https://doi.org/10.1016/j.jclepro.2017.05.200

Examining industrial structure changes and corresponding carbon emission reduction effect by combining input-output analysis and social network analysis: A comparison study of China and Japan

Zhaoling Li [a] , Lu Sun [b, c] , Yong Geng d, e, * , Huijuan Dong d, **, Jingzheng Ren f , Zhe Liu g, Xu Tian d , Helmut Yabar a , Yoshiro Higano a

[a]Graduate School of Life and Environmental Sciences, University of Tsukuba, Tsukuba, 305-8577, Japan

[b]Graduate School of Frontier Sciences, The University of Tokyo, Kashiwa, 277-8563, Japan

[c]National Institute for Environmental Studies, Tsukuba, 305-8506, Japan

[d]School of Environmental Science and Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China

[e]China Institute for Urban Governance, Shanghai Jiao Tong University, Shanghai, 200030, China

[f]Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hong Kong Special Administrative Region

[g]School for Resource and Environmental Studies, Dalhousie University, Halifax, B3H 4R2, Canada

[*]Correspoding author. School of Environmental Science and Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China.

[**]Correspoding author. School of Environmental Science and Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China.

E-mail addresses: ygeng@sjtu.edu.cn (Y. Geng), donghj@sjtu.edu.cn (H. Dong).

Abstract: Industrial structure adjustment is one solution for responding economic slowdown and environmental problems occurred during China's rapid industrialization. Such an adjustment may also lead to carbon emission reduction since it encourages industrial innovation and resource efficiency. However, few studies have been conducted on examining the effect of industrial structure adjustment on carbon emission reduction. Under such a circumstance, this study develops an integrated evaluation model based on Input-Output Analysis and Social Network Analysis to quantify the evolutionary trends of industrial structure, demonstrate the inner-relationship between different sectors and investigate the industrial structure-related carbon emissions. China and Japan were selected as case study countries. Results show that industrial structure was gradually improved in China and various connections were established betweenness different sectors. For Japan, the industrial network densities were lower than for China and exhibited a downward trend that reflected the weakened relationship between different industries. Service sectors dominated the Japanese economy, as shown by the relatively higher degree centrality and between centrality of service sectors. The electricity and heat production sector was further investigated to illustrate the industrial structure-related carbon emissions. Finally, this study concluded that compared to the industrial structure features in a developed country, such as Japan, China's industrialization is still in its infancy. Thus, it is crucial to prepare industrial structure adjust policies so that the overall social-economic performance can be improved.

Keywords: Input-output analysis; Social network analysis; Industrial structure ; Carbon emissions ;China

1 Introduction

Industrial structure reflects the complex relationship or connected between different industrial sectors and the impact of each industry on the whole industrial network. After decades of industrialization, China's industrial structure has been improved greatly and the proportions of secondary and tertiary industry have also increased quickly. However, China still produces many low value-added products, indicating that China's industrial structure is still at the low-end in the whole value chain (Zhao, 2011). Moreover, rapid industrialization and urbanization also brought many environmental problems, such as air and water pollution, solid wastes and climate change (Dong et al., 2013a, 2014a). Thus, it is critical to seek solutions so that these concerns can be addressed. Industrial structure adjustment aims at optimizing the proportions and relationships of different industrial sectors and can help improve resource utilization and mitigate the overall environmental emissions (Cui and Yang, 1998; Zhang and Deng, 2010). It can contribute to economic recovery and address environmental concerns and should be promoted (Chang, 2015; Zhang and Deng, 2010; Zhou et al., 2013).

Many studies on industrial structure adjustment have been done. From methods point of view, several studies explored the dramatic industrial structure changes by calculating the GDP contribution rates. For example, Lu and Deng (2011) evaluated the industrial structure of China's western provinces by considering GDP growth and financial investment. Cluster analysis is also employed to further understand the spatial concentrations of industrial structure, such as hierarchical cluster analysis (Liang et al., 2013), industrial-complex model (Gordon and McCann, 2000), and K-means algorithm (Cui et al., 2013). However, these methods cannot fully reflect the complex economic or material connections between different industrial sectors. From industrial sectors point of view, previous studies focused mainly on three major industries, namely, primary industry (agriculture), secondary industry (manufacturing) and tertiary industry (service). For instance, Cui et al. (2013) evaluated the industrial structure of Hebei and its 11 cities according to the ratios of three major industries. Zhang et al. (2014) found that industrial structure change by improving the share of tertiary industry in the total GDP could curb carbon emissions. However, these studies can only provide partial assessment, unable to provide more detailed policy suggestions for making regional or national development plans.

The rapid growth of carbon emissions is another serious problem in China. Current studies mainly highlight the effect of economic growth and other key driving forces, such as population scale and land use changes (Tian et al., 2014). Industrial structure has only been used as one impact factor in the decomposition analysis studies to evaluate the contribution to carbon emission intensity changes (Liu et al., 2007, 2012; Sun et al., 2015a). The direct causal relationship between industrial structure and carbon emissions has not been adequately analyzed. Under such a circumstance, it is necessary to conduct industrial structure studies at the sector level to identify the importance of each sector in the whole industrial network and interactions between different sectors. Also, the quantitative analysis on the carbon reduction effect induced by industrial structure changes needs to be further investigated (Mi et al., 2015). Moreover, it’s rational to carry out a comparison study between one developed country and one developing country so that more experiences can be shared.

Aiming to fill these research gaps, this study combines a social and behavioral analysis method, a social network analysis method (SNA), and an input-output analysis method to investigate the industrial structure evolution and assess industrial structure-related carbon emissions.1 China and Japan are selected as the reference countries because of their close economic ties. The structure of this paper is organized as below. After this introduction section, section 2 depicts research methods and data sources. Section 3 presents the research results. Section 4 provides policy implications and section 5 draws research conclusions.

2 Methods and data sources

2.1 The combined SNA-IO model

Social Network Analysis (SNA) is a normative method to analyze the social relationship, structure and resource liquidity between different actors within one network (Wasserman and Faust, 1994; Scott, 2012). It has been widely used in social and behavioral sciences, including virtual community (Albert et al., 1999; Chen and Ting, 2013), biological areas (Williams and Martinez, 2000; Kwait et al., 2001) and forest research (Fuller et al., 2008; Harris et al., 2008). SNA has also been applied in the field of industrial ecology because it can facilitate the operation of industrial symbiosis networks by combining the impact of both economic and environmental aspects and focusing on the network structure morphology, interaction patterns and the effects on the outcomes of the collaboration (Chertow, 2007; Domenech and Davies, 2009). On the other hand, unlike material flow analysis, carbon footprint, water footprint and industrial symbiosis, SNA method is not limited to explore the connection of sectors on one industrial chain. It’s more suitable for regional and national studies. For example, Wei et al. (2012) applied SNA to investigate industrial restructuring based on cross-region mergers and acquisitions. Domenech and Davies (2011) applied this method to investigate the industrial symbiosis network in

Kalundborg of Denmark, one of the most famous industrial symbiosis cases in the world.

