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Interregional trade among regions of urban energy metabolism: A case study between Beijing-Tianjin-Hebei and others in China

Hongmei Zheng[a], Xinjing Wang[a], Mingjing Li[a], Yan Zhang[a,*], Yachun Fan[b]

[a] *State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Beijing Normal University, Xinjiekouwai Street No. 19, Beijing 100875, PR China*

[b] *College of Information Science and Technology, Beijing Normal University, Xinjiekouwai Street No. 19, Beijing 100875, PR China*

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ABSTRACT

Interregional trade of energy exchanges from urban metabolism perspective fills the gap of regional disparity due to economic development, physical geography, and lifestyle. The integrated development of Beijing-Tianjin-Hebei (Jing-Jin-Ji) urban agglomeration results in actors changes of the three provinces (or municipalities) between provider or receiver from 2002 to 2010, meanwhile, to treat them as Jing-Jin-Ji region, the energy transfer with other seven regions in China also changed. This research will analyze energy flows between Jing-Jin-Ji agglomeration and other regions in China from two perspectives: first, treat Beijing-Tianjin-Hebei as a whole, and to trace the energy processes among Jing-Jin-Ji region and other seven regions; second, see Beijing, Tianjin, and Hebei as three and to analyze the energy exchanges among them three and also the exchanges with other 27 provinces. Each perspective includes the energy exchanges through direct, indirect, and integral processes from 2002, 2007, and 2010. The results show that the flow through multiple paths from the Northern region accounts for more than 25% of total input throughflow from other seven regions, and the Eastern region receives the highest flow and takes a proportion more than 31% of total output throughflow. The flow through multiple paths among Beijing, Tianjin, and Hebei has changed since 2007 due to the industrial restructuring in 2007. After comparing the path flow through one path and multiple paths at two levels, the regional analysis shows the directions of energy flows between Jing-Jin-Ji and other regions, furthermore, the provincial level reflects the details within the region.

1. Introduction

The unbalanced economic development in China results in frequent trade among regions or provinces in China (Zhang et al., 2015b). Meanwhile, as the industrialization and urbanization are increasing rapidly, urban agglomeration has become one kind of core area for regional economic development (http://city.ce.cn/news/201510/13/t20151013_2940863.shtml). The total area of Beijing-Tianjin-Hebei (Jing-Jin-Ji) region accounted for 2.30% in China, and the proportion of population was 7.23%, but its GDP took an account of 10.2% in 2015. Furthermore, the capital transferred through trade among the three provinces (or municipalities) increased from 2002 to 2010, taking an average growth of 15% each year. However, the capital output from Beijing to Tianjin and Hebei decreased, the decreasing proportion were 4% and 6% for each year, separately. This increase or decrease trend will cause the quantity of energy consumption or carbon emission which embodied in transferring commodities also changed. Under this circumstance, it is a hot topic that how the trade within Jing-Jin-Ji region influence the corresponding energy flows. Otherwise, Jing-Jin-Ji region is an area with limited energy resources that cannot meet its own requirement, to be specific, Beijing needs to input physical capital from other provinces outside Jing-Jin-Ji region, Tianjin is a port in the Northern area and the input and output with other regions in China, or import and export with areas outside China are its center for economy, and Hebei mainly runs goods trade with others. Therefore, not only the interregional trade within Jing-Jin-Ji regions, but these three provinces with others in China are contributed to fill the gap of regional disparity. In summary, the two aims for this research are, firstly figuring out how other regions in China support the development of Jing-Jin-Ji region; secondly, illustrating the interactions among Beijing, Tianjin, Hebei, and also with other 27 provinces in China when exchanging resources.

Urban energy metabolism includes processes for exploiting, transforming, and consuming energy, as well as processes for recycling by-products and wastes (Zhang et al., 2010). Current analysis of urban energy metabolism typically focuses on a single city or several cities in one region. Then urban energy metabolism extended to the level of

* Corresponding author.
E-mail address: yzhang@bnu.edu.cn (Y. Zhang).

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urban agglomeration (Zhang et al., 2016b; Baynes and Bai, 2012; Garcia-Montiel et al., 2014). Baynes and Bai (2012) analyzed Melbourne region in Australia from urban metabolism perspective, firstly they conducted calculation of primary energy, and then extended the results to a lone time span, and attribute upstream primary energy consumption to sectors based on the direct secondary energy use. Garcia-Montiel et al. (2014) illustrated how the socio-ecological processes in San Juan metropolitan area of Puerto Rico influence the energy flows within the region. Zhang et al. (2016b) chose Jing-Jin-Ji region as a case study, when tracing energy metabolic processes, they accounted for the energy flows among sectors within each city or province in Jing-Jin-Ji region, and also the flows among sectors in different provinces (or municipalities). In addition, their results explained the energy utilization structure of this sectors and cities as well.

