Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 105 (2017) 3132 – 3137

Energy Procedia

The 8th International Conference on Applied Energy – ICAE2016

Demand-driven primary energy requirements by Chinese economy 2012

Xue Qu[a], Jing Meng[b], Xudong Sun[a], Bo Zhang[a]*

[a] School of Management, China University of Mining & Technology (Beijing), Beijing 100083, P.R. China
[b] College of Urban and Environmental Sciences, Peking University, Beijing 1000871, P.R. China

Abstract

This study examines demand-driven primary energy requirements of the Chinese economy in 2012. The discrepancies and inter-linking paths of demand-driven energy uses via domestic supply chains have been identified. The total embodied energy uses (EEUs) in final demand amount to 3318.69 Mtce, of which investment contributes 45.97% to the total. All manufacturing sectors account for 45.75% of the total EEUs, followed by construction for 29.43% and services for 13.69%. By tracing embodied energy fluxes starting from resource extraction to final uses, several critical industrial sectors and crucial routes starting from resource extraction to final use are extracted and ranked. To develop more appropriate policy designs for energy saving and emission reduction in China, demand-driven embodied energy uses deserve to be considered from a systematic viewpoint.

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.

Keywords: Embodied energy; Input-output model; Structural path analysis; Domestic supply chains; Chinese economy

1. Introduction

Energy is one of the most crucial natural resources to sustaining socio-economic development [1]. China has recorded as the world's largest primary energy user since 2009, and the total primary energy consumption in 2014 amounts to 4.26 Billion tonnes of coal equivalent, about 2.90 times that of 2000 [2]. A holistic investigation of the country's primary energy use patterns in recent years becomes imperative to the policy makers [3].

Demand-driven energy requirement or embodied energy use (EEU) is defined as the total primary energy input to satisfy final demand, i.e., the direct plus indirect energy resources input through the

* Corresponding author. Tel.: +0186 62339315; fax: +0186 62339315.
E-mail address: zhangbo@cumtb.edu.cn.

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.
doi:10.1016/j.egypro.2017.03.675

production processes to produce the goods used for final demand [4]. By using an energy input-output model to connect the natural ecosystem with the socio-economic system, it is possible to identify how much primary energy resource supply for production can be attributed to a specific economic output throughout the whole supply chain [5, 6]. Previous studies have focused on energy embodiments in the economic activities at different scales by considering the inter-industry linkages between energy producers and energy users, such as China's primary energy uses embodied in final demand and trade [3-6]. Nevertheless, the embodied energy use paths from resource extraction to final use along with the industrial activities still remain unrevealed. Structural path analysis (SPA) can trace embodied energy fluxes starting from producers to consumers and extract the critical paths that drive embodied energy uses to satisfy different final demand categories throughout the supply chains [7]. This paper aims to illustrate the demand-driven primary energy requirements by Chinese economy 2012 and indentify the discrepancies and inter-linking paths of embodied energy uses via domestic supply chains, which will be useful to facilitate understanding China's potentials and pathways for energy conservation.

2. Methodology and data sources

2.1. Methods of input-output embodiment analysis

The basic row balance for China's economic input-output table can be expressed as [8],

$$X = AX + F - X^m \tag{1}$$

where X is the total output; A is the technology coefficients matrix; F is the final demand vector; and X^m is the imports. The import items are removed to isolate the domestic supply chain in China, and we assumed that each economic sector and domestic demand category utilize sectoral imports in the same proportions, referring to previous studies [7, 9]. Thus, new requirements coefficient matrices in which only domestic goods are included can be derived as,

$$A^d = (I - M)A \tag{2}$$

$$m_{ii} = \frac{X_i^m}{X_i + X_i^m - f_i^e} \tag{3}$$

where $M = diag(m_{ii})$, m_{ii} is the share of imports in the supply of products and services to each sector.

The new balance equations are shown as

$$X = Z^d + f^d + f^e = A^d X + f^d + f^e \tag{4}$$

where Z^d is the matrix of domestic intermediate demands; f^d is the vector of domestic final consumption; and f^e is the vector of domestic exports.

Rearranging Eq. (4) leads to following basic equations,

$$X = (I - A^d)^{-1}(f^d + f^e) = L^d(f^d + f^e) \tag{5}$$

where I is the identity matrix; $L^d = (I - A^d)^{-1}$ is the domestic Leontief inverse matrix.

According to Eq. (5), it is easy to formulate the total EEUs as

$$EEU = \varepsilon^d L^d(f^d + f^e) = \varepsilon(f^d + f^e) \tag{6}$$

where ε^d represents the direct primary energy input intensity; ε is the domestic EEU (direct plus indirect) intensity; εf^d is the domestic energy uses embodied in domestic final consumption; and εf^e is the domestic energy uses embodied in exports.