The input-output analysis can reveal the complex inter dependency and mutual relationships between different industrial sectors connected by departmental monetary transactions (Dong et al., 2016). However, it is difficult to evaluate the industrial structure at the macro scale and cannot help judging the status of one industrial sector in the entire network. Therefore, the integration of input output analysis and SNA can not only provide a theoretical and methodological framework for understanding industrial networks but also reveal the inner structure of the industrial network and evaluate the position of each member and the financial connection between them (Domenech and Davies, 2011)

The construction process for the combined IO-SNA model is shown in Fig.1. First, the Chinese input-output tables for the years of 2002, 2007 and 2012, and the Japanese input-output tables for the years of 2000, 2005 and 2011 were collected due to their public availability. To reconcile the different separation criteria between China and Japan, more than 100 industrial sectors in the national Input-Output tables were merged into 37 sectors (Table 2). Second, the model was divided into two parts. One part is the industrial structure evaluation using the SNA method. The input-output relationships or the capital flows between different sectors were taken as the edges of the network. The “Small World” theory is the basis for testing the model’s feasibility. If the industrial structure follows this theory, then the model analysis could be continued. If not, then the model fails. The second part of the model is an environmental impact evaluation by using the EIO-LCA method to calculate the industrial structure-related carbon emissions. Third, the industrial structure-related carbon emissions, network density, average distance, degree centrality and between centrality obtained from the second step are used as the key indicators for evaluating the social relationship between different sectors and their effects on the entire network. Finally, the industrial evolutionary features can be fully revealed by this model. Given the directivity of capital flow, the industrial network is considered as a directed network. To avoid the enclosed ring case, the intermediate input of each node to itself is removed.

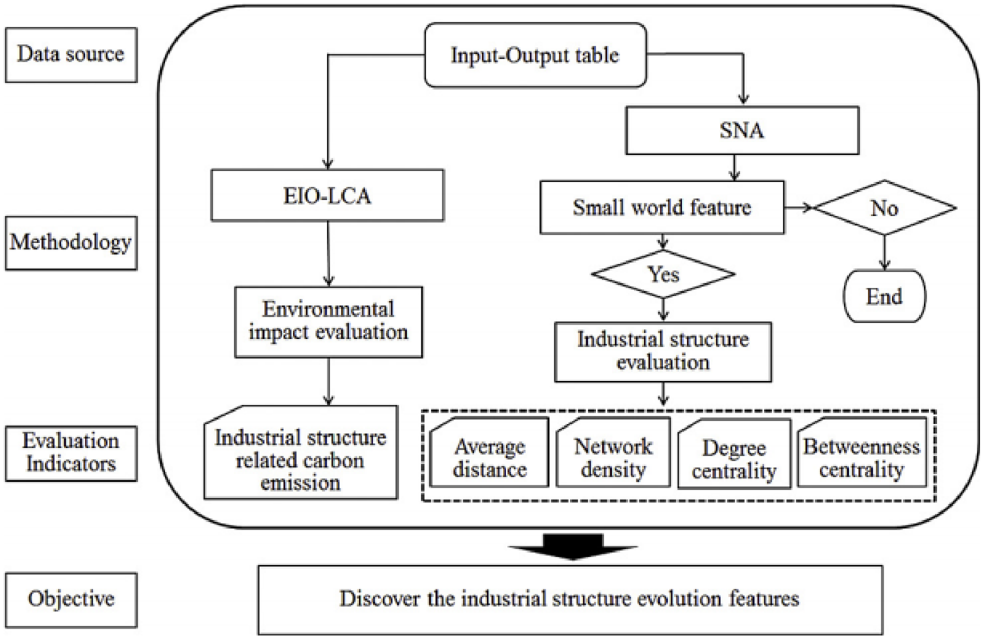

Fig.1. Research framework of the hybrid SNA-IO Model.

2.1.1 Feasibility analysis

Small-world characteristics are a necessary prerequisite for the application of SNA, which is defined as a network in which the typical distance between two randomly chosen nodes (the number of steps required) grows proportionally to the logarithm of the nodes number in the network (Luo, 2005; Wall and Knaap, 2007; Watts and Strogatz, 1998). In another word, a network with a short average distance and a high clustering coefficient between two nodes can be called a "small world network" (Watts, 1999; Sun et al., 2014). The average distance means the average shortest distance between two nodes in the network, and can be used to evaluate the transmission efficiency (Luo, 2005). The average distance can be calculated as:

$$B = \frac{\sum_{i \neq j} b_{ij}}{n(n-1)} \quad (1)$$

Where n is the number of nodes in the network, and b_{ij} is the shortest distance between node i and node j.

The clustering coefficient is separated into the node clustering coefficient and the network clustering coefficient. The former means the proportion of actual edges between one industry node and its neighbors, accounting for the maximum possible edges. The latter represents the average clustering coefficient value of each node. The larger the clustering coefficient is, the closer association between two nodes. These two indexes are used to show the subgroup integrated degree of the actors in the network, which can be obtained by

$$C_i = \frac{V_m}{m_i(m_i - 1)/2}; \quad C = \frac{1}{n}\sum_{i=1}^{n} C_i \quad (2)$$

where C_i is the clustering coefficient of node i, C is the network clustering coefficient, V_m is the number of edges among mi nodes (excluding i), m_i is the number of nodes adjacent to node i, and $m_i(m_i\text{-}1)/2$ is the maximum possible number of edges between m_i nodes.

2.1.2 Network density

Network density means the ratio of the actual connected number of the potential maximum connected number between the network nodes. A higher density indicates a closer relationship between industries and higher profits. In contrast, a lower density indicates an exiguous relationship and a lower degree of linkage within the industry network. The formula for the calculation of the network density is

$$D = \frac{T}{n(n-1)} \quad (3)$$

where T is the actual connected number, n is the number of nodes in the network, and $n(n-1)$ is the potential maximum connection of the industrial network.

2.1.3 Centrality

Centrality reflects the importance of one industry within the entire network. It can be further classified into degree centrality and between centrality.

(1) Degree centrality

Degree centrality means the boundary amount that connects to one node. The more direct connections, the more important a position that the node occupies, which can also be termed as “in the central”. That is, if one sector has more connections with other sectors, it is usually considered as prominent or having high prestige. At the same time, this sector will have a dominant position and a priority right in the industrial network. Due to the directivity of the connection that indicates “who gives what to whom”, degree centrality can be separated into in-degree and out-degree. The in degree of node i measures the material input from other sectors to i; the out-degree of node i reflects the material output from node i to other sectors (Hanneman and Riddle, 2005; Sun et al., 2015b). If the direction does not play a role during the analysis then it can be ignored, and the network is undirected. A disconnection between any of these nodes may cause a serious disturbance to network operation and lead to fragmentation. This principle indicates that the industrial network can be strengthened by increasing the connection pathways between the nodes, especially nodes that have weak connections with others.

We apply the weighted out-degree and in-degree of node i for the next step analysis, calculated as follows:

$$Weighted\ \ out-\deg ree: E_{out(i)} = \frac{\sum_{j=1}^{n} x_{ij}}{n-1} \qquad (4)$$

$$Weighted\ \ in-\deg ree: E_{in(i)} = \frac{\sum_{j=1}^{n} x_{ji}}{n-1} \qquad (5)$$

$$Weighted\ \ \deg ree\ \ Centrality: E_{(i)} = \frac{E_{out(i)} + E_{in(i)}}{2} \qquad (6)$$

where n is the number of nodes in the network, x_{ij} is the connections from node i to j, and x_{ji} is the connections from node j to i.

(2) Betweenness centrality

Betweenness centrality measures the ability to pass information and to ensure the cohesiveness of a node. If a node with high betweenness centrality changes its development direction and gives up its mediating role, the indirect connection between the upstream and downstream industries will break and a new partnership is difficult to form in the short term. Therefore, the industrial network may be paralyzed (Lv and Fu, 2010). Thus, a higher betweenness centrality of an industrial sector indicates a larger impact on the overall network. Betweenness centrality is calculated as follows:

$$F_i = \frac{\sum_{j}^{n}\sum_{h}^{n} g_{jh}(i)}{\left(n^2 - 3n + 2\right)/2} \qquad (7)$$

where $g_{ih}(i)$ is the number of the shortest pathway between industries j and h through industry i; $j \neq h, h \neq i, j < h$.