Embodied energy is the total energy consumed during the whole production processes (Lenzen, 1998), and it includes direct energy and indirect energy. Indirect energy is unphysical energy that embodied in the by-products, products, or service exchanges from upstream steps. Multi-regional input-output analysis has been used to account for embodied resources among different regions, it represents the economic flows among sectors not only within one region, but also between different regions (Zhang et al., 2013). This method quantifies exchanges among sectors from economic perspective, reflects the interactions between sectors when trading resources, and traces resource flows among regions caused by one region's consumption activities (Wiedmann, 2009; Wiedmann et al., 2007). It was firstly used to analyze economic flows among sectors in Italy or America (Polenske, 1980). And now the multi-regional input-output analysis has been used in the analysis of materials footprint (Wiedmann et al., 2015), pollution emission related to air quality, such as black carbon (Li et al., 2016), atmospheric mercury (Liang et al., 2014), particulate matter (Yang et al., 2015), or carbon emission (Tian et al., 2014), and also energy consumption (Liang et al., 2007). In energy analysis, Liang et al. (2007) divided China into eight administrative regions based on the data in 1997, accounted for and compared the embodied energy consumption of all these regions from final consumption perspective, and also predicted their energy consumption in 2010 and 2020. Based on the same method, Cui et al. (2015) studied energy flows caused by trade between China and other counties using the data from Global Trade Analysis Project. Li et al. (2014) compared the embodied energy trade flows from the perspectives of production and consumption as the regional disparity in China. Then, some analysis combined system ecology and input-output analysis, they stated that besides direct energy in form of physical fuel consumed by countries or the sectors within the countries, the production processes need the indirect energy embodied in the exchanges among sectors. These helped establish an equilibrium describing economic or energy flows among sectors. Chen and Chen (2013) constructed a network model with 6384 nodes to account for the proportion of energy sources in global embodied energy consumption, the directions of energy flows, and finally chose five countries to discuss the contributions of all their sectors. Chen (2011) specified 29 sectors in each of the 30 provinces and cities in China, calculated the embodied energy consumption from final consumption aspect, also the input, output and net embodied energy of them. Zhang et al. (2013, 2016a) analyzed the embodied energy consumption of 30 sectors in Chinese 30 provinces or cities. However, when combining system ecology to conduct embodied energy flow accounting among regions or countries, they used the embodied energy coefficient from output region multiplying the quantity of input energy, but did not quantify the energy flows through multiple paths among sectors or regions.

Flow analysis in ecological network analysis can assess the integral flows among nodes in the network model, and analyze the contribution of each node (Lu et al., 2014; Zhang et al., 2016b). Combining multi-regional input-output table and ecological network analysis is effective to calculate the indirect energy embodied in the exchanges among sectors. Otherwise, ecological network analysis also fulfills the structural and functional characteristics of sectors. Chen and Chen (2015) compared material flow analysis, input-output analysis and ecological network analysis when analyzing urban energy metabolic processes, and they stated that ecological network analysis can indicate the mechanism of sectors among their interaction. The combination of input-output table and ecological network analysis has already been used to study the ecological element, energy, and carbon footprint in single city, urban agglomeration, and country (Zhang et al., 2014a,b, 2015b, 2016b). Based on the traditional input-output analysis of Li et al. (2014), some research introduced ecological network analysis to account for energy-water nexus in urban systems, Chen and Chen (2016) took Beijing as an example, Wang and Chen (2016) studied Beijing-Tianjin-Hebei agglomeration. Although they used control analysis in ecological network analysis, they did not quantify the direct or indirect energy or water flows among sectors or regions. Zhang et al. (2014a) based on the resource flows between any two sectors (the input and output processes) and with external environment to establish an equilibrium equation. They converted the monetary input-output table into a physical table with resource flows among sectors in Beijing from 1997 to 2007. The calculation of direct, indirect, and embodied ecological elements helped to evaluate the resource distribution within the system. Then, Zhang et al. (2014b) discussed embodied energy consumption and carbon footprint of 28 sectors in Beijing from 2000 to 2010, and proposed energy reduction and carbon emission policies for future. This method has been extended to the levels of urban agglomeration (Zhang et al., 2016b) and provinces (Zhang et al., 2015b). However, current research are mainly on one level, such as city, region, or country, instead of combining two levels.

This research chooses Jing-Jin-Ji urban agglomeration as case study, and conducts at two levels, firstly, treats Jing-Jin-Ji region as a whole, this region will be divided from the Northern region which is named by the administrative division, to analyze the energy flows between Jing-Jin-Ji region and other regions in China; secondly, sub-divides Jing-Jin-Ji region, to see Beijing, Tianjin, and Hebei as three separate city or province, traces energy flows between each of them with the other 27 provinces or cities in China. Both of the two levels will be discussed from path flow and node flow. At regional level, the Jing-Jin-Ji is one node in the network model, and at provincial level, Beijing, Tianjin, and Hebei are three nodes. The supplementary analysis between regional and provincial levels not only indicates the energy flows between Jing-Jin-Ji urban agglomeration and other regions, but also presents the heterogeneity of the two cities and one province within the agglomeration. This paper will reflect the dependence of the urban agglomeration on other regions in China and the independence within the agglomeration comprehensively.

2. Method

To combine multi-regional input-output analysis with ecological network analysis can not only account for the energy consumption embodied in the exchanges of commodities through one path or multiple paths among sectors in one city, and the sum of all these indirect energy consumption is equal to the integral energy in this research (the integral energy consumption in this research plus the direct energy consumption for each sector that consumes the energy in the form of various forms of physical fuel is the embodied energy), in this study, two terms have been proposed, **the path flow** means the flow among sectors through one path or more than one path (multiple paths), and **the node flow** is the sum of the flows through one path and multiple paths, it equals to the total indirect energy flow into one sector; but also reflect the relationships or actors of different sectors in the same system (Zheng et al., 2017). These advantages could fully be used to achieve our goal that are to calculate the energy flows through one path and multiple paths among sectors, and to analyze the receiver or provider between Jing-Jin-Ji region and other regions in China or even within Jing-Jin-Ji region. To conduct our analysis, based on the monetary