Embodied Energy in Service Industry in Global Cities: A Study of Six Asian Cities

Shan Guo[a], Yilin Li[b], Yunhao Hu[c,d], Fan Xue[e], Bin Chen[f], Zhan-Ming Cheng[g,*]

a Department of Land Management, School of Public Administration and Policy, Renmin University of China, Beijing 100872, PR China

b Laboratory for Systems Ecology and Sustainability Science, College of Engineering, Peking University, Beijing 100871, PR China

c School of Economics and Management, Tsinghua University, Beijing 100084, PR China

d School of Information Resource Management, Renmin University of China, Beijing 100872, PR China

e Department of Real Estate and Construction, The University of Hong Kong, Pokfulam, Hong Kong SAR

f State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing 100875, China

g School of Applied Economics, Renmin University of China, Beijing 100872, PR China

* Corresponding author.

E-mail addresses: chenzhanming@ruc.edu.cn.

Abstract

Energy is a resource of strategic importance for cities, a fortiori global cities that rely on tremendous indirect energy embodied in interregional trades of service industries. The assessment of embodied energy in service industries is thus vital to the committed sustainable development of global cities and fundamental to tailor-made local policymaking. This paper applies Multi-Regional Input-Output analysis to the assessment of total embodied energy in service industries in six global cities, i.e., Beijing, Chongqing, Hong Kong, Shanghai, Singapore, and Tianjin. It is found that Hong Kong and Singapore have relatively lower energy use intensities compared with the four cities located in Mainland China. Service industries consume 17.02~46.40% of total embodied energy in the six cities. Coastal cities like Tianjin, Shanghai, Hong Kong, and Singapore have higher proportions of transportation consumption. The four Chinese mainland cities consume a larger proportion of coal than Hong Kong and Singapore. The method and the findings of this paper are expected to facilitate both the government and the industries in energy policymaking for a smarter and more sustainable urban economy.

Key Words: globalization; urbanization; service industries; global city; input-output analysis

Highlights:

- An MRIO model is used to assess the embodied energy of service industries of six global cities.
- Service industries consume 17.02~46.40% of total embodied energy in the six selected global cities.
- Hong Kong and Singapore are found to have relatively low energy use intensities.
- The four Chinese mainland cities consume a larger proportion of coal.

1. Introduction

By 2030, 75% of the world's energy will be consumed in cities (Appleby, 2018), where 68% of the global population lives in (UNDESA, 2018). The term "global cities" was put forward by Saskia Sassen in 1991, which was defined as important nodes in the global economic network (Sassen, 1991). Global cities, with virtually little self-sufficiency on energy and close links with other global economies, are highly dependent on external energy provision. Energy security which should always be ensured for the basic functions of cities has become a worldwide concern (Dhakal, 2009; Webb et al., 2016).

To ensure energy security and foster sustainable development in a city, many studies and policies have been conducted for assessing and regulating urban direct energy use. For example, Beijing released the energy development planning during the Thirteenth Five-Year Plan, which is part of a long-term key plan about social and economic development established by Chinese government since 1953, and set a target of energy consumption per GDP reduced by 17% by 2020 based on the 2015 level (BMPG, 2017). Hong Kong proposes to reach an energy-saving target of "reducing energy intensity by 45% by 2035 based on 2005 level" (APERC, 2015). Chow (Chow, 2001) studied sectoral direct household energy consumption in Hong Kong during 1984-1997. However, the ignored indirect energy consumption in global cities is so immense that sometimes it can be more than two times of direct energy according to Li et al. (Li et al., 2014). Thus, the ignored indirect energy use triggered by trading, which involves a significant level of energy-intensive activities during the production process, will greatly underestimate the energy use in cities.

The negligence of indirect energy in cities rooted, in part, in the conventional understanding of “non-material” and “environment-friendly” nature of the service industry (Fourcroy et al., 2012). Recently, evidence suggested that service industries are large energy consumers (Gadrey, 2010) due to the indirect consumption through interregional trade (Ge and Lei, 2014; Piaggio et al., 2015). The service industry accounted for over 65% of the world’s GDP in 2016 (WorldBank, 2018); and an about 40s to 90s percentage of a global city’s GDP (WorldBank, 2018). Given an increasing pressure from the population, economic growth, and limited energy resources in global cities (He et al., 2018; Zheng et al., 2017), a comprehensive assessment of total energy use in the service industry in global cities is vital to both public policymaking and private sectors.

Embodied energy is used to depict the total (direct plus indirect) energy required to produce services in cities (Costanza, 1980). Examples of embodied energy – as well as embodied carbon emission – analysis can be found in recent studies (Chen et al., 2019). Typical examples include Singapore (Schulz, 2010), Macao (Chen et al., 2017; Li et al., 2014), Beijing (Guo and Chen, 2013; Guo et al., 2012) and etc. (Chen and Chen, 2015; Li et al., 2018a; Paloheimo and Salmi, 2013). Schulz (Schulz, 2010) compared direct emissions with trade corrected estimates of indirect emissions in Singapore. Multi-Regional Input-Output (MRIO) analytical framework is also frequently used. For instance, based on the input-output (IO) model, Zhang and Lei (Zhang and Lei, 2017) calculated the carbon emissions of residents in Beijing in 2012. Zhang et al. (Zhang et al., 2015) presented an MRIO analysis of energy use embodied in final demand and interregional trade of Beijing, Tianjin, Shanghai, and Chongqing. Li et al. (Li et al., 2018b) have tracked carbon transfers embodied in Chinese four municipalities' domestic and foreign trade. Some other studies combined MRIO model with other analytical models. By integrating the MRIO model with the complex network approach, Tang et al. (Tang et al., 2019) built two embodied energy flow networks (EEFNs) from the regional and sectoral perspectives. The small-world nature was explored in the current EEFN by assessing the average clustering coefficient and average path length. Zhu et al. (Zhu et al., 2017) applied input-output analysis (IOA) and structural decomposition analysis to analyze the CO_2 emissions cost of the industrialization and urbanization processes from 1997 to 2012, using the manufacturing center Tianjin as an example. As for service industries, Guo et al. (Guo et al., 2016) investigated the embodied energy in Hong Kong's service industry. Results show that Mainland China and the USA are the two largest sources of embodied energy in imports of services. However, relevant studies are still lacking.

Particularly, embodied energy performances of the service industry, the conventional "environmental-friendly" industry but actually the large energy consumers, in global cities at different development stages were not systematically assessed in the literature.

This paper aims to apply MRIO analysis to the assessment of embodied energy in the service industry in global cities. Six global cities in the Asian area, Beijing, Tianjin, Shanghai, Chongqing, Hong Kong, and Singapore, are selected from the list of global cities by Globalization and World Cities Research (GaWC, 2018), which explained the development stages and correlations among various global cities. These six cities come from different development stages, as according to GaWC, Chongqing ranks Beta- in the global city ranking, while Tianjin ranks Beta, and the rest four cities rank Alpha+. This paper first calculates the total embodied energy in service consumptions (which is short for final consumption of service industries) in six global cities from a macro perspective. Furthermore, the decomposition and the supply routes of embodied energy are analyzed. The findings can serve as a piece of evidence for the development of sustainable energy policies in the six global cities.