2.2 Carbon emissions calculation

The fuel types considered in this study are consistent with the categories defined in the China Energy Statistical Yearbooks. The corresponding GHG emissions are calculated according to the IPCC national GHG inventory guidelines. Following China's national GHG inventory, this study only considered three kinds of GHG emissions (i.e., carbon dioxide, methane and nitrous oxide) and converted them to carbon dioxide equivalents (CO_2e) (IPCC, 2006; Liu et al., 2012). The energy-related CO_2 emissions in sector i are based on energy consumption, carbon emissions factors and the fraction of oxidized carbon by fuel. The equation is as follows:

$$E_{ci}^{d} = \sum_{j} C_{ij} EF_j O_j M \quad (8)$$

where E_{ci} represents the CO_2 emission in sector i, the subscript i represents the energy consumption sectors, the subscript j is the fuel type, C_{ij} is the consumption of fuel j by sector i (TJ), EF_j is the CO_2 emission factor of fuel j (tC/TJ), O_j is the oxidation rate of fuel type j, and M is the molecular weight ratio of carbon dioxide to carbon (44/12). Similar methods are used in the CH_4 and N_2O emission calculations.

The carbon emission intensity is the average carbon emissions rate per unit of GDP. This indicator allows the carbon emissions in different years and different regions to be compared, facilitating the characterization of emissions changes. The carbon emission intensity can be calculated by:

$$r_{Ci} = \frac{E_{Gi}^{d}}{GDP_i} \quad (9)$$

where r_{ci} is the carbon emission intensity in industry i which indicates the environmental impact of sector i, E_{Gi} is total direct GHG emissions in industry i (tons) including CO_2, CH_4, and N_2O, and GDP_i is the added value of industry i

(USD).

Each sector has a double attribute in the industrial network. On the one hand, one sector needs raw material and services from upstream sectors; on the other hand, its products and services can be used as raw materials by downstream industries. Carbon emissions in each sector can also be considered from these two aspects. The Economic Input-Output Life Cycle Assessment (EIO-LCA) proposed by Hendrickson et al. (1998) can help follow the carbon flow track between different industrial sectors. It has been widely used in environmental studies including greenhouse gas accounting (Zhao et al., 2012). The conversion relationships are listed below.

$$X = \left(I + A + A^2 + A^3 + \ldots\right)Y = \left(I - A\right)^{-1} Y \qquad (10)$$

$$E_G^i = \hat{R}\left(I - A\right)^{-1} \hat{Y} \qquad (11)$$

where X is the total production of each sector (column vector), I is the unit matrix, A is the direct requirements coefficient, $A = \left\{a_{ij}\right\}$, Y is a column vector of the final demand, E_G^i means the indirect GHG emission matrix, $E_G^i = \left\{e_{ij}\right\}$, and $\hat{R}$ denotes the diagonal matrix of carbon emissions intensity, $R = \left(r_{c1}, r_{c2}, \ldots, r_{cn}\right)$.

$$\mathrm{e}_i = \left\{e_{ij}\right\}\left(i = 1, 2, \ldots, n; j = 1, 2, \ldots, n\right) \qquad (12)$$

$$\mathrm{e}_j = \left\{e_{ij}\right\}\left(i = 1, 2, \ldots, n; j = 1, 2, \ldots, n\right) \qquad (13)$$

where $\sum e_i$ is carbon emissions in production process, which can also be termed as the production perspective carbon emissions of industry i, $\sum e_j$ is the consumption perspective carbon emissions of industry j, which means the carbon emissions hidden in the raw material that comes from upstream.

Carbon sources of each industry can be characterized by consumption perspective carbon emissions which would indicate the actual environmental impact and responsibility of each industry (Mozner, 2013). By comparing the carbon source changes, the industrial structure-related carbon emissions can be found.

Data source comes from the Chinese Energy Statistics Yearbook (NBSC), Agency for Natural Resources and Energy of Japan and IPCC 2006. Several parameters used in the carbon emissions calculations refer to the research of Liu et al. (2012) and Geng et al. (2013b).

3 Results

3.1 Comprehensive evaluation of the industrial network in China and Japan

As one of the largest developing countries, China's economy has experienced rapid development during the last three decades. The average distance between different industrial sectors in China is getting closer decreasing from 1.057 to 1.037 during the research period (Table 1). This suggests that one industry in the network will access to another one by passing 1.057-1.037 industries. The rapid development of eco-industrial parks, where products and waste produced in one factory can be utilized by another, are one of the important reasons for the closer distances between industries in China. The distance-based cohesiveness (i.e., larger values indicate greater cohesiveness) of the industrial association network of China during 2000-2012 correspondingly increased from 0.926 to 0.982, which means that the actual number of edges (or direct connections) between industrial nodes with their neighbors occupy 91.4%-97.8% of the maximum possible number of edges. The increasing network density confirms the closer association of the industrial network from an overall point of view.

Table 1 Comprehensive evaluation index of the industrial structure in China and

Japan

	China			Japan		
	2002	2007	2012	2000	2005	2011
Average distance	1.057	1.044	1.037	1.133	1.148	1.177
Distance-based cohesiveness	0.926	0.978	0.982	0.908	0.901	0.911
Clustering coefficient	0.865	0.799	0.746	1.013	0.999	0.943
Density	0.898	0.956	0.963	0.844	0.829	0.823

Japan is the most developed country in Asia. However, its economic growth has slowed down in recent years. Transfer distance of resources and information from one industry to another became longer since 2000 because of an increase in the average distance from 1.133 to 1.177. The distance-based cohesiveness increased from 0.908 to 0.911 over the period of 2000-2010. A compact industrial network would provide more resources for the development of its members. However, the network density in Japan has been decreasing, indicating a lesser effect of the network on the industry.

The short average distance, large distance-based cohesiveness and relatively large clustering coefficients confirm that the industrial networks in China and Japan are consistent with small-world characteristics. Thus, we can use an SNA to assess the industrial network in these two countries based on Input-Output data. On the other hand, the average distance between different industrial sectors in China is shorter and the distance-based cohesiveness is relatively larger than that in Japan. These indexes indicate that the efficiency of material or information delivery in China's industrial network is higher and the association between different industrial sectors is closer.

Moreover, after excluding the effect of the Asian financial crisis, China's industrial network has been improved and the actors' relationships are much closer, as indicated by the increasing industrial density. However, industrial network structure in Japan is loosely connected because of the lower network density and its decreasing trend.

3.2 Centrality analysis of the industrial association network

Fig.2 shows the industrial network structure pattern, with the structures in China in 2012 and in Japan in 2011 serving as examples. The directional lines represent the edges between different industrial sectors that show the associative relationship between different sectors and the capital flow direction. The size of the nodes indicates their degree centrality trend in the network. The structure of the industrial network in both China and Japan is complex; each node has more than one pathway that connects with the others. This kind of multiple contacts make the network stronger and have higher density than a single tie, thereby decreasing the risk of fragmentation.

