2015, 2017 and 2018). From the linkage of energy consumption perspective, we quantitatively analyzed the internal consumption, mixed consumption, net backward linkage consumption and net forward linkage consumption of Chinese construction sector, which aimed at investigating impacts of energy consumption of construction on the entire economic system and further revealing energy flow paths and volumes from other sectors to the construction sector.

2. Methodology

2.1. Energy Consumption Input–Output Model

The fundamental input–output model is described below:

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

where X is an $n \times 1$ vector of total output with elements x_i , where n stands for number of industries in the economy; I is the identity matrix; A is n -by- n matrix of technical coefficients, whose element a_{ij} measures the flow from industry i required to produce the per unit output of industry j (where $i, j = 1, \dots, n$); $(I - A)^{-1}$ is the Leontief inverse matrix, in which elements show the output of a sector required directly and indirectly to produce the per unit of final demand for the other sector. Y is an $n \times 1$ vector of final demands with elements y_i .

The energy consumption input–output model which is derived from the structure of the fundamental input–output equation. First, the direct energy consumption coefficient is defined as:

$$\rho = DC/X \quad (2)$$

where DC is direct energy consumption. Combining Equations (1) and (2), the energy input–output model is described below:

$$\omega = \rho(I - A)^{-1}Y = B^{\rho} \times Y \quad (3)$$

where ω is the energy input–output matrix; B^{ρ} is the matrix of total energy consumption coefficient with elements b_{ij}^{ρ} demonstrating the total volumes of direct and indirect energy consumption generated per unit's worth of final demand presented to the economy.

2.2. Linkage Analysis of Energy Consumption by HEM

HEM was first used by Schultz [43] to research the economic impact of a sector's activity change. The original idea of the HEM is to extract a sector from the economic system under hypothetical situations and then to measure the effect of this extraction on other sectors in the economy. Linkage analysis of energy consumption by HEM in greater details as described below, it is assumed that the economy has been partitioned into two blocks: Z_t is block one, while Z_{-t} is block two. Both block Z_t and Z_{-t} can represent a single sector or several sectors, and the economy as follows:

$$Z = \begin{bmatrix} Z_{t,t} & Z_{t,-t} \\ Z_{-t,t} & Z_{-t,-t} \end{bmatrix} \quad (4)$$

Combining Equations (3) and (4), the energy consumption matrix before a sector is extracted can be expressed as:

$$\begin{bmatrix} \omega_t \\ \omega_{-t} \end{bmatrix} = \begin{bmatrix} \rho_t & 0 \\ 0 & \rho_{-t} \end{bmatrix} \begin{bmatrix} \Delta_{t,t} & \Delta_{t,-t} \\ \Delta_{-t,t} & \Delta_{-t,-t} \end{bmatrix} \times \begin{bmatrix} Y_t \\ Y_{-t} \end{bmatrix} \quad (5)$$

where $(I - A)^{-1} = \begin{bmatrix} \Delta_{t,t} & \Delta_{t,-t} \\ \Delta_{-t,t} & \Delta_{-t,-t} \end{bmatrix}$ is the Leontief inverse matrix.

Block Z_t is to be hypothetically extracted from the economy, block Z_t and Z_{-t} neither have economic activity. The hypothetical energy consumption relationships are shown below:

$$\begin{bmatrix} \omega_t^* \\ \omega_{-t}^* \end{bmatrix} = \begin{bmatrix} \rho_t & 0 \\ 0 & \rho_{-t} \end{bmatrix} \begin{bmatrix} (I - A_{t,t})^{-1} & 0 \\ 0 & (I - A_{-t,-t})^{-1} \end{bmatrix} \times \begin{bmatrix} Y_t \\ Y_{-t} \end{bmatrix} \quad (6)$$

The change in energy consumption, which reflects the impact of the extracted block can be obtained by subtracting Equation (5) from Equation (6):

$$\begin{aligned}
\begin{bmatrix} \omega_t - \omega_t^* \\ \omega_{-t} - \omega_{-t}^* \end{bmatrix} &= \begin{bmatrix} \rho_t & 0 \\ 0 & \rho_{-t} \end{bmatrix} \begin{bmatrix} \begin{bmatrix} \omega_t \\ \omega_{-t} \end{bmatrix} - \begin{bmatrix} \omega_t^* \\ \omega_{-t}^* \end{bmatrix} \\ \Downarrow_{t,t} - (I - A_{t,t})^{-1} \Downarrow_{t,t} \quad \Downarrow_{t,-t} - (I - A_{-t,-t})^{-1} \Downarrow_{t,-t} \end{bmatrix} \times \begin{bmatrix} Y_t \\ Y_{-t} \end{bmatrix} \\
&= \begin{bmatrix} \rho_t \left(\Downarrow_{t,t} - (I - A_{t,t})^{-1} \right) & \rho_t \Downarrow_{t,-t} \\ \rho_{-t} \Downarrow_{-t,t} & \rho_{-t} \left(\Downarrow_{-t,-t} - (I - A_{-t,-t})^{-1} \right) \end{bmatrix} \times \begin{bmatrix} Y_t \\ Y_{-t} \end{bmatrix} \\
&= \begin{bmatrix} \xi_{t,t} & \xi_{t,-t} \\ \xi_{-t,t} & \xi_{-t,-t} \end{bmatrix} \times \begin{bmatrix} Y_t \\ Y_{-t} \end{bmatrix} \tag{7}
\end{aligned}$$

According to Equation (7), the total, backward and forward energy consumption linkage by HEM are defined as follows:

$$TEL = v' \begin{bmatrix} \omega_t - \omega_t^* \\ \omega_{-t} - \omega_{-t}^* \end{bmatrix} \quad (8)$$

$$BEL = v' \begin{bmatrix} \xi_{t,t} & \xi_{-t,t} \end{bmatrix} Y_t \quad (9)$$

$$FEL = v' \begin{bmatrix} \tilde{\xi}_{t,-t} \\ \tilde{\xi}_{-t,-t} \end{bmatrix} Y_{-t} \quad (10)$$

where v' is the identity vector. At the same time, Equations (8)–(10) possess the following relation: $TEL = BEL + FEL$.

2.3. Linkage Analysis of Energy Consumption by MHEM

The modified hypothetical extraction method (MHEM) proposed by Duarte et al. [59] is based on the vertically integrated sector Pasinetti (1977) and HEM. From Equations (8)–(10) they decompose the water use associated with Z_c into four separate components, namely: internal effect, mixed effect, net backward linkage and net forward linkage. According to MHEM, this study is conducted to construct the vertically integrated consumption of energy (*VICE*), and then decompose energy consumption into the internal consumption (*IC*), mixed consumption (*MC*), net backward linkage consumption (*NBLC*) and net forward linkage consumption (*NFLC*).

VICE can be obtained as follows:

$$VICE_j = \sum_{i=1}^n \rho_i \eta_{ij} Y_j \quad (11)$$

where $VICE_j$ is the total volumes of direct and indirect energy consumption to obtain the final demand sector j ; ρ_i is the direct energy consumption coefficient of sector i ; η_{ij} is the element of the Leontief Inverse matrix; Y_j is the final demand of sector j .

IC is the energy consumed with the processes within the Z_t itself [66,67], which is stated as:

$$IC = \rho_t(I - A_{t,t})^{-1}\Upsilon_t \quad (12)$$

MC is the part of energy consumed that is associated with the participation of both Z_t and Z_{-t} , representing the energy consume that are embodied in the goods which are originally sold to Z_{-t} by Z_t , and after being processed by Z_{-t} , consequently repurchased by Z_t , for production purposes, and the formula of MC is as follows:

$$MC = \rho_t \left[\mathcal{J}_{t,t} - (I - A_{t,t})^{-1} \right] Y_t \quad (13)$$

$NBLC$ is the energy consume requirements of from Z_{-t} to obtain the final demand of Z_t , which reflects the net energy consume inflows of Z_t . $NBLC$ can be described as follows:

$$NBLC = \rho_{-t} \downarrow_{-t,t} Y_t \quad (14)$$

$NFLC$ is the energy consume of Z_c and used by Z_{-t} for production, which represents the net energy consume exports of Z_t , and the formula of $NBLC$ can be obtained as:

$$NFLC = \rho_t \downarrow_{t,-t} Y_{-t} \quad (15)$$

where VIE , IC , MC and $NBLC$ possess the following relations: $VIE = IC + MC + NBLC$.

Thus, the total of energy net flow ($TENF$) can be expressed by subtracting Equation (15) from Equation (14):

$$TENF = NFLC - NBLC \quad (16)$$

In order to clarify the role of block in energy consumption, the concepts of energy supplier and energy receiver are proposed in this study. If $TENF > 0$, which reflects energy flow from Z_t to Z_{-t} , that is to say, Z_t is the energy supplier; If $TENF < 0$, which reflects energy flow from Z_{-t} to Z_t , that is to say, Z_t is the energy receiver.

This study aims to explore the volumes and paths of energy flow among the different sectors. Assume block $-t_1$ is one of the blocks that make up Z_{-t} . Decomposing Equation (14), the volumes of energy flow from block $-t_1$ to block Z_t can be defined as follows:

$$NBLC_{-t_1 \rightarrow t} = \rho_{-t_1} \downarrow_{-t_1,t} Y_t \quad (17)$$

Decomposing Equation (15), the volumes of energy flow from block Z_t to block $-t_1$ can be defined as follows:

$$NFLC_{t \rightarrow -t_1} = \rho_t \downarrow_{t,-t_1} Y_{-t_1} \quad (18)$$

Then, the volumes and paths of energy net flow among blocks can be expressed by subtracting Equation (15) from Equation (14):

$$ENF_{t \rightarrow -t_1} = NFLC_{t \rightarrow -t_1} - NBLC_{-t_1 \rightarrow t} \quad (19)$$

where a positive value of $ENF_{t \rightarrow -t_1}$ reflects energy flow from Z_t to $-t_1$, which represents net output of energy; while a negative value of $ENF_{t \rightarrow -t_1}$ indicates energy flow from $-t_1$ to Z_t , which represents net input of energy.

3. Empirical Analysis

3.1. Data Source and Processing

In this study, we measure the energy consumption linkages and energy flow of the construction sector in 2002, 2005, 2007, 2010, 2012, 2015, 2017 and 2018. Therefore, this paper requires two sets of data: the time series of input–output tables and the corresponding energy consumption. The input–output tables and energy consumption data come from China (National Bureau of Statistics of China, 2002, 2005, 2007, 2010, 2012, 2015, 2017 and 2018). It is necessary to indicate that China's National Bureau of Statistics compiles an input–output table based on national surveys every 5 years, during which an input–output is extended. Therefore, the most recent national input–output table is 2018.

According to the classification in the input–output Table and the energy statistics of China, we allocated more than 100 sectors in the economy. In accordance with Industrial classification for national economic activities of China, these sectors were grouped into eight blocks. The eight blocks are as follows: Agriculture (U1), Mining (U2), Manufacturing (U3), Production and Supply of Electricity Power, Heat Power, Gas and Water (U4), Construction (U5), Retail and catering industry (U6), Transportation (U7) and Other Industries (U8).

3.2. Direct and Indirect Energy Consumption

Figure 1 shows both the direct and indirect energy consumptions of the construction sector. The direct energy consumption is derived from National Bureau of Statistics of China. And the indirect energy consumption is obtained by subtracting the direct energy consumption from Equation (11). As shown in Figure 1, the direct and indirect energy consumptions of the construction sector kept increasing over the 2002–2018 period. It is worth noting that, although the direct energy consumption in the construction sector of China was relatively small, it had large indirect energy consumption. More specifically, the indirect energy consumption all exceeded the direct energy consumption between 2002 and 2018, representing more than 90% of total (direct plus indirect) energy consumption. Between 2002 and 2018, the indirect energy consumption of the construction sector increased from 27,579 to $111,760 \times 10^4$ tce. In the construction sector, the indirect energy consumption has a significant effect on VICE (the total energy consumption to satisfy the final demand). This implies that the sectoral linkages between the construction sector and other economic sectors cannot be ignored when exploring energy consumption of the whole economy.

Figure 1. The direct and indirect energy consumptions of the Chinese construction sector in 2002–2018.

3.3. Linkage of Energy Consumption

For other seven blocks, the energy consumption linkages of the construction sector in different periods are shown in Table 1. Four significant differences can be observed among the ranks of the internal consumption, mixed consumption, net backward linkage consumption and net forward linkage consumption. First, except for 2010 and 2015, all ranking values of the internal consumption of the construction sector are below number 3. Second, all values of the mixed consumption of the construction sector are ranked in the number 7. Third, the net backward linkage consumption of the construction sector all exceeded the other three linkages in 2002–2018, which means that there are greater consumption inflows. Between 2002 to 2018, the net backward linkage of the construction sector increased from 27,670 to $111,877 \times 10^4$ tce. The construction sector has the largest net backward linkage of energy consumption than other seven blocks from 2002 to 2018, which indicates the construction sector has the largest inflows of energy to obtain its own demand. Last, the net forward linkage consumption of the construction sector was the least. Low net forward linkage consumption means that the construction sector emits little energy in providing outputs required by other blocks.

Table 1. The four components of energy consumption linkages in construction sector, 2002–2018 (10^4 tce).

Linkage	2002		2005		2007		2010		2012		2015		2017		2018	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
IC	1506	7	3129	4	3940	4	6080	3	5942	4	7455	3	8431	4	8544	4
MC	13	7	32	7	12	7	21	7	38	7	54	7	21	7	24	7
NBLC	27,670	1	37,940	1	53,943	1	69,366	1	75,046	1	106,030	1	100,050	1	111,877	1
NFLC	91	8	248	8	79	8	125	8	187	8	188	8	102	8	117	8

3.4. Components of VICE

According to Equations (11)–(14), Figure 2 shows the VICE (the total energy consumption to satisfy the final demand) composition of the construction sector. It can be noted that more than 91% of the VICE in the construction sector comes from NBLC. This high NBLC ratio indicates that a significant part of the directly and indirectly energy consumed by the construction sector comes from inflows from the other blocks in 2002–2018. Between 2002 to 2018, the value of internal consumption was stabilizing at a low value less than 8.1%. The low internal consumption, demonstrating significant non-dominance of internal consumption in the construction sector. Additionally, the value of mixed consumption of the construction sector was less than 0.09% in 2002–2018. Similarly, the low mixed consumption reflects that the energy consumption component associated with the participation of the construction sector and other blocks is the least.

Figure 2. VICE composition of the construction sector in eight different years. Note: the VICE stands for total energy consumption to satisfy the final demand.

3.5. Total of Energy Net Flow (TENF)

The total of energy net flow in Figure 3 is obtained using Equation (16). As shown in Figure 3, TENF of the construction sector are all negative in 2002–2018, which means that energy flow from other blocks to the construction sector, that is to say, the construction sector is the energy receiver between 2002 and 2018. In this part, we also can get the tendency of TENF from 2002 to 2018. In 2002–2018, the energy flow from other blocks to the construction sector is mounting. For the construction sector, the imported energy consumption increased from 27,575 to $111,760 \times 10^4$ tce between 2002 and 2018. Thus, the volumes and paths of energy net flow from other blocks to the construction sector has an increasingly important impact on the whole economy's energy consumption.

Figure 3. The total of energy net flow of the Chinese construction sector, 2002–2018.

3.6. Net Flow of Energy Consumption

According to Equation (19), the clear understanding of the construction sector's energy consumption linkages between 2002 and 2018 were obtained as shown in Figure 4. The flow paths and volumes of energy consumption in different sectors can be found in Figure 4, and then we can see where the energy consumption of the construction sector comes from. Where Figure 4a shows the net flow of energy consumption in 2018. The development of the other seven blocks also had a pull effect on the energy consumption in the construction sector. In 2018, the imported net flow of energy consumption to the construction sector is from the other seven blocks. Specifically, the construction sector with 1858, 9061, 74,535, 9232, 2857, 10,516 and 3701×10^4 tce energy consumption net flow from the Agriculture, Mining, Manufacturing, Production and Supply of Electricity Power, Heat Power, Gas and Water, Retail and catering industry, Transportation and Other Industries, respectively, where Manufacturing occupies the largest proportion.

From Figure 4b it is clearly seen that the average of the net flow of energy consumption between 2002 and 2018. It can be noted that the average annual energy consumption net flow from the Agriculture, Mining, Manufacturing, Production and Supply of Electricity Power, Heat Power, Gas and Water, Retail and catering industry, Transportation and Other Industries flow to the construction sector were 1477, 6287, 47,998, 6067, 1483, 7362 and 1923×10^4 tce in 2002–2018, respectively, where Manufacturing occupies the largest proportion.

The percentages of energy consumption net flow from other seven blocks to the construction sector in Table 2 is obtained using Figure 4. Where row(a) shows the percentages of energy consumption net flow from other sectors to the construction sector in 2018. It can be noted that the percentage of Manufacturing was 66.69%. The percentages of other six sectors were 1.66%, 8.11%, 8.26%, 2.56%, 9.41% and 3.31%, respectively. Thus, Manufacturing is the largest energy supplier of the construction sector in 2018. This suggests that Manufacturing has the largest relative impact on energy consumption net flow of the construction sector in 2018.

Table 2. The percentages of energy consumption net flows of construction sector.

Sector	U1	U2	U3	U4	U6	U7	U8	Total
a	1.66%	8.11%	66.69%	8.26%	2.56%	9.41%	3.31%	100.00%
b	2.03%	8.66%	66.12%	8.36%	2.04%	10.14%	2.65%	100.00%

Note: The total of energy net flows to the construction sector is 100%. Row(a) shows the percentages of energy consumption net flows in 2018. Row(b) shows the averages of percentages of energy consumption net flows between 2002 and 2018.

Figure 4. The net flow paths and volumes of energy consumption in different sectors of China (10^4 tce). Note: (a) Shows the net flow of energy consumption in 2018. (b) Shows the average of the net flow of energy consumption between 2002 and 2018. Colors indicate the eight different sectors. Energy consumption flows from the sectors on the left to the sectors on the right. The width of the line represents the volumes of energy consumption net flow, and the specific volumes are shown in the middle.

The averages of percentages of energy consumption net flow from other sectors to the construction sector between 2002 and 2018 were obtained as shown in row(b). The average percentage of Manufacturing was 66.12%. The percentages of other six sectors were 2.03%, 8.66%, 8.36%, 2.04%, 10.14% and 2.65%, respectively. Similarly, in the case of energy for construction sector we can find that the Manufacturing is the largest energy supplier between 2002 and 2018.

4. Conclusions and Policy Implications

The construction sector is important to realize the target of energy conservation and emission reduction in China. Besides, energy consumption in China's construction sector has attracted significant attention in academia for many years. Different from previous studies, this research aimed to apply MHEM to the linkage of energy consumption, concentrating on the linkage of energy consumption between Chinese construction sector and the rest of the economic sectors. Understanding the energy consumption relationship between the construction sector and other sectors can provide useful information for the target of energy conservation and emission reduction in China. Therefore, we used MHEM to calculate indirect energy consumption of Chinese construction sector in 2002, 2005, 2007, 2010, 2012, 2015, 2017 and 2018. Then, we quantitatively analyzed the energy consumption linkages between construction sector and the rest of economy, and further revealing energy flow paths and volumes from other sectors to the construction sector. Moreover, we analyzed the relative impact of other sectors on the construction sector by relative percentages of energy consumption net flow. It is necessary to indicate that China's National Bureau of Statistics compiles an input–output table based on national surveys every 5 years, during which an input–output is extended. The most recent national input–output table is 2018. Therefore, the dataset in this paper is complete. Based on our analysis, the following key conclusions are drawn:

First, the direct and indirect energy consumptions of the construction sector kept increasing over the 2002–2012 period. Although the direct energy consumption in the construction sector of China was relatively small, it had large indirect energy consumption. More specifically, the indirect energy consumption all exceeded the direct energy consumption between 2002 and 2018, representing more than 90% of total (direct plus indirect) energy consumption. Between 2002 and 2018, the indirect energy consumption of the construction sector increased from 27,579 to $111,760 \times 10^4$ tce. This indicates that the sectoral linkages between the construction sector and other economic sectors cannot be ignored when exploring energy consumption of the whole economy.

Second, the construction sector has the largest inflows of energy to obtain its own demand than other sectors from 2002 to 2018. For the construction sector, the total of imported energy consumption increased from 27,575 to $111,760 \times 10^4$ tce between 2002 and 2018. Between 2002 to 2018, the net backward linkage of the construction sector increased from 27,670 to 111,877. The construction sector has the largest net backward linkage of energy consumption compared with other seven blocks from 2002 to 2018. And the net forward linkage consumption of the construction sector was the least. This means that the construction sector has the largest inflows of energy to obtain its own demand.

Finally, the net energy consumption flow from the Agriculture, Mining, Manufacturing, Production and Supply of Electricity Power, Heat Power, Gas and Water, Retail and catering industry, Transportation and Other Industries to the construction sector was identified, in which Manufacturing occupies the largest proportion in 2018 (according to Table 2, the relative percentage is 466.84%). Moreover, we can find that Manufacturing is the largest energy supplier of the construction sector between 2002 and 2018 (according to Table 2, the relative percentage is 462.81%).

Through the analysis of the research results, some specific energy policy implications can be made to contribute to play the role of China's construction sector in promoting energy conservation and emission reduction. First, although the direct energy consumption of the Chinese construction sector is less, the indirect energy consumption is large. Therefore, it is

imperative to improve the energy efficiency in the construction sector and reduce energy loss, which plays an important role in energy conservation and emission reduction. Second, the net inflows of energy to construction sector is from the other seven sectors. Additionally, the manufacturing sector is the largest energy supplier of the construction sector. Therefore, in order to reduce the energy consumption of the construction sector, the energy inflows from other sectors should be reduced. Among them, the manufacturing should be regarded as the key sector. Finally, the government should reasonably increase the investment in green technology innovation to encourage construction companies to reduce energy use and pollutant emissions.

This research provides a good opportunity to study the energy consumption relationship between the construction sector and other sectors in China. Nevertheless, the study is limited to the sectors in the economic system. Some discussions in terms of the Life Cycle Assessment for the kind of analysis conducted in this research will surely produce reliable outcomes for energy consumption linkages in the future research.

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