2. Methodology and data

2.1 Study area

This study selects six global cities in Asian cities as the study cases, as listed in Table 1. Four cities, i.e., Beijing, Chongqing, Shanghai, and Tianjin, are the direct-controlled municipalities in Mainland China; while the other two are developed economies, i.e., Hong Kong and Singapore. The primary selection criteria is a variance in services share in GDP for the representation of both developing and developed economies. As listed in Table 1, the target services share in the selected cities cover a wide spectrum from about 48% to over 90%. The other selection criteria is a close trade and cultural network within, e.g., one country or a region such as Asia, for the trade flows analysis.

Table 1 List of selected six global cities (in alphabetic order)

City	Global city ranking[a]	Developed economy?	Megacity[b]	Coastal city?	Population[c] (M)	Service share in GDP^ (year)
Beijing	Alpha+	No	Yes	No	21.7	80.23% (2016)
Chongqing	Beta−	No	Yes	No	30.5	48.10% (2016)
Hong Kong	Alpha+	Yes	No	Yes	7.4	92.40% (2017)
Shanghai	Alpha+	No	Yes	Yes	24.2	69.80% (2017)
Sigapore	Alpha+	Yes	No	Yes	5.6	67.12% (2017)
Tianjin	Beta	No	Yes	Yes	15.6	56.43% (2016)

Notes: [a] According to Globalization and World Cities Research (GaWC, 2018), [b] Over 10 million population, [c] Data sources: (CSDHK, 2018a) (UNDESC, 2015)

As for service industries in these six cities, they all account for a large proportion of its total

GDP. Beijing's service sector accounted for 72.27% and 80.23% of its total GDP in 2006 and 2016 respectively (BMBS, 2018), though Beijing depended mainly on the manufacturing industry (71% of its total GDP) in 1978. Chongqing's service industry output accounted for 48.1% of its total GDP in 2016 (USD 266.72 trillion), 10 percentage points above what it was in 1998 (CD, 2018). The percentage of Shanghai's service industry as a proportion of its GDP increased from 47.8% in 1998 to 64.8% in 2014. In 2017, 69.80% of its RMB 2,817 trillion GDP corresponded to the services sector output (SMSB, 2018). In Shanghai, the output of the tertiary industry exceeded the secondary industry in 1999, but for China as a whole, it happened only in 2013 (Li et al., 2017). Tianjin has also experienced significant growth in its service industry sector over the past decades. Even though in 1998 it accounted for 30.36% of its GDP, by 2016, the output of the service industry represented 56.43% of Tianjin's GDP. The proportion of service industry accounting for Hong Kong's total GDP increased from 91% to 93% during 2005-2015 (CSDHK, 2018c). Hong Kong's total imports and exports of service trade values reached USD 74.00 billion and USD 104.22 billion respectively in 2015 (CSDHK, 2018b). The growth of average service sector in Singapore was 5.18%. The service industry accounted for a 57.98% of its GDP in 1978, 62.61% in 1998, 66.89% in 2008 and 67.12% in 2017 (DSS, 2018) which shows the increasing importance of the tertiary industry in the city's economic development.

2.2 Data sources and preprocess

This study constructs a large-scale high-resolution nested MRIO table, which provides complete interregional trade among these global cities as well as the detailed regional-international trade with 169 regions, to investigate energy embodied in trade connections in the service industry of the six typical global cities. The 2012 Chinese MRIO tables, which are compiled by the Institute of Geographic Sciences and Natural Resources Research of Chinese Academy of Sciences, are connected to the global MRIO tables obtained from version 9 of the GTAP database. The GTAP database disaggregates trade links for 57 sectors of 140 regions in 2011. Considering that the Chinese MRIO table used in this paper describes inter- and intra- regional trade among 30 provinces in 2012, the 2011 global MRIO table selected from the GTAP database is deflated to standard prices of 2012 using the double-deflation method.

Owing to that Chinese MRIO table consists of 30 provinces, each containing 30 sectors, we disaggregate and allocate the Chinese IOT in GTAP into 30 province-level tables according to our data on provincial exports and imports. The original international import and export metrics in the GTAP database, which distinguish 57 sectors, are also integrated into 30 sectors to achieve consistency (sectoral classification criteria are described in the Appendix). Such processing is based on the following assumption that the international exports/imports of a sector in a province are distributed among all foreign economies in the same proportion as China's exports/imports for that sector. The revised global MRIO contains 30 Chinese provinces and 139 foreign economies, which can be used for further embodied energy accounting. Besides, the province-level energy consumption data adopted in this study are obtained from the China Energy Statistical Yearbooks, and the global energy use inventory is also originated from the GTAP database, which is matched with the 2011 global MRIO table.

2.3 Algorithm

In the present paper, the multi-regional input-output analysis (MRIOA) is adopted for a systematic analysis of energy consumption by the globalized economy, covering the largest existing scope in combination with detailed regional-international trade (Lenzen et al., 2004; Meng et al., 2018; Minx et al., 2009; Wiedmann, 2009; Wiedmann et al., 2010). By integrating the embodiment theory in systems ecology (Costanza, 1980; Odum, 1983) into the biophysical modelling (Bullard, 1975; Bullard III and Herendeen, 1975; Hannon et al., 1983), Chen and his colleagues have generalized a systems MRIO method that pays equal attention to the intermediate use and the final use as the two basic components of the total output. This method has become a well-established tool in depicting flows of ecological endowments such as energy use (Chen and Chen, 2013a; Wu and Chen, 2018), land use (Han and Chen, 2018; Wu et al., 2018), water use (Chen and Chen, 2013b), carbon emissions (Chen and Zhang, 2010; Chen and Chen, 2011a, 2011b) and mercury emissions (Chen et al., 2016; Zhang and

Chen, 2014).

As showed in Table 2, the global multi-regional input-output account is chosen to model the world economy. In the revised global MRIO table, global cities and other regions are connected through inter-regional and regional-international trade (Li et al., 2017). As shown in Table 2, there are *m* regions under the world economy and *n* economic sectors within each region. z_{ij}^{sr} enunciates the intermediate economic inputs from Sector *i* in Region *s* to Sector *j* in Region *r*. Correspondingly, f_i^{sr} is on behalf of the monetary flows for the final demand. x_i^s stands for the total outputs of Sector *i* in Region *s*. d_i^s denotes the on-site energy use by Sector *i* in Region *s*. ε_i^s represents the embodied energy intensity of the output products by Sector *i* in Region *s*, it refers to the total (including direct and indirect) energy required for the generation of per unit of the sectoral output commodities.

The biophysical balance in terms of embodied energy for Sector *i* in Region *s* can be expressed as:

$$d_i^s + \sum_{r=1}^{n}\sum_{j=1}^{m} \varepsilon_j^r z_{ji}^{rs} = \varepsilon_i^s x_i^s \tag{1}$$

Using familiar matrix notation and dropping the subscripts, we have the following:

$$D + EZ = E\hat{X} \tag{2}$$

Therefore, by solving Eq. (2) could we obtain the matrix for embodied energy intensity as:

$$E = D\left(\hat{X} - Z\right)^{-1} \tag{3}$$

in which D could be obtained from environmental statistics $\hat{X}$ and Z could be derived from a given global MRIO account.