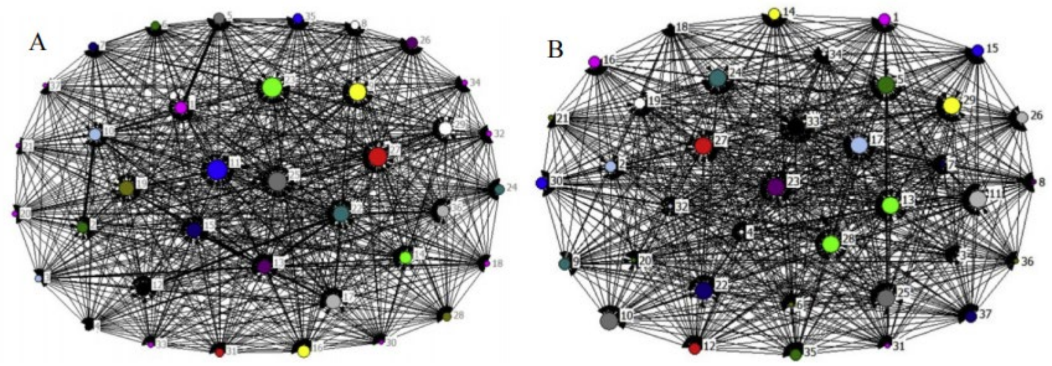

Fig.2. Industrial network diagrams of China in 2012 (A) and Japan in 2011 (B).

3.2.1 Degree centrality analysis

The degree centrality of each industry in the two target countries is shown in Fig.3, in which solid lines with different colors represent the degree centrality values of different sectors in China, and three dashed lines demonstrate the degree centrality changes in Japan. The results show that the degree centrality change in China fluctuated, including the in-degree and out-degree centrality, decreased heavily in 2007 and then increased slightly in 2012. Few industries did not follow this pattern. For example, the metal smelting industry (13) kept growing from 2002 to 2012 because it provided indispensable metal material for construction sector and other important strategic sectors. Conversely, the values of out-degree centrality in most sectors are higher than their in-degree centrality, such as agriculture sector (1), mining and quarrying sectors (Nodes 2e4 in Table 2), chemical sector (11) and metal related sectors. This means that these sectors output more material for downstream than they input from upstream. A similar situation exists in the electricity production sector (19), transportation sector (23), commerce sector (25) and financial sector (27). Other sectors present opposite manners, implying that they need more material but have less output.

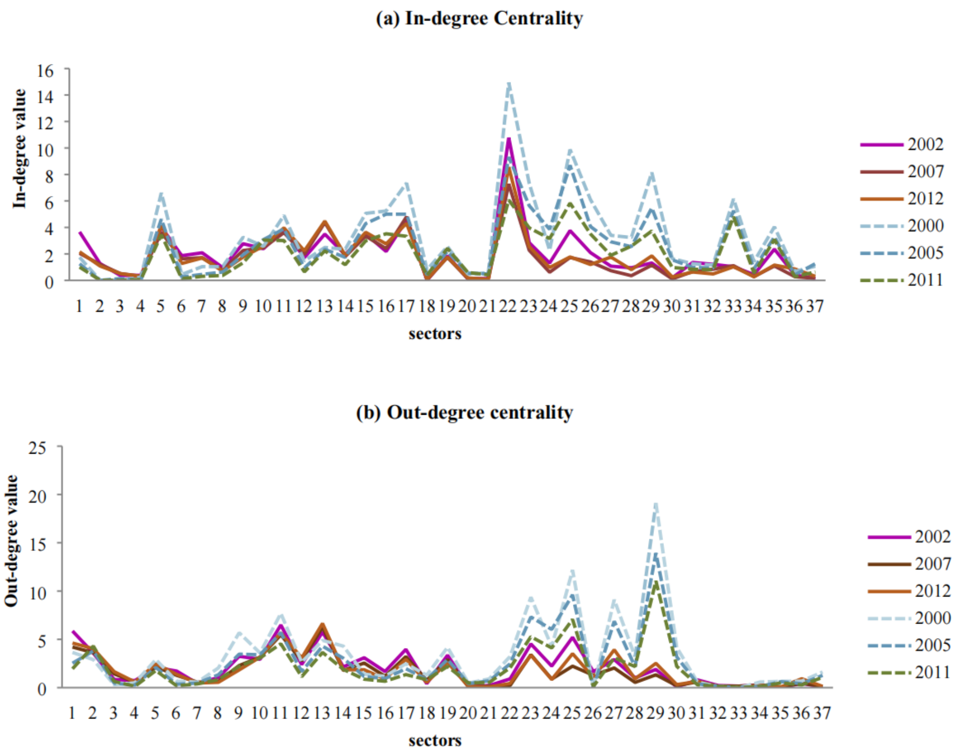

Fig.3. In-degree centrality (a) and out-degree centrality (b) of different sectors in China and Japan. Solid line: China; dashed line: Japan.

Table 2 Sectors in China and Japan

Number	Industry	Number	Industry
1	Agriculture, forestry and fishing	20	Gas production and supply industry
2	Coal mining, Petroleum and natural gas exploitation	21	Water production and supply industry
3	Metal mining industry	22	Construction industry
4	Nonmetallic mineral and other mining industry	23	Transportation and warehousing industry
5	Food manufacturing and tobacco processing industry	24	Postal, information transmission, computer service and software industry
6	Textile industry	25	Wholesale and retail trade industry
7	Textile garments, shoes, hats, leather, down and their product industry	26	Accommodation and catering industry
8	Wood processing and furniture manufacturing	27	Financial industry
9	Paper printing, culture, education and sports goods, instrumentation and other handicraft	28	Realty industry
10	Petroleum processing, coking and nuclear fuel processing	29	Leasing and business services industry
11	Chemical industry	30	Research and experimental development industry
12	Nonmetallic mineral products industry	31	Resident services and other services
13	Metal smelting and plating industry	32	Education
14	Metal products industry	33	Health, social security and social welfare
15	General/special equipment manufacturing industry	34	Culture, sports and entertainment
16	Transportation equipment manufacturing industry	35	Public management and social organization
17	Electrical, communications equipment, computers and other electronic equipment manufacturing	36	Comprehensive technical service industry (others in Japan)
18	Scrap and waste	37	Water conservancy, environmental and public facilities management industry (Unclear classification in Japan)
19	Electricity and heat production, supply industry		

Secondary industry (manufacturing) is predominant in China, as indicated by its higher in-degree centrality and out-degree centrality. This result also reflects that China is still in the immature industrialization stage. The food manufacturing sector (5), petroleum processing (10), chemical sector (11), metal smelting sector (13), general/special equipment manufacturing sector (15) and electronic manufacturing sector (17) are typical examples. However, furniture manufacturing (8) and scrap sector (18) in this category have low degree centrality. The effect of agriculture sector (1) even decreased during these years. This could be explained by China's transition from an agricultural country to an industrial country. Manufacture-related service industries, for example, the transportation sector (23), commerce (25), financial sector (27) and commercial service (29) are the primary drivers of service industry development, of which the financial sector (27) has shown the most rapid increase.

The mining and quarrying sectors (Node 2e4 in Table 2) had relatively lower in-degree centrality in China, which indicated their relatively simple demands from their upstream sectors. However, the huge demand effect from the downstream sectors can be confirmed by its higher out-degree centrality. Among the electricity, heat, gas and water production and supply sectors (Node 19e21 in Table 2), the electricity sector (19) has many connections with its upstream and downstream sectors.

The construction sector (22) has more upstream than downstream connections. Especially, for most sectors, their in-degree centrality values in the same year experienced the same trend as its out-degree centrality values. Only the construction sector (22) is an exception. The in-degree value of this sector performed well, peaking in 2002, but the out-degree centrality was quite low, which means this sector needs more input materials from its upstream sectors, but only outputs to a limited number of sectors. Such a special feature indicates that construction sector (22) can play a key role on promoting circular economy because the relevant policies on construction sector can influence other sectors' development.

China is a special developing country with rapid urbanization and infrastructure improvement, such as for roads, railways, bridges and ports. Especially China has become a heavy industrial country with capital intensive investment after 1998. But with more mature urbanization, industrial expansion has slowed down, leading to less demand on construction sector. According to Zhu and Li (2016), the current unsold real estates can provide living space to more than 400 million population, which indicates that this sector will not grow rapidly as before. The next challenge would be how to digest the existing houses and improve the service quality for this sector.

Japan is a service industry-dominated country, a sign of mature industrial economy. Service sectors, such as commerce (25), commercial service (29) and social welfare (33), have broad connections with other sectors and thus have a larger effect on Japan's industrial network. The out-degree centrality of commercial service (29) is larger than its in-degree centrality, which means that this sector has more connections with its downstream sectors than with its upstream sectors. In contrast, the out-degree centralities of social welfare (33) and public management (35) are lower than their in-degree centralities, which means that these sectors have more connections with their upstream sectors, but with few connections with their downstream sectors. Only several secondary industrial sectors are advantageous in Japan, such as the chemical sector (11), the general/special equipment manufacturing sector (15), the transportation manufacturing sector (16) and electronic manufacturing sector (17). Agriculture sector (1) in Japan is almost isolated from other sectors because of the low in-degree and out-degree centrality. This is mainly because Japan has a highly developed food processing sector and their agricultural products are processed first in such food processing factories rather than entering the market directly. Also, Japan imports a lot of food from other countries. The coal mining sector (2) promotes the development of downstream industries. The in-degree of the construction industries (22) decreased significantly from 2000 to 2011. The bursting of an economic bubble is an important reason for this result. The degree centrality of most sectors in Japan decreased significantly during 2000-2011, which means that these sectors had less contact with their upstream and downstream sectors. Comparing the degree centrality of China and Japan from 2002 to 2012 (2000-2011 in Japan), the degree centrality of service sectors in Japan was higher than in China. However, other sectors in China have more connections and more effects than those in Japan.

3.2.2 Betweenness centrality analysis

The betweenness centrality values of different sectors in China and Japan are shown in Fig.4. The high betweenness centrality of one sector represents its central position in resource delivery and its great effect throughout the entire industrial network. In general, the betweenness centrality in Japan is higher than that in China. For the changing trend, the betweenness centrality values in Japan have increased over the years, especially in service sectors. However, such values in China have gone down although the manufacturing sectors still have clear advantages. In general, direct connections between sectors have recently declined in Japan, indicated by the decreasing degree centrality. Therefore, more resources need to be transferred by intermediates to maintain the normal operation of the industrial network, which leads to an increase in betweenness centrality. However, the degree centralities of most sectors in China are higher than those in Japan and more direct connections between different sectors existed in 2012. Therefore, betweenness centralities in China are lower than those in Japan and have recently decreased. Given the immaturity of the industrial network development in China, some sectors cease to serve as intermediaries, which weakened the connections between different sectors. For example, if a particular supply chain/route breaks, no intermediary sector can fill such a gap.

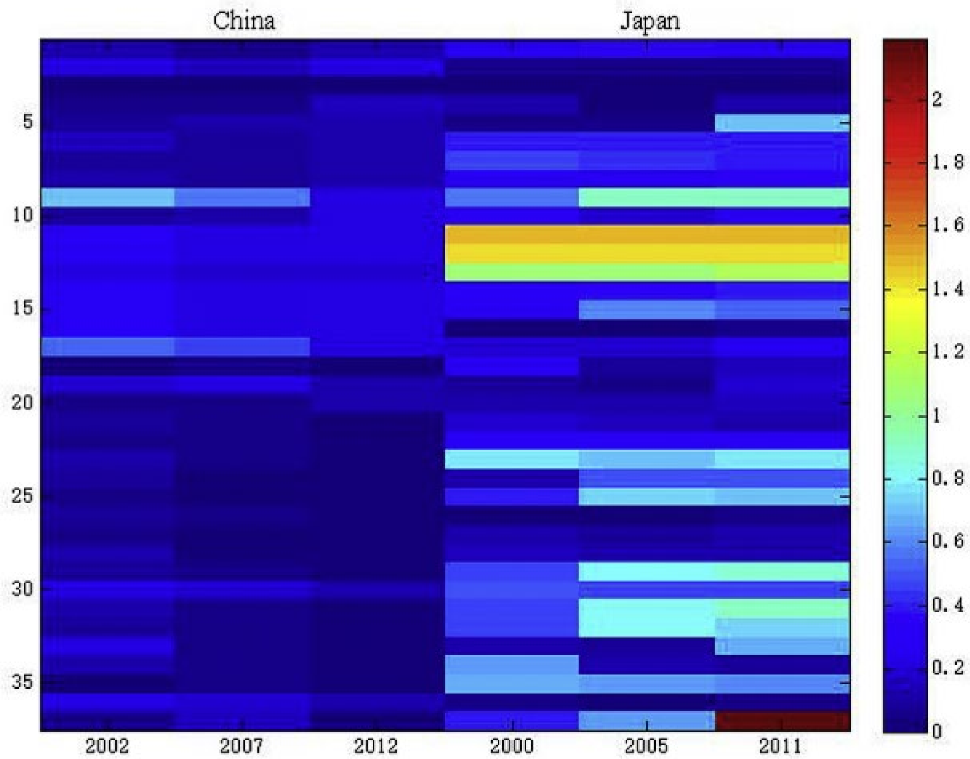

Fig.4. Betweenness centralities of different sectors in China and Japan.

Manufacturing sectors have higher betweenness centralities than other sectors in the two countries. In Japan, the chemical sector (11) and the nonmetallic mineral products sector (12) have relatively higher betweenness centralities, following by the metal smelting sector (13). Most service sectors have high betweenness centralities, implying the dominating role of service sectors as the intermediary function. In China, the paper printing sector (9) and electronic manufacturing (17) had the highest betweenness centralities in 2002 and 2007. The electricity production sector (19) and some service sectors, such as the research development sector (30), also had relatively higher betweenness centralities than other sectors. The resource delivery effect of the coal mining sector (2) and construction sector (22) became less prominent.

3.3 Industrial structure-related carbon emissions

Different kinds of fossil fuels emit different amounts of GHGs in relation to their emission factors and different production processes. Therefore, different products derived from different fossil fuels would produce different carbon emissions over their life cycles. The percentage changes in the carbon input from one sector to another specific sector are called industrial structure-related carbon emissions, which is another form to reflect the relationship changes between these sectors.

In order to investigate the industrial structure-related carbon emissions between Japan and China, it is necessary to first clarify the energy structure differences in the two countries. Natural gas and oil are the major sources of primary energy in Japan and have less GHG emission factors, while coal is still the major energy source in China and has much higher GHG emission factor. In order to simplify the sectoral comparisons, based on the statistical rules of energy balance table of China, sectors 28-37 were merged as sector 28. Fig.5 illustrates the carbon emission intensity change rates in China and Japan for the period of 2000-2012. The results show that the carbon emissions intensity in most sectors increased slightly from 2000 to 2005 in Japan (Fig.5). The only two sectors for which the growth rates of the carbon intensity exceeded 50% are the garments sector (7) and the gas production sector (20). Several sectors had reduced their carbon emissions, of which the scrap sector (18), the information sector (24) and the financial sector (27) were the top three, decreased by more than 30%. However, some sectors experienced rapid carbon emission intensity increase in 2011. Carbon emission intensity in the paper printing sector (9) and the financial sector (27) increased by more than 100%, and such figures in the textile sector (6), the metal production sector (14) and water supply sector (21) even increased by over 200%. Conversely, the carbon emission intensity of the garment sector (7), the electricity production sector (19), and several service sectors significantly decreased.