2.2. Methods of structural path analysis

To perform SPA for the embodied energy use paths, the revised Leontief inverse in Eq. (5) is expanded using Taylor series approximation as [7],

$$L^d = (I - A^d)^{-1} = I + A^d + (A^d)^2 + (A^d)^3 + \cdots + (A^d)^t \quad (7)$$

On the right-hand side of Eq. (7), each element in the expansion denotes a different production layer or tier. Thereafter, embodied energy uses in domestic final demands can be calculated as,

$$\varepsilon(I - A^d)^{-1} y = \varepsilon^d I y + \varepsilon^d A^d y + \varepsilon^d (A^d)^2 y + \varepsilon^d (A^d)^3 y + \cdots + \varepsilon^d (A^d)^t y \quad (8)$$

where $\varepsilon^d (A^d)^t y$ represents the contribution of energy uses from the tth production tier. The quantity of nodes in the production network increases exponentially with each tier. There are n^{t+1} nodes in each tier where t represents the tier and n is the number of industrial sectors in the economy. Detailed procedures to illustrate the process of SPA can be referred to Meng et al. [7].

2.3. Data sources

In this study, the latest input–output table for China 2012 compiled by the National Bureau of Statistics of China [8] is adopted, which covers 42 industrial sectors. The major primary energy inputs into Chinese economy include raw coal, crude oil, natural gas, hydro power, nuclear power and other renewable energy. The updated data of primary energy input are available from China Energy Statistical Yearbook 2014 [10]. The hydropower, nuclear power and other renewable energy inputs are estimated according to electricity generation data and corresponding electricity generation efficiencies. To keep the data consistency, the electricity generation efficiencies are all directly obtained from previous studies [3-6]. Totally, the domestic primary energy inputs into Chinese economy in 2012 are 3318.69 Mtce, of which raw coal accounts for 80.65% of the total, followed by crude oil & natural gas for 13.26% and other primary energy for 6.09%.

3. Results and discussions

3.1. Embodied energy use intensity

Fig. 1 presents the EEU intensity by sector in 2012 through a histogram. Evidently, Sector 2 (*Mining and Washing of Coal*) holds the largest EEU intensity of 1424.13 gce/CNY, far more than other sectors, of which 82.82% from its direct energy use intensity. Sectors 25 (*Production and Supply of Electricity and Steam*) and 3 (*Extraction of Crude Petroleum and Natural Gas*) also have high EEU intensities, with the value of 441.30 and 409.82 gce/CNY, respectively. Prominently, indirect energy use intensity dominates the EEU intensity of most industrial sectors, except for Sectors 2 and 3. Therefore, the estimation of energy uses in China's manufacturing, construction, utility and service sectors should take indirect energy into account.

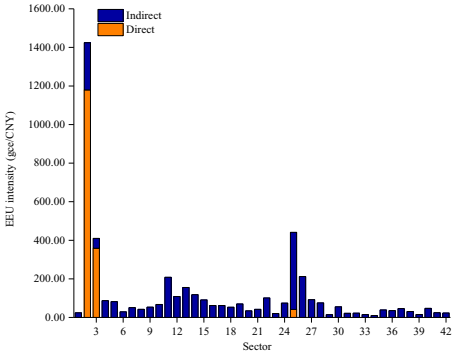

Fig. 1. Embodied energy use intensity by sector.

3.2. Embodied energy uses in final demand

Fig. 2 presents the sectoral EEUs in final demand in terms of different final demand categories. There are remarkable disparities on the EEUs among the 42 sectors. Sector 28 (*Construction*) has the largest EEU of 976.74 Mtce, accounting for 29.43% of the total EEU. Capital formation contributes to 99.4% of the EEU of this sector. As an important driver for maintaining China's economic growth [3], investment-driven construction activities need a great deal of direct and indirect industrial inputs (e.g., cement, electricity and metal products), which always result in increasing energy-intensive production and huge embodied energy requirements. Consumption is the important final demand category in the sectors which are closely linked with people's life such as Sectors 6, 1, 25-27 and most of the service industries. 62.27% of the EEUs in consumption can be attributed to urban household consumption, 17.53% to rural household consumption and 20.21% to government consumption, respectively. Obviously, per capita EEUs between urban and rural household consumption present a wide gap, considering that the urbanization rate is 52.57% in this year [2]. For most manufacturing sectors such as Sectors 7-20, the shares of exports in the sectoral EEUs are especially high, owing to China's exports of textile products, industrial raw materials, and primary machinery and equipment products [3, 5].

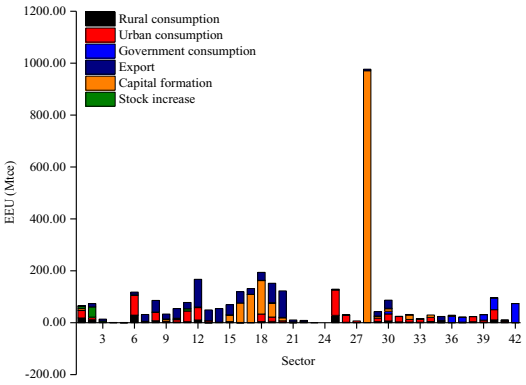

Fig. 2. Embodied energy uses in final demand by sector.

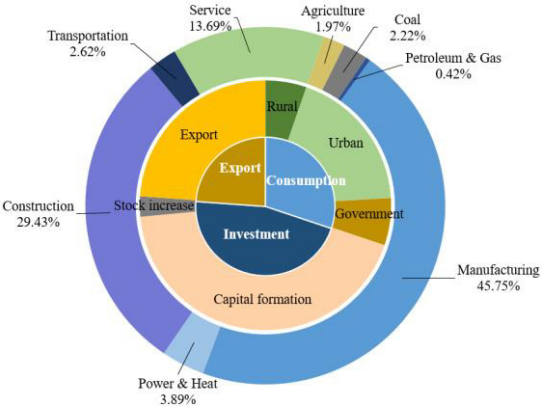

Fig. 3. Composition of the EEUs by final demand category (inner circle) or industrial sector (outer circle).

The EEU structures by Chinese economy are summarized in Fig. 3. In the composition of EEU inventories by final demand category (inner circle in Fig. 3), investment is the leading category (1528.74 Mtce, 45.97% of the total EEU), followed by consumption (1001.50 Mtce, 30.18%) and exports (791.75 Mtce, 23.85%), respectively. To reduce the complexity of the economic system, the original 42 sectors have been merged into eight broad categories (outer circle in Fig. 3): *Agriculture*, *Coal*, *Petroleum & Gas*, *Manufacturing*, *Power & Heat*, *Construction*, *Transportation* and *Service*. *Manufacturing* accounts for 45.75% of the total EEUs in final demand, followed by *Construction* for 29.43%, *Service* for 13.69% and *Power & Heat* for 3.89%. The remained three categories are responsible for only 7.23% of the total.

3.3. Tracing embodied energy uses via domestic supply chains

Table 1 presents the distribution of demand-driven primary energy requirements in the production tier along the supply chains. From the production perspective, the embodied energy fluxes can be traced to the three aggregated sectors consisting of *Coal*, *Petroleum & Gas* and *Power & Heat* related with direct

primary energy extraction. These sectors at the Tier 0 provide the primary energy to meet final demand directly, with the share of 82.82%, 87.52% and 9.39% of their respective total inputs. The EEU of *Manufacturing* appears to be evenly distributed across the production tiers, mainly due to its complex economic relationships among different industrial sectors. In the *Service* sector, most of the EEUs occur at the third and higher tiers, and the EEUs of *Transportation* and *Agriculture* are concentrated on Tier 2 and other higher tiers with a similar structure in sectoral contribution. As to the *Power & Heat* sector, primary energy inputs can be mainly attributed to Tier 1, accounting for 48.34% to its total EEUs, and Tier 2 and all the other tiers contribute the remained half.

Table 1. Distribution of induced direct primary energy inputs in the production tier along the supply chain.

Aggregated sector	EEU (Mtce)	Attribution of direct primary energy inputs						
		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5→∞	Total
Agriculture	65.39	0.00%	2.00%	27.85%	23.62%	17.03%	29.50%	100.00%
Coal	73.76	82.82%	12.27%	2.62%	1.00%	0.53%	0.76%	100.00%
Petroleum & Gas	13.95	87.52%	1.47%	4.38%	2.82%	1.59%	2.22%	100.00%
Manufacturing	1518.27	0.00%	13.49%	19.64%	21.04%	16.36%	29.48%	100.00%
Power & Heat	129.24	9.39%	48.34%	23.80%	9.80%	4.23%	4.44%	100.00%
Construction	976.74	0.00%	1.10%	28.99%	25.95%	17.44%	26.52%	100.00%
Transportation	86.90	0.00%	2.58%	47.17%	19.67%	11.32%	19.26%	100.00%
Service	454.43	0.00%	4.50%	21.92%	23.55%	17.49%	32.53%	100.00%

After extracting and ranking individual critical supply chain, Table 2 lists the 10 top-ranking paths through which the final demands drive the production processes, representing approximately one third (33.48%) of the EEUs. The path of '*Capital formation→ Construction→ Manufacture of Nonmetallic Mineral Products→ Mining and Washing of Coal*' contributes the largest share of 11.65%. Four of the top ten ranking paths are associated with *Construction* related activities. In addition, *Production and Supply of Electricity and Steam* is responsible for three of the high-ranking paths. *Manufacture and Pressing of Metals* appears in three top ranking paths.

Table 2. The ten top-ranking paths for EEUs starting from a final demand and ending with a consuming sector.

Rank	Tier	Contribution (%)	Path
1	2	11.65	Capital formation→ *Construction→ Manufacture of Nonmetallic Mineral Products→ Mining and Washing of Coal*
2	2	6.74	Capital formation→ *Construction→ Manufacture and Pressing of Metals→ Mining and Washing of Coal*
3	2	2.24	Capital formation→ *Construction→ Production and Supply of Electricity and Steam→ Mining and Washing of Coal*
4	1	2.11	Government consumption→ *Health Care and Social Work Activities→ Production and Supply of Electricity and Steam*
5	1	2.11	Urban consumption→ *Production and Supply of Electricity and Steam→ Mining and Washing of Coal*
6	1	1.96	Export→ *Manufacture of Chemical and Chemical Products→ Mining and Washing of Coal*
7	2	1.86	Export→ *Manufacture of Electrical Machinery and Apparatus→ Manufacture and Pressing of Metals→ Mining and Washing of Coal*
8	0	1.67	Capital formation→ *Manufacture of Transport Equipment*

9	2	1.67	Capital formation→ *Construction*→ *Manufacture of Chemical and Chemical Products*→ *Mining and Washing of Coal*
10	2	1.47	Capital formation→ *Manufacture of Transport Equipment*→ *Manufacture and Pressing of Metals*→ *Mining and Washing of Coal*

4. Conclusions

This study uses input-output analysis and structural path analysis to reveal demand-driven primary energy requirements by Chinese economy 2012 and trace the sectoral energy uses throughout domestic supply chains. Indirect energy use intensity dominates the embodied energy use (EEU) intensity of most industrial sectors. The total EEUs amount to 3318.69 Mtce, of which investment contributes 45.97% to the total. After examining all the embodied energy fluxes along domestic supply chain, several critical industrial sectors such as *Construction*, *Production and Supply of Electricity and Steam* and *Manufacture and Pressing of Metals*, and crucial routes such as 'Capital formation→*Construction*→*Manufacture of Nonmetallic Mineral Products*→*Mining and Washing of Coal*', are extracted and ranked. Since China's demands for energy resources will continue to increase along with its rapid economic development, it is critical to examine demand-driven energy requirements and explore the energy uses embodied in domestic and even global supply chains, so that more appropriate policy designs for energy saving and emission reduction can be achieved by considering the hidden socio-economic driving factors.

Acknowledgements

This study has been supported by the National Natural Science Foundation of China (Grant no. 71403270) and the Research Fund of Chinese Academy of Engineering (Grant no. 2016-XY-19).

References

[1] Chow J, Kopp RJ, Portney PR. Energy resources and global development. Science 2003; 302:1528-31.

[2] CSY. China Statistical Yearbook 2015. Also available at: http://www.stats.gov.cn/tjsj/ndsj/2015/indexch.htm.

[3] Zhang B, Chen ZM, Xia XH, Xu XY, Chen YB. The impact of domestic trade on China's regional energy uses: a multi-regional input–output modeling. *Energ Policy* 2013;63:1169–81.

[4] Chen ZM, Chen GQ. Demand-driven energy requirement of world economy 2007: A multi-region input–output network simulation. *Commun Nonlinear Sci Nume Simular* 2013;18:1757-74.

[5] Zhang B, Qiao H, Chen ZM, Chen B. Growth in embodied energy transfers via China's domestic trade: Evidence from multi-regional input–output analysis. *Appl Energ* 2015,doi:10.1016/j.apenergy.2015.09.076.

[6] Zhang B, Qiao H, Chen, B. Embodied energy uses by China's four municipalities: a study based on multi-regional input–output model. *Ecol Model* 2015;318:138-49.

[7] Meng J, Liu J, Xu Y, Tao S. Tracing Primary $PM_{2.5}$ emissions via Chinese supply chains. *Environ Res Lett* 2015;10:1748-9326.

[8] National Bureau of Statistics of China. 2012 Input–Output Tables of China. China Statistics Press, Beijing; 2015.

[9] Zhang B, Chen ZM, Qiao H, Chen B, Hayat T, Alsaedi A. China's non-CO_2 greenhouse gas emissions: Inventory and input–output analysis. *Ecol Inform* 2014;26:101-10.

[10] CESY. China Energy Statistical Yearbook 2014. China Statistics Press, Beijing; 2015.