Integrated with the embodied energy intensity calculated, the energy embodied in the products used as final consumptions in Region *s* (EEF), which are usually consist of five categories according to China's IO statistics: rural consumption, household consumption, government consumption, fixed capital formation, and change in inventories, could be calculated as:

$$EEF^s = \sum_{r=1}^{m}\sum_{j=1}^{n}\varepsilon_j^r f_j^{rs} \tag{4}$$

Meanwhile, the formulations for the energy embodied in imports (EEI) and exports (EEE) of the service industry of the six global cities are respectively shown as:

$$EEI^s = \sum_{r=1(r\neq s)}^{m}\sum_{j=1}^{n}\sum_{i=1}^{n}\varepsilon_j^r z_{ji}^{rs} + \sum_{r=1(r\neq s)}^{m}\sum_{j=1}^{n}\varepsilon_j^r f_j^{rs} \tag{5}$$

$$EEE^s = \sum_{r=1(r\neq s)}^{m}\sum_{i=1}^{n}\sum_{j=1}^{n}\varepsilon_i^s z_{ij}^{sr} + \sum_{r=1(r\neq s)}^{m}\sum_{i=1}^{n}\varepsilon_i^s f_i^{sr} \tag{6}$$

Correspondingly, the formulations for the energy embodied in the total trade balance of Region s could be described as:

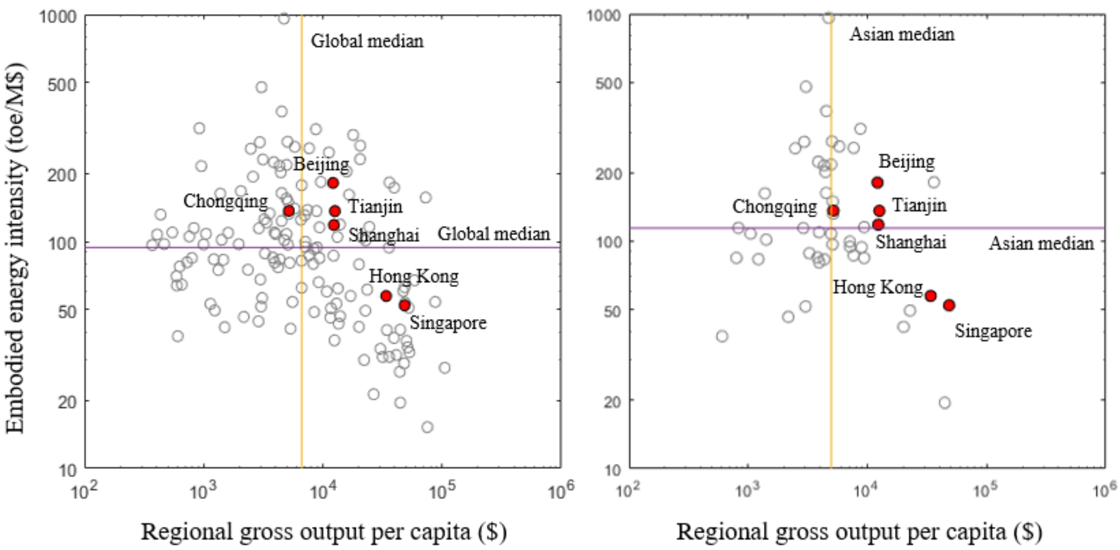
$$\begin{aligned} EETB = EEI^s - EEE^s = & \sum_{r=1(r\neq s)}^{m}\sum_{j=1}^{n}\sum_{i=1}^{n}\varepsilon_j^r z_{ji}^{rs} + \sum_{r=1(r\neq s)}^{m}\sum_{j=1}^{n}\varepsilon_j^r f_j^{rs} \\ & - \sum_{r=1(r\neq s)}^{m}\sum_{i=1}^{n}\sum_{j=1}^{n}\varepsilon_i^s z_{ij}^{sr} - \sum_{r=1(r\neq s)}^{m}\sum_{i=1}^{n}\varepsilon_i^s f_i^{sr} \end{aligned} \tag{7}$$

Table 2. Systems multi-region input-output table

Input/Output			Intermediate use							Final use							Total output
			Economy *1*			⋯	Economy *n*			Economy *1*			⋯	Economy *n*			
			Sector *1*	…	Sector *m*		Sector *1*	…	Sector *m*	Category *1*	…	Category *k*		Category *1*	…	Category *k*	
Intermediate input	Economy *1*	Sector *1*															
		⋮															
		Sector *m*															
	⋮					z_{ij}^{sr}							f_i^{sr}				x_i^s
	Economy *n*	Sector *1*															
		⋮															
		Sector *m*															
Total energy use						d_i^s											

3. Results and discussions

3.1 Embodied energy intensity of service industry



(a) Global economies

(b) Asian economies

Figure 1. Comparison of the average embodied energy intensity of service industries in the six cities against regional gross output per capita

Figure 1 shows the comparison of the average embodied energy intensity of service industries in the six cities against the regional gross output per capita. Figure 1.a contrasts the six cities in a background of worldwide economies. As the global developed economies, except for Chongqing, the gross outputs per capita of the rest five cities researched are higher than the global median value (6.62×10^3 $). The four cities in Mainland China have energy intensities higher than the global median value at 93.6 toe/million $. While Hong Kong and Singapore's energy intensities are lower than the global median value, proving that they have high energy use efficiency in the efforts of economic, social, and regulatory initiatives over many years. Figure 1.b zooms the background to the Asian economies, including Hong Kong, Taiwan, and Singapore. Figure 2.b shows that the four cities in Mainland China are around the median of the Asian Area (114.38 toe/million $), which shows that these four cities do not have significant advantages in terms of energy use efficiency as China's service-dominated economies. The average embodied intensities in Singapore and Hong Kong are almost at the lowest level compared with other regions in Mainland China, which demonstrates that their service industries have established a sustainable competitive advantage within the Asian Area.