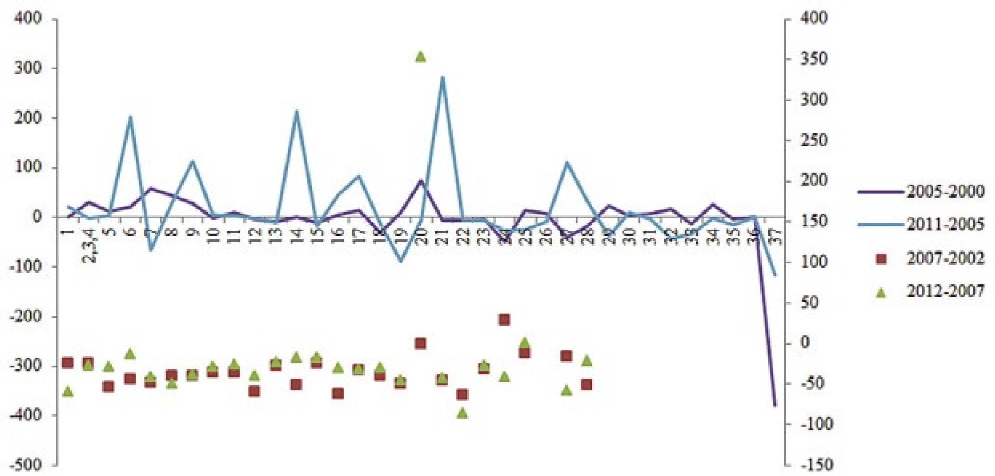

Fig.5. Carbon emission intensity change rates in China (point, right axis) and Japan (line, left axis) from 2000 to 2012.

Although China's total carbon emission is higher than Japan's, its carbon emission intensity decreased in almost all sectors from 2002 to 2012, especially the gas production sector (20) from 2007 to 2012 (Fig.5). The carbon emission intensity reduction in food production (5), textile sector (6) and petroleum production (10) is also remarkable. Metal mining (3) and nonmetal production sector (12), metal production (14) and accommodation sector (26) experienced a quick emission intensity reduction in the early days of the research period, but then kept fluctuated. The scrap sector (18) and construction sector (22) are the only two sectors with increased carbon emission intensity.

In order to further study industrial structure-related carbon emissions, one specific sector, namely, electricity and heat production sector (19), was selected. Fig.6 illustrates changes in the industrial structure-related carbon emission sources for the electricity and heat production sector in China and Japan. It is clear that its upstream sectors contributed more than 85% of the carbon emissions to this sector (19). In China, the electricity and heat production sector (19) obtained the most carbon-related investment due to tis higher carbon emission intensity. Such large investment has reduced its carbon emission intensity. However, due to less control on its upstream sectors, carbon emission intensity in these sectors still increased, offsetting the efforts that this sector received. For instance, carbon emission intensity in the mining industry increased from 18.60% to 32.05%, while carbon emission intensity in the metal smelting industry (13) increased from 11.43% to 18.97%. In this regard, Liu and his colleagues (2016a) found that carbon investment in the upstream sectors can bring significant carbon emission reduction effect to electricity and heat production sector. Therefore, more collaboration activities should be initiated so that these upstream sectors can optimize their energy structure by applying more renewable and clean energy sources and improving their energy efficiency.

With regard to Japan, the coal mining sector (2) is becoming more important for the electricity and heat production industry (19), especially after the Fukushima accident in March 2011. According to the Federation of Electric Power Companies of

Japan, more than 30% of the electricity was generated by the nuclear power plants in 2005, but this percentage deceased to 11% in 2011. Natural gas became the primary raw material for producing electricity and heat, generating 40% of the electricity and heat in 2011, twice that of 2000 and 2005. But it is not adequate to totally rely on natural gas due to its limited supply. Thus, coal has become a key energy source to replace the role of nuclear power. Fig.6 shows that most of its upstream sectors reduced their carbon emission inputs to the electricity and heat production sector. The main reason is that the Japanese government adjusted the electricity prices and encouraged clean power generation, especially the wide application of residential solar system.

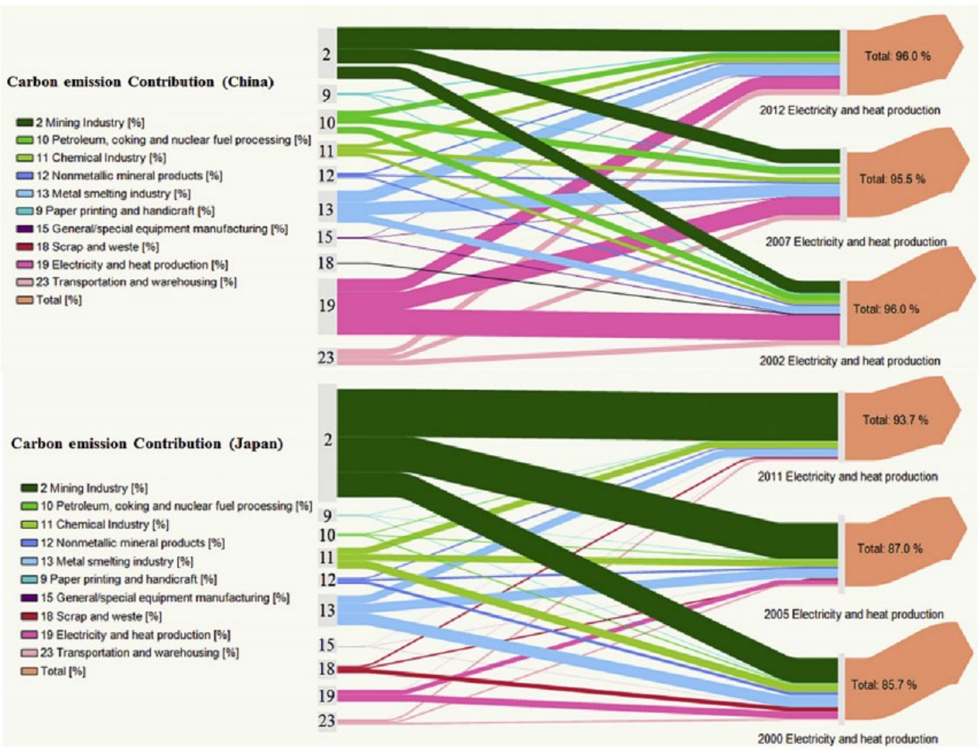

Fig.6. Changes in the industrial structure-related carbon emission sources for the electricity production sector in China and Japan.

4 Discussions

China is in its early stage to transfer its industrial structure toward more service-oriented one. However, China still needs to operate many of its manufacturing sectors in order to meet the demand of such products and provide employment opportunities. It is very challenging to upgrade its industrial structure due to increasing concerns on resource depletion and environmental issues. An integrated effort should be made in order to address these concerns.

Firstly, industrial structure should be transferred from independent operations to the cycle network so that most sectors can connect with others through various supply chain relationships.

To pursue ecological civilization has become China’s national development strategy since it can address both resource conservation and environmental protection issues (Geng et al., 2016). Circular economy is the major approach for the Chinese government to achieve ecological civilization. Since the circular economy promotion law was released in 2009, a series of related policies have been announced, including national demonstration projects, financial subsidies, planning principles (Geng et al., 2013a). In this regard, eco-industrial parks have been widely promoted to reduce GHG emissions and improve the overall resource efficiency (Dong et al., 2014b; Liu et al., 2016b). For example, the powder generated by slag in the iron making process could be used in a cement factory; burnable wastes could be sent to an iron or a cement factory, or a thermal power plant to produce electricity (Dong et al.,2013b).

Second, innovative technologies should be incubated and transferred through various measures. As early as the 1980s, Japan completed industrialization and the output ratio of manufacturing industry decreased, while the proportion of service industries quickly increased, and added values from service industries are considerably higher than agriculture and manufacturing industries. Moreover, the total intermediate input rate in Japan has been steady and much lower than the ratio in

China (Wang et al., 2010).

However, China is still in its early industrialization stage. Comparing with Japan, China lacks technology innovation abilities. In order to improve such a situation, the Chinese government should invest more research funds to support more innovative technologies by considering the local realities. Also, those energy intensive enterprises should establish their own research funds since they know exactly which technologies are more important for their production. Plus, those eastern provinces should consider transferring their energy efficient technologies to their western counterparts so that leapfrog can be achieved. Similarly, international technology transfer should be encouraged. As the neighbor country of China, Japan has many advanced energy and resource efficient technologies and may consider transferring these technologies to China so that win-win situations can be obtained.

Third, energy structure optimization should be implemented.

It is clear that energy demand is increasing in China. However, greenhouse gases emitted from burning fossil fuels have resulted in significant climate changes (Matthews et al., 2009; Meinshausen et al., 2009). To control global warming and meet the 2 target, a third of the oil reserves, half of the gas reserves and over 80% of the coal reserves should remain unused from 2010 to 2050 (McGlade and Ekins, 2015). China is a coal-dominating country (Wu et al., 2016). The corresponding carbon emission from coal burning also led to many other environmental emissions, such as SO2, PM matters, NO_x, inducing serious public health concerns. Therefore, replacing fossil fuels (particularly coal) with clean and renewable energy sources is critical, such as solar power, wind power, geothermal power and hydro-power. China has actively promoted such clean and renewable energy during the last decade. For instance, by simply promoting ground source heat pumps, the city of Shenyang in northeast China reduced over 2.5 million CO2 during 2006-2009, leading to significant co-benefits (Geng et al., 2013c). However, such efforts are still rare and many similar projects should be initiated.

5 Conclusions

Industrial structure has a significant impact on one country's resource consumption and environmental performance. Many developing countries chose to support those heavy industries in order to quickly develop their economy. However, irrational industrial structure induced many problems, such as rapid resource depletion and corresponding environmental emissions. Therefore, it is critical to identify how industrial structure influences one nation's economic development so that appropriate solutions can be found out. Under such a circumstance, this study employed a combined IO-SNA model to investigate the inner structure of industrial networks in China and Japan. It was observed that China's industrial structure has moved from independent operations to cycle networks. Compared with Japan, China's industrialization is still in its infancy, and its industrial structure should be adjusted. Particularly, by using the electricity production sector as an example, a further analysis on industrial structure-related carbon emissions indicates that rational industrial structure adjustment can mitigate carbon emissions.

Policy implications from this study suggest that China should encourage more innovative efforts, such as eco-industrial parks, investment more research funds to support energy and resource efficient technologies through various measures, and optimize its energy structure. Although the case is for China and Japan, relevant policy insights can be referred by many other developing countries so that they can seek more appropriate industrial structure adjustment solutions by considering their own situations.

For the future study, more comparison studies with the EU, U.S. and some emerging countries should be conducted in order to further provide more valuable policy implications. Moreover, due to the regional differences, different regions in China are in different economic development levels with different resource endowments and geographical limitations. It is irrational for all the regions to take the same industrial structure adjustment measures. More region-specific studies should be undertaken by considering the regional situations so that more appropriate policy recommendations can be raised to those decision makers.

Acknowledgements

This research was supported by the National Natural Science Foundation of China (71603165, 71325006, 71461137008, 71690241), the Fundamental Research Funds for the Central Universities through Shanghai Jiao Tong University (16JCCS04), the Shanghai Municipal Government (17XD1401800), and Yunnan Provincial Research Academy of Environmental Science.

References

Albert, R., Jeong, H., Barabasi, A.L., 1999. Internet: diameter of the world-wide web. Nature 401, 130e131.

Chang, N., 2015. Changing industrial structure to reduce carbon dioxide emissions: a Chinese application. J. Clean. Prod. 103, 40e48.

Chen, B.J., Ting, H.I., 2013. Applying social networks analysis methods to discover key users in an interest-oriented virtual community. In: 7th International Conference on Knowledge Management in Organizations: Service and Cloud Computing. Springer, pp. 333e344. Chertow, M.R., 2007. "Uncovering" industrial symbiosis. J. Ind. Ecol. 11, 11e30.

Cui, D., Yu, Y., Song, Z., 2013. Spatial evolution of industrial structure in Hebei Province research. J. Appl. Sci. Eng. Technol. 5, 2142e2146.

Cui, F., Yang, Y., 1998. The assessment on the inflfluence of industrial structure on urban ecological environment. China Environ. Sci. 18, 166e169 (in Chinese with English abstract).

Domenech, T., Davies, M., 2009. The social aspects of industrial symbiosis: the application of social network analysis to industrial symbiosis networks. PIE 6, 68e99.

Domenech, T., Davies, M., 2011. Structure and morphology of industrial symbiosis networks: the case of Kalundborg. Proced. Soc. Behav. Sci. 10, 79e89.

Dong, H., Fujita, T., Geng, Y., Dong, L., Ohnishi, S., Sun, L., Dou, Y., Fujii, M., 2016. A review on Eco-city evaluation methods and highlights for integration. Ecol. Indic. 60, 1184e1191.

Dong, H., Geng, Y., Xi, F., Fujita, T., 2013a. Carbon footprint evaluation at industrial park level: a hybrid life cycle assessment approach. Energy Policy 57, 298e307.

Dong, H., Ohnishi, S., Fujita, T., Geng, Y., Fujii, M., Dong, L., 2014a. Achieving carbon emission reduction through industrial & urban symbiosis: a case of Kawasaki. Energy 64, 277e286.

Dong, L., Gu, F., Fujita, T., Hayashi, Y., Gao, J., 2014b. Uncovering opportunity of lowcarbon city promotion with industrial system innovation: case study on industrial symbiosis projects in China. Energy Policy 65, 388e397.

Dong, L., Zhang, H., Fujita, T., Ohnishi, S., Li, H., Fujii, M., Dong, H., 2013b. Environmental and economic gains of industrial symbiosis for Chinese iron/steel industry: Kawasaki's experience and practice in Liuzhou and Jinan. J. Clean. Prod. 59, 226e238.

Fuller, M.M., Wagner, A., Enquist, B.J., 2008. Using network analysis to characterize forest structure. Nat. Resour. Model 21, 225e247.

Geng, Y., Sarkis, J., Ulgiati, S., Zhang, P., 2013a. Measuring China's circular economy. Science 339, 1526e1527.

Geng, Y., Zhao, H., Liu, Z., Xue, B., Fujita, T., Xi, F., 2013b. Exploring driving factors of energy-related CO2 emissions in Chinese provinces: a case of Liaoning. Energy Policy 60, 820e826.

Geng, Y., Sarkis, J., Wang, X.B., Zhao, H.Y., Zhong, Y.G., 2013c. Regional application of ground source heat pump in China: a case of Shenyang. Renew. Sustain. Energy Rev. 18, 95e102.

Geng, Y., Sarkis, J., Ulgiati, S., 2016. Sustainability, well-being, and the circular economy in China and worldwide. Science 6278 (Supplement), 73e76. Special issue on Pushing the boundaries of scientifific research: 120 years of addressing global issues.

Gordon, I.R., McCann, P., 2000. Industrial clusters: complexes, agglomeration and/or social networks? Urban Stud. 37, 513e532.

Hanneman, R.A., Riddle, M., 2005. Introduction to Social Network Methods, on Line Book.

Harris, J.K., Luke, D.A., Burke, R.C., Mueller, N.B., 2008. Seeing the forest and the trees: using network analysis to develop an organizational blueprint of state tobacco control systems. Soc. Sci. Med. 67, 1669e1678.

Hendrickson, C., Horvath, A., Joshi, S., Lave, L., 1998. Economic inputeoutput models for environmental life-cycle assessment. Environ. Sci. Technol. 32, 184e191.

Intergovernmental Panel on Climate Change (IPCC), 2006. IPCC Guidelines for National Greenhouse Gas Inventories.

Kwait, J., Valente, T.W., Celentano, D.D., 2001. Interorganizational relationships among HIV/AIDS service organizations in Baltimore: a newtwork analysis. J. Urban Health 78, 468e487.

Liang, S., Zhang, T., Jia, X., 2013. Clustering economic sectors in China on a life cycle basis to achieve environmental sustainability. Front. Environ. Sci. Eng. 7, 97e108.

Liu, L.C., Cao, D., Wei, Y.M., 2016a. What drives intersectoral CO2 emissions in China? J. Clean. Prod. 133, 1053e1061.

Liu, Z., Geng, Y., Park, H.S., Dong, H., Dong, L., Fujita, T., 2016b. An emergy-based hybrid method for assessing industrial symbiosis of an industrial park.

J. Clean. Prod. 114, 132e140. Liu, L.C., Fan, Y., Wu, G., Wei, Y.M., 2007. Using LMDI method to analyze the change of China's industrial CO2 emissions from fifinal fuel use: an empirical analysis. Energy Policy 35, 5892e5900.

Liu, Z., Liang, S., Geng, Y., Xue, B., Xi, F., Pan, Y., Zhang, T., Fujita, T., 2012.Features, trajectories and driving forces for energy-related GHG emissions from Chinese mega cites: the case of Beijing, Tianjin, Shanghai and Chongqing. Energy 37, 245e254.

Lu, Z., Deng, X., 2011. China's Western Development Strategy: Policies, Effects and Prospects. MPRA Paper.

Luo, J., 2005. Social Network Analysis, fifirst ed. Social Sciences Academic Press, Beijing (in Chines).

Lv, K., Fu, M., 2010. Construction and structural measurement of the inter-regional industrial spatial networks in China. Econ. Geogr. 30, 1785e1791.

Mi, Z.F., Pan, S.Y., Yu, H., Wei, Y.M., 2015. Potential impacts of industrial structure on energy consumption and CO2 emission: a case study of Beijing. J. Clean. Prod. 103, 455e462.

Mozner, Z.V., 2013. A consumption-based approach to carbon emission accountingesectoral differences and environmental benefifits. J. Clean. Prod. 42, 83e95.

Matthews, H.D., Gillett, N.P., Stott, P.A., Zickfeld, K., 2009. The proportionality of global warming to cumulative carbon emissions. Nature 459, 829e832.

McGlade, C., Ekins, P., 2015. The geographical distribution of fossil fuels unused when limiting global warming to 2C. Nature 517, 187e190.

Meinshausen, M., Meinshausen, N., Hare, W., Raper, S.C., Frieler, K., Knutti, R., Frame, D.J., Allen, M.R., 2009. Greenhouse-gas emission targets for limiting global warming to 2C. Nature 458, 1158e1162.

Scott, J., 2012. Social Network Analysis. Sage Publication, London.

Sun, L., Dong, H., Geng, Y., Li, Z., Liu, Z., Fujita, T., Ohnishi, S., Fujii, M., 2015a. Uncovering driving forces on urban metabolismda case of Shenyang. J. Clean. Prod. 114, 171e179.

Sun, L., Xue, B., Geng, Y., Zhang, L., 2015b. Analysis on regional industries based on input-output table and SNA: a case of seven provinces in Eastern China. J. East China Normal Univ. Nat. Sci. 1, 224e233 (in Chinese with English abstract).

Sun, L., Xue, B., Zhang, Z., Zhang, L., Geng, Y., 2014. A SNA-based measurement on industrial structure change and industrial networking of China. Ecol. Econ. 30, 83e87 (in Chinese with English abstract).

Tian, X., Chang, M., Shi, F., Tanikawa, H., 2014. How does industrial structure change impact carbon dioxide emissions? A comparative analysis focusing on nine provincial regions in China. Environ. Sci. Policy 37, 243e254.

Wall, R., Knaap, B.V.D., 2007. Sustainability with an evolving world city network. In: Proceedings of International Forum on Metropolitan Region Development. Shanghai Jiaotong University, Shanghai, pp. 31e51.

Wang, D., Fang, C., Gao, X., 2010. Comparison on evolution of industrial linkage structure based on input-output table amomg China, Japan and the US. Prog.

Geogr. 29, 609e618 (in Chinese with English abstract). Wasserman, S., Faust, K., 1994. Social Network Analysis: Methods and Applications. Cambridge university press, New York.

Watts, D.J., 1999. Small Worlds: the Dynamics of Networks between Order and Randomness. Princeton University Press, New Jersey.

Watts, D.J., Strogatz, S.H., 1998. Collective dynamics of ‘small-world’networks. Nature 393, 440e442.

Wei, L., Zhang, Q., Zhao, L., 2012. Industrial restructuring and transferring based on complex networks of CRMAs. Econ. Geogr. 32, 89e93 (in Chinese with English abstract).

Williams, R.J., Martinez, N.D., 2000. Simple rules yield complex food webs. Nature 404, 180e183.

Wu, R., Geng, Y., Dong, H., Fujita, T., Tian, X., 2016. Changes of CO2 emissions embodied in China-Japan trade: drivers and implications. J. Clean. Prod. 112, 4151e4158.

Zhang, J.F., Deng, W., 2010. Industrial structure change and its eco-environmental inflfluence since the establishment of municipality in Chongqing, China. Proced. Environ. Sci. 2, 517e526.

Zhang, Y.J., Liu, Z., Zhang, H., Tan, T.D., 2014. The impact of economic growth, industrial structure and urbanization on carbon emission intensity in China. Nat. Hazards 73, 579e595.

Zhao, H., Geng, Y., Xi, F., Liu, Z., Dong, H., 2012. Analysis of CO2 emissions related to sectoral energy consumption in Liaoning Province based on production and consumption perspectives. Res. Environ. Sci. 25, 1290e1296 (in Chinese with English abstract).

Zhao, J., 2011. 2030 China's Economic Outlook Report. http://www.esri.go.jp/jp/prj/int_prj/2010/prj2010_03_04.pdf (In Chinese, Last access: 25 March 2017).

Zhou, M., Chen, Q., Cai, Y., 2013. Optimizing the industrial structure of a watershed in association with economic-environmental consideration: an inexact fuzzy multi-objective programming model. J. Clean. Prod. 42, 116e131.

Zhu, B., Li, M., 2016. Why many security houses are still emply in China? China Constr. 7, 14e16 (in Chinese).