3.2 Embodied energy in service consumption

3.2.1 Embodied energy in final consumption of services

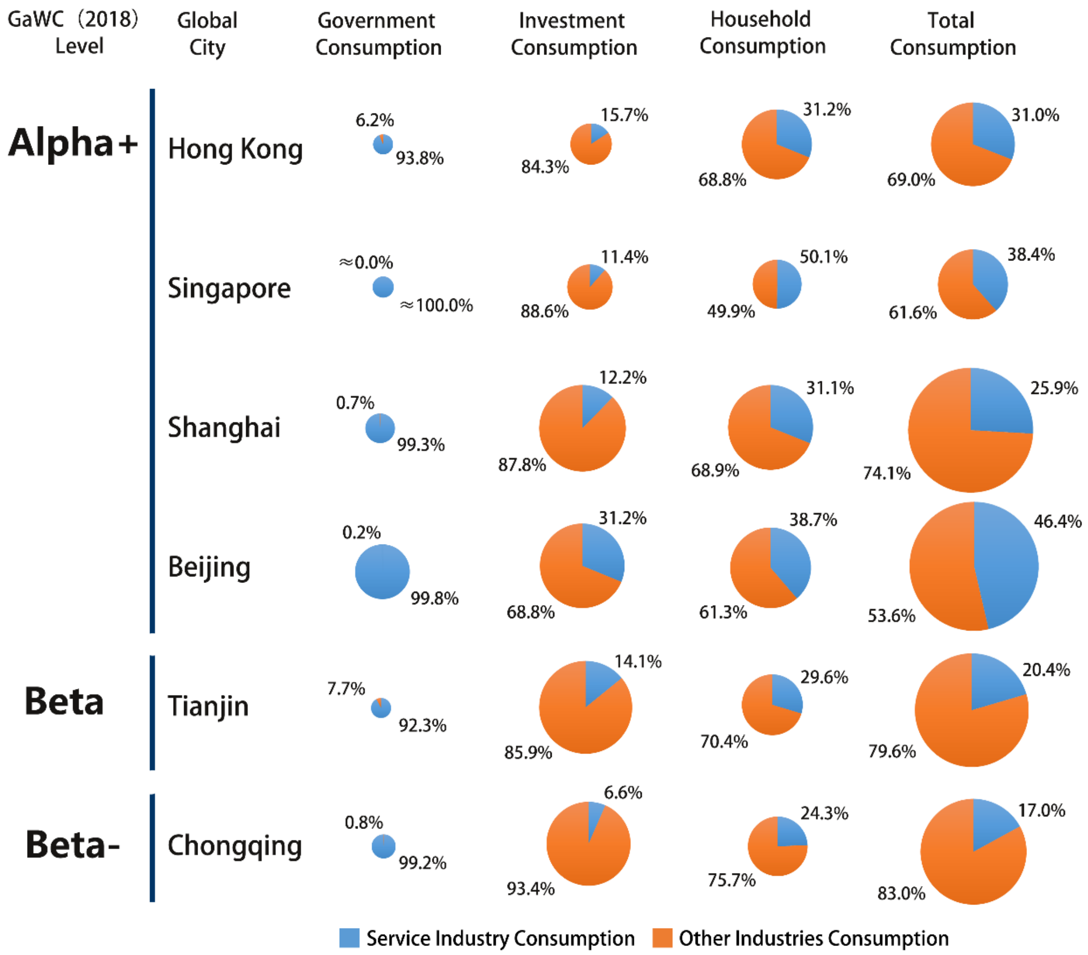


Figure 2. Comparison of embodied energy in final consumption of service and non-service industries in the six global cities

Figure 2 shows the pie chart of the embodied energy in final consumptions of service and non-service industries in the six global cities. The specific values are shown in Table A1. As for the embodied energy in total consumption, Hong Kong and Singapore are much smaller compared with the four Chinese mainland cities, which is partly contributed by Hong Kong and Singapore's higher production levels with lower energy consumption. The embodied energy use intensities of these two cities are lower than the averaged level of the other several cities, whose economy scales are not vastly different from Hong Kong and Singapore. We can also find out that service industries consume 25.88%~46.40% of total embodied energy in the four Alpha level global cities with a large economic weight of services, and 17.02%~20.45% in the two Beta level cities. Table 3 shows the per capita embodied energy in final consumptions in the six global cities. For per capita embodied energy in service industries, Beijing, Singapore, and Hong Kong, with the values of 1.09E-03, 1.04E-03, 8.05E-04 kgoe, are much larger than Tianjin, Shanghai, and Chongqing. Service industries consume 25.79%~46.38% of per capita embodied energy in the four Alpha level global cities and 17.27%~20.51% in the two Beta level cities. Taken together, the four Chinese mainland cities have a bigger total number of embodied energy consumption than the two international developed cities. Beijing, Singapore, and Hong Kong have a larger per capita embodied energy in service consumptions compared with the other three cities. And the proportions of service consumption both total and per capita in the four Alpha level cities are greater than the two Beta level cities.

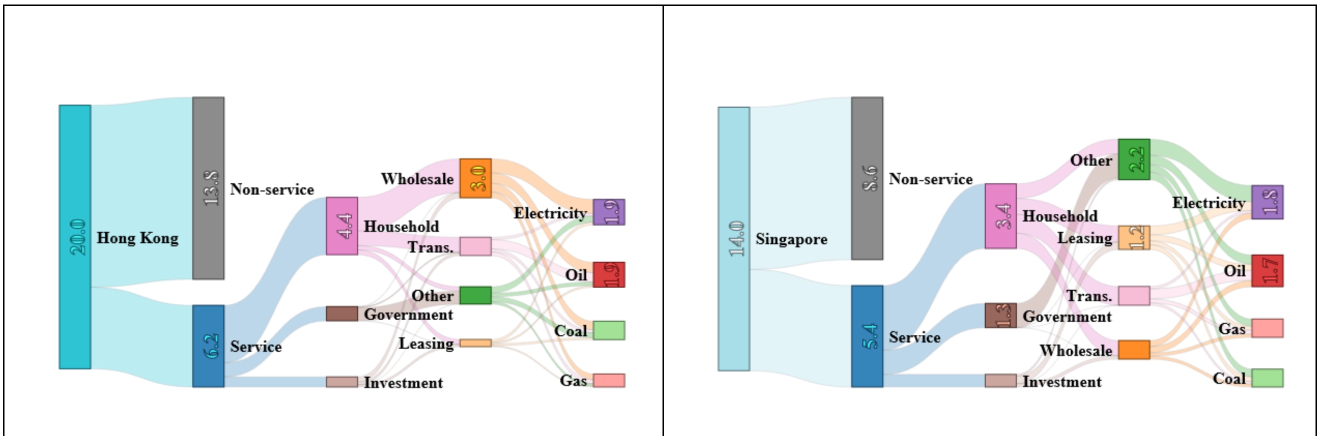
For three final consumptions in cities, government consumption is considerably less than household consumption and investment consumption in general. For the total embodied energy in three final consumptions in these six cities, the percentage of embodied energy consumption of service industries is dominating government consumption, steadily swinging from 6.57%~31.21% in investment consumption, and account for 24.34%~50.14% in household consumption. Comparisons between cities (rows) in Figure 1 suggest more results. The investment consumption is about the same in the four Chinese mainland cities, while the other two international cities are considerably less. It is probably because these four Chinese mainland cities are still experiencing a process of relatively large-scale infrastructure construction during China's urbanization, which occupies a large proportion of investment consumption. As the political center of China, Beijing has a much higher government consumption than other cities. While for household consumption, Shanghai and Beijing are greater compared with the other four cities, due to their large population and high household living standard.

Table 3. Per capita embodied energy in final consumption of service and non-service industries in the six global cities

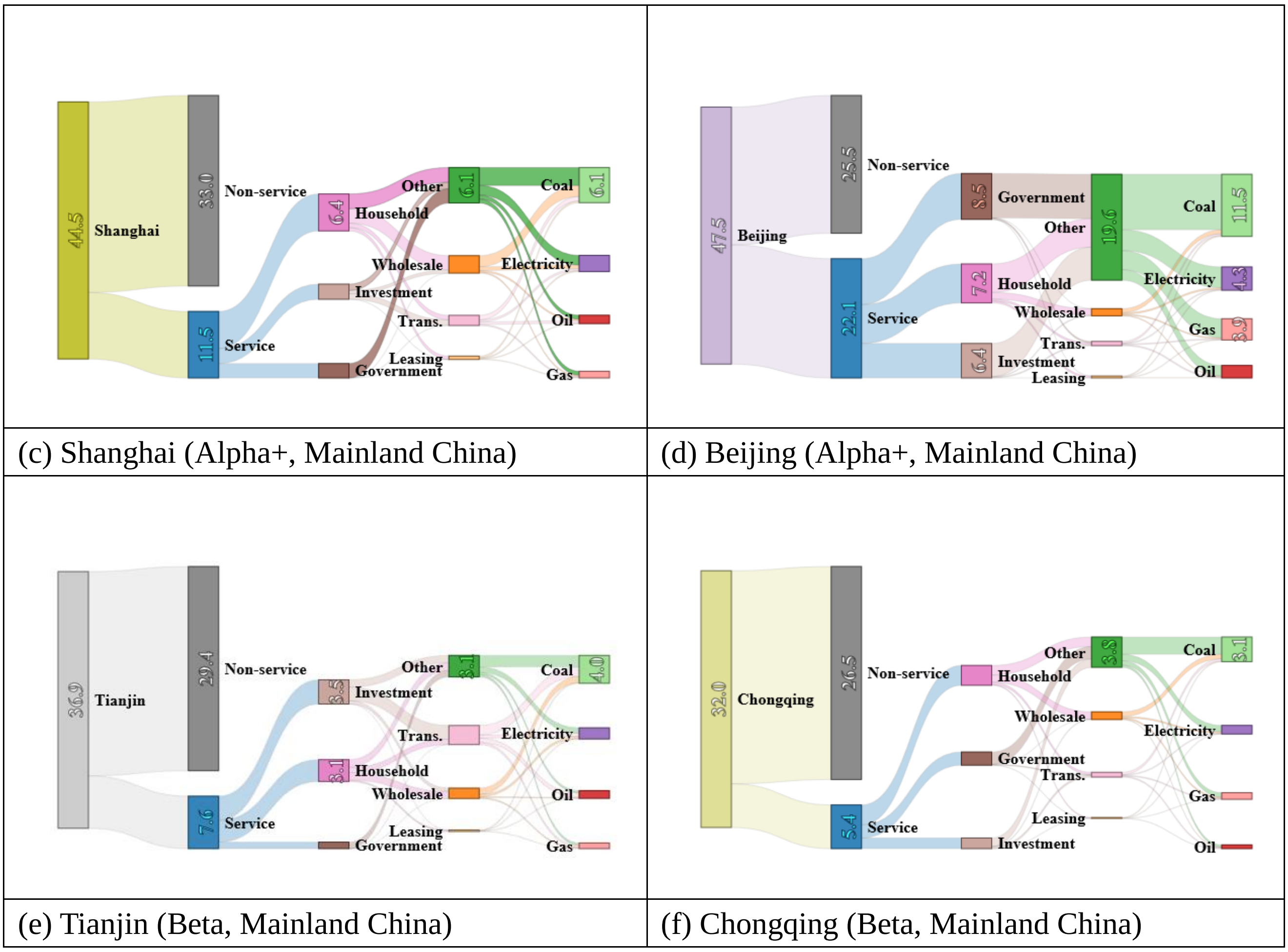
	Government Consumption (ktoe)		**Investment Consumption (ktoe)**		**Household Consumption (ktoe)**		**Total Consumption (ktoe)**	
	Service	Non-service	Service	Non-service	Service	Non-service	Service	Non-service
Hong Kong	1.40E-04	9.29E-06	9.94E-05	5.36E-04	5.65E-04	1.25E-03	8.05E-04	1.79E-03
Singapore	2.48E-04	3.14E-09	1.29E-04	1.00E-03	6.62E-04	6.58E-04	1.04E-03	1.66E-03
Shanghai	1.06E-04	7.69E-07	1.12E-04	8.01E-04	2.73E-04	6.04E-04	4.91E-04	1.41E-03
Beijing	4.20E-04	7.42E-07	3.16E-04	6.96E-04	3.57E-04	5.65E-04	1.09E-03	1.26E-03
Tianjin	6.91E-05	5.65E-05	2.57E-04	1.56E-03	2.31E-04	5.49E-04	5.57E-04	2.17E-03
Chongqing	5.64E-05	4.68E-07	4.54E-05	6.45E-04	8.47E-05	2.63E-04	1.86E-04	9.09E-04

For per capita embodied energy in three final consumptions, the embodied energy consumption of service industries account for a dominant position in government consumption, account for 6.58%~31.23% and 29.62%~50.15% in investment consumption and household consumption. Comparisons between cities in Table 3 suggest that Beijing has a much higher government consumption, followed by Singapore and Hong Kong. Tianjin has the largest per capita embodied energy in investment consumption, next are Singapore, Beijing, Shanghai, Chongqing, and Hong Kong. Per capita embodied energy in household consumption is positively related to economic development level. The top city is Singapore, others in descending orders are Hong Kong, Shanghai, Beijing, Tianjin, and Chongqing.

3.2.2 Decomposition of the embodied energy in the final consumption of services



(a) Hong Kong (Alpha+, developed)	(b) Singapore (Alpha+, developed)



(c) Shanghai (Alpha+, Mainland China) | (d) Beijing (Alpha+, Mainland China)

(e) Tianjin (Beta, Mainland China) | (f) Chongqing (Beta, Mainland China)

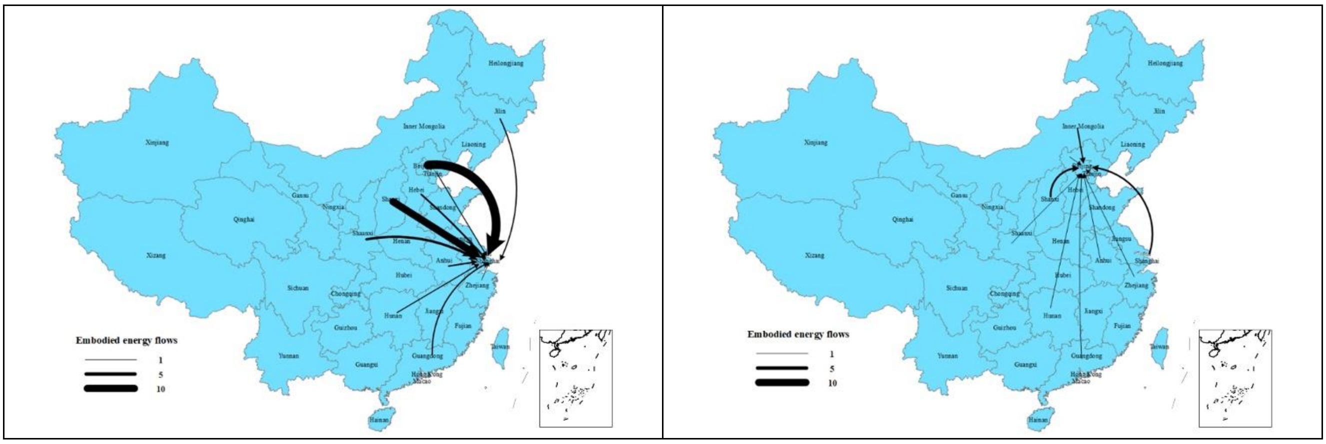
Figure 4. Sankey chart of embodied energy consumption by three major service consumptions (third column) and the service sectors (last column) in the six global cities (unit: Mtoe)

Figure 4 shows the decomposition of the embodied energy consumption in the specific service industries. As shown in Figure 4, household consumed the largest portion of embodied energy in service in four cities, i.e., 70.23% in Hong Kong, 63.71% in Singapore, 55.58% in Shanghai, and 45.42% in Chongqing. In contrast, household consumption was also considerable in Beijing (32.65%) and Tianjin (41.53%). However, the government consumed more (38.43%) in Beijing, and investment was consumed slightly more (46.08%) in Tianjin due to its large infrastructure investment. Another notable phenomenon was that investment consumption was the least in the three and almost consistently and slightly less than government consumption in each global city, except for Tianjin. In summary, there seems no significant correlation between the three final consumptions and the level of global cities. The embodied energy in three final consumptions is mainly affected by the special economic, political and cultural characteristics of cities.

To make a specific comparison of the embodied energy in service consumption, the service sectors are categorized into four groups, i.e., transportation, wholesale, leasing, and others, considering the sectoral consistency of global GTAP database and Chinese MRIO table, as well as the data comparability. The energy consumption embodied in specific service sectors in the six cities is shown in Figure 4. The portions of the leasing sector are relatively low in Shanghai (5.17%), Beijing (1.62%), Tianjin (2.95%), and Chongqing (2.16%); while the leasing sector in Hong Kong and Singapore have relatively high percentages (8.79%, 23.20%) contributed by their prosperous leasing industries. For transportation, the portions are low in inland cities like Beijing (3.57%) and Chongqing (10.93%), while high in coastal cities like Tianjin (36.32%), Shanghai (15.27%), Hong Kong (22.35%), and Singapore (18.53%). Maybe it is due to the important role that ocean shipping plays in these coastal cities. In addition, the most significant parts in investment consumption are relating to leasing and wholesale in Hong Kong and Singapore; while investment consumption is consistently directing to transportation in Mainland China, which mainly contributed to the extensive infrastructure projects, e.g., high-speed railways and subways.

The last layer indicates different energy types used in service industries in these six global cities. For Hong Kong and Singapore, the energy use is evenly distributed among different types. But for the four Mainland China cities, the portion of coal is much greater than other energy types (52.1%-56.5%) compared with Hong Kong and Singapore (22.6%, 17.6%). In other words, service industries in these four Mainland China cities have a markedly higher dependence on coal than Hong Kong and Singapore. The data of service sectors and energy types offers a closer look at the importance of coal for Mainland China. Coal almost occupies a greater portion in all the four service sectors in four Mainland China cities than Hong Kong and Singapore. In contrast, Hong Kong and Singapore have a greater portion of hydro, nuclear, and renewable electricity and oil use.

3.3 Embodied energy in service trade



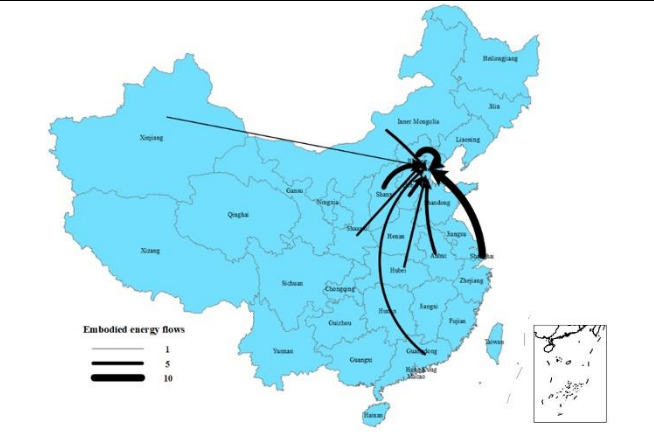
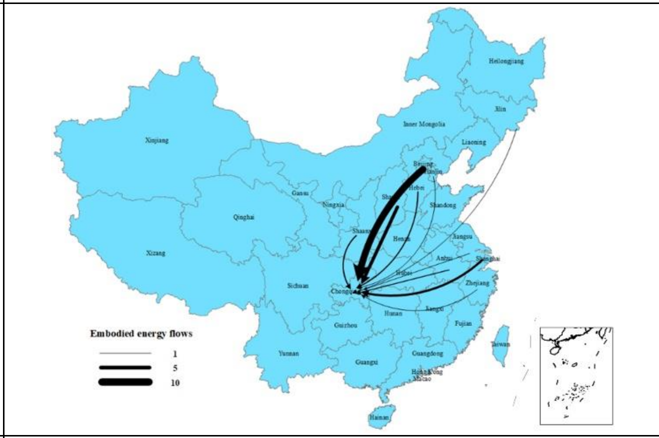
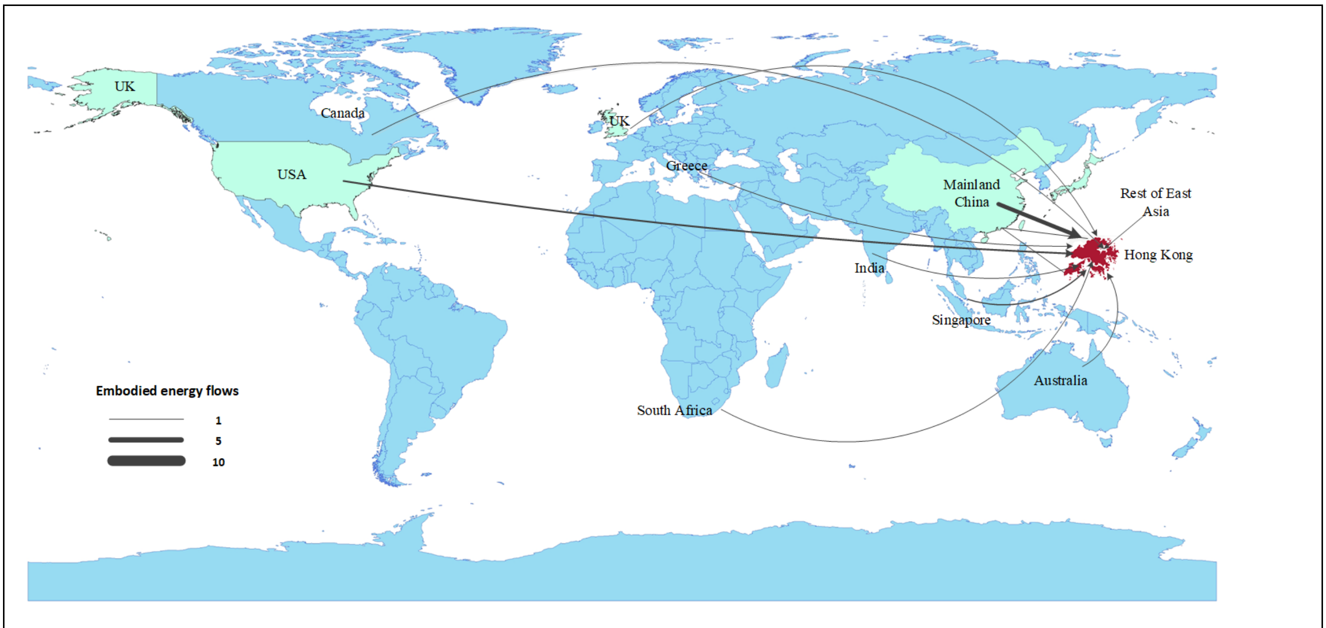
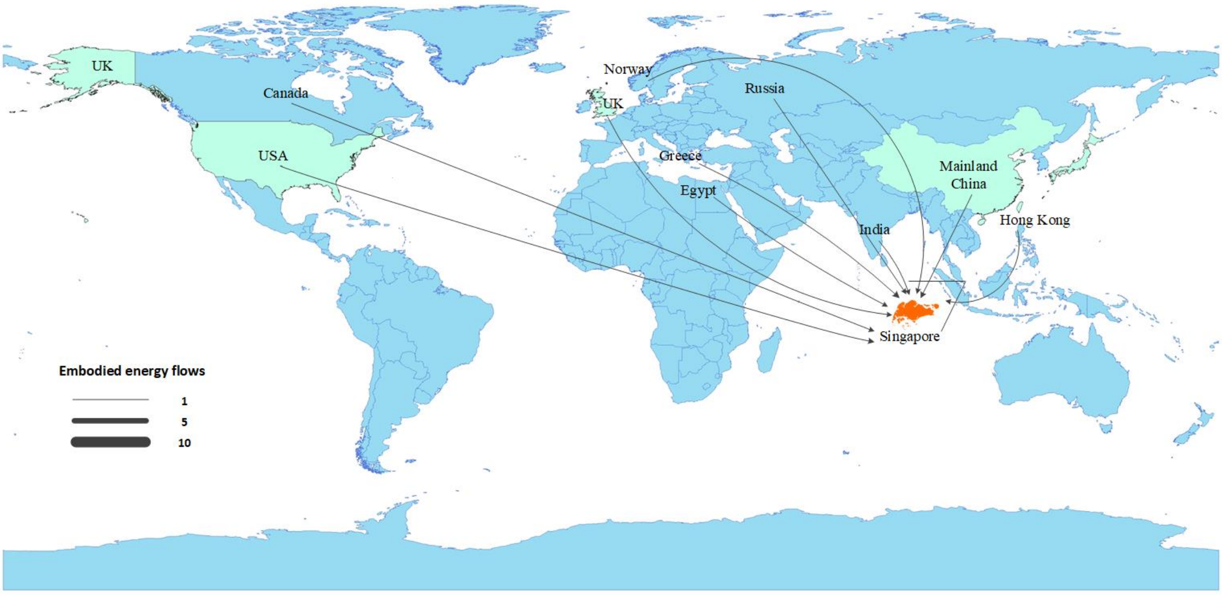
(a) Shanghai (21.45%)	(b) Beijing (2.60%)
	
(c) Tianjin (42.13%)	(d) Chongqing (26.54%)

Figure 5. The top ten trade routes of embodied energy in service in the four global cities in Mainland China except for themselves, where the percentage of contribution to overall service consumption was in brackets (the value shown in figures is 1+log(Embodied energy flow(Mtoe)))



(a) Hong Kong (9.58%)



(b) Singapore (2.93%)

Figure 6. The top ten trade routes of embodied energy in service in Hong Kong and Singapore except for themselves (the value shown in figures is 1+log(Embodied energy flow(Mtoe)))

According to the geographic distribution of the largest trade partners, the six cities were split into two groups for the visualization and analysis of their major trading routes. Figure 5 shows the top ten energy providers of the four cities in Mainland China in terms of embodied energy in service, where the self-supply was excluded. Since all of the four Chinese mainland cities receive little energy supply from outside mainland China, we only show the top ten supply flows from Mainland China. Figure 6 shows the top ten energy suppliers of Hong Kong and Singapore from worldwide in terms of embodied energy in service, where the self-supply was excluded. The width of arrows represents the amount of supply and the percentage in brackets shows the reliance on the ten supplies with respect to the city's overall consumption received from all over the world.

The top two service suppliers for the four Chinese mainland cities are Beijing and Shanghai, which are the largest service-dominated economies in China. As a big coal-producing province, Shanxi also plays an important role in a big supplier of embodied energy in service of four mainland cities. Specific to each city, Beijing occupies 8.73% of the total service supply in Shanghai at the amount of 2.01 Mtoe; while Shanghai only offers 0.53% of the total service supply of Beijing with the amount of 0.23 Mtoe. The top ten suppliers, including Beijing, Shanghai, Shanxi, Hebei, Anhui, and etc., offer 42.13% of the total service supply for Tianjin. While Shanghai, Shanxi, and Shannxi offer the most for Chongqing.

Mainland China, the United States, and Singapore are the top three service suppliers to Hong Kong at the values of 0.44, 0.16, and 0.11 Mtoe. For Singapore, the top three suppliers are Greece, United States, and Mainland China at the values of 0.08, 0.05, and 0.05 Mtoe. In contrast, Singapore receives considerably less amount of service from mainland China than that of Hong Kong. The main suppliers of Hong Kong and Singapore are distributed in both developed regions like Europe, Australia, and North America, and developing regions like mainland China and India.

4. Conclusions and policy implications

4.1 Conclusions

Energy is an important strategic resource for developing sustainable cities. In the context of globalization, the energy connections among global cities become more and more complex due to the increasing interregional trade. For global cities, the 40s to 90s percentage of GDP is contributed by service industries, thus it is necessary to conduct a systematic assessment of the embodied energy in service industries. Global cities, with virtually little self-sufficiency on energy and close links with other global economies, are highly dependent on external energy provision. To ensure energy security and foster sustainable development in a city, many studies have focused on direct energy use, with the immense indirect energy use ignored. This will greatly underestimate the energy use in cities. Thus, we choose to focus on embodied energy use to get an accurate view of energy use in global cities.

This study presents an overview of embodied energy in service industries in six global cities based on MRIOA. These six global cities are nested to a 169-region, 30-sector trading network to calculate the embodied energy in service consumption and trading, meanwhile, to illustrate the links between the source of energy production and the energy use in final consumption in the shape of services. The specific results are as follows.

1) Embodied energy intensity of service industry

By comparing the embodied energy intensity of the service industry, it is easy to notice that Hong Kong and Singapore have relatively lower energy use intensities compared with other mainland cities. The other four mainland cities have energy intensities higher than global median value and around the median of Greater China economies in terms of energy use efficiency. With a lower intensity than almost all regions in mainland China, we can conclude that the service industries in Hong Kong and Singapore have established a sustainable competitive advantage within the Asian Area.

2) Embodied energy in service consumption

Embodied energy in the service industry both total and per capita in global cities accounts for a considerable proportion, i.e., 25.88%~46.40% of total embodied energy in the four Alpha level global cities with a large economic weight of services, and 17.02%~20.45% in the two Beta level cities. The proportions of embodied energy in service consumption are related to the level of the cities. The change in embodied energy in service consumption among six global cities can be explained by three drivers, i.e., urban consumption structure of services, external supply chains of services, and local energy use efficiency. The decomposition of the embodied energy consumption in the specific service industries is completed in this study. Beijing, as the capital of China, has a considerable embodied energy in government consumption of services. Coastal cities like Tianjin, Shanghai, Hong Kong, and Singapore have higher proportions of transportation consumption. Four Chinese mainland cities consume a larger proportion of coal than Hong Kong and Singapore.

3) Embodied energy in service trade

Energy sources of each city studied include not only themselves but also many other regions. For the four Chinese mainland cities, Beijing, Shanghai, Shanxi are the top three suppliers of energy for their service industries. While for Hong Kong and Singapore, mainland China and the United States both play an important role in supplying energy for their service industries. Other important suppliers distribute in regions like Europe, Australia, North America, and India.

4.2 Policy implications

To achieve the global climate change agreement, energy-saving and emission reduction target has been set in global cities. Chinese cities were directed to reduce its energy consumption per unit of GDP by 18% and carbon emission per unit GDP by 17% during the "12th Five-Year" period via a comprehensive energy reduction program (NEA, 2013). China's 13th Five Year Plan on Energy Development (2016-2020) targeted a 15% reduction in energy consumption per unit of GDP by 2020 and aimed to cut carbon intensity 18% in the same period (NPCPRC, 2016). Hong Kong is in the process of implementing energy policies to ensure sustainability. It proposes to optimize the fuel mix and improve the energy efficiency to reach the energy-saving target of “reducing energy intensity by 45% by 2035 based on 2005 level” (APERC, 2015). Singapore promised to reduce its emissions intensity by 36% by 2030 based on the level of 2005. To achieve this goal, Singapore focuses on developing energy policies, enhancing infrastructure, investing in research and development, and build a strong capable workforce (EMA, 2015).

Service industry should be paid enough attention to achieve sustainable development goals in global cities since embodied energy in the service industry in global cities accounts for a large proportion. However, most current policies mainly focus on industrial energy saving, like the steel industry, the coal industry and etc. Thus, a comprehensive analysis of embodied energy in consumption and trading of services is crucial to reduce energy use. It will provide an important complement to energy-saving policymaking at the city level. Completing the transformation by focusing on the service industry could contribute significantly to overall energy conservation. To realize the sustainable development of mainland cities whose energy consumption is mainly attributed to secondary industries rather than service industry, the industrial transformation to increase the proportion of the service industry is a way to achieve urban saving energy. Currently, the total area of these four Chinese mainland cities makes up merely 1.22% of mainland China, while their embodied energy consumption in service industry occupies 14.27% of total consumption in the service industry in China mainland, and

2.32% of total consumption, which is quite a large number.

The policy suggestions focusing on the specific service industries are given. Service industries provide very global up-stream commodities/services, which will be affected by the worldwide trade. The division of global service industries based on the specialization and different urban characters began to be formed. Thus, to identify the critical part along the global supply chains should be attached great importance. As our results imply, as service industry covers most of the government consumption in cities of different developing stages according to this research., it is important for the government to consider improving energy use intensity in the service industry by optimizing its own energy consumption. Transportation services in coastal cities, like Tianjin, Shanghai, Hong Kong, and Singapore are important concerns to realize energy conservation in global cities. With the implementation of China's Belt and Road initiative, the infrastructure investment efforts have been made by China and other participating countries. The embodied energy of large cities, especially the cities along the Road, like Shanghai and Hong Kong, will be more driven by transportation services.

Specific policies should also be based on different urban economies' own specific economic, political and cultural characteristics. The large cities should improve the energy use efficiency of their local energy-intensive industries. And the efficiency improvement effect will be finally transferred to the upstream industries, i.e., service industries. Large cities have implemented many targeted energy-saving policies. For example, Beijing began promoting low-carbon energy sources and implemented strict control of coal consumption to enhance the utilization level of natural gas, electricity, and renewable energy. This reduced the proportion of coal consumption to 19.57% in 2012 and raised the consumption of natural gas energy, electricity, petroleum, and other energy resources (Liu et al., 2016). Singapore's Climate Action Plan in 2016 aimed to improve energy efficiency by expanding the scope of current initiatives across all sectors, including buildings, transport, household, waste, and water. The plan proposed to invest in low-carbon technologies and developing new Waste-to-Energy plants to optimize resource and energy recovery (Quek et al., 2018; SGPC, 2016).

From the trading perspective, the interregional cooperation policies in global cities based on the regional advantages should be emphasized based on the results of embodied energy in service trading. As developed economies, global cities take more responsibilities to provide more economic and technical supports for undeveloped regions worldwide to achieve energy saving. The findings concerning embodied energy in its service trading in this study shed new light on our understanding of the service trading flows from developed regions to developed regions, which accounts for a large proportion, like Beijing to Shanghai. That conclusion highlights the urgent need for these cities to establish an incentive mechanism for cooperative energy saving. The governments of energy importing cities could provide price subsidies and low-interest rates for low energy-intensive products, and cultivate the low energy consumption culture in society to offer guidance in enhancing low energy consumption behavior. Besides, regions providing rich resources for other regions are important, too. For example, as a large coal-producing province in a mainly coal-consuming country, Shanxi ranks as a top embodied energy provider in the service industry next to Beijing and Shanghai. Therefore, more capital investment could be devoted to improving its production efficiencies. The embodied energy along the supply chain of every service industry can help optimize the trade structures. Regional cooperation is an important strategy for sustainable energy use in global cities. It is appropriate for all global cities to join forces so that more sustainable and effective measures can be established. The regulation within the urban agglomeration can encourage global cities to export energy-saving services.

Acknowledgments

This research was supported by the Fund of Coordinately Supporting the Construction of Top Universities and First-class Disciplines of Renmin University of China, the “Support for Oversea Talent Scientific Research Funding” established by the Renmin University of

China.", and fund for building world-class universities (disciplines) of Renmin University of China. The authors are grateful to Ms. Ana Laura Camacho Cerdas and Ms. Linzhen Han for their helpful comments on this study.

References

APERC, 2015. Asia Pacific Energy Research Centre. APEC Energy Overview. https://aperc.ieej.or.jp/file/2017/6/2/APEC_Energy_Overview_2015.pdf.

Appleby, K., 2018. Global cities are stepping up on climate action. https://www.cdp.net/en/articles/cities/global-cities-are-stepping-up-on-climate-action.

BMBS, 2018. Beijing Municipal Bureau of Statistics .http://www.bjstats.gov.cn/tjsj/cysj/201511/t20151109_311729.html.

BMPG, 2017. Beijing Municipal People's Government. Beijing Thirteen-Five Energy Development Plan.

Bullard, C.W., 1975. Energy costs, benefits, and net energy/CAC No. 174. CAC document; no. 174.

Bullard III, C.W., Herendeen, R.A., 1975. The energy cost of goods and services. Energy policy 3, 268-278.

CD, 2018. Chongqing Data. http://www.cqdata.gov.cn/tablequery.htm?code=AG02.

Chen, B., Yang, Q., Zhou, S., Li, J.S., Chen, G.Q., 2017a. Urban economy's carbon flow through external trade: Spatial-temporal evolution for Macao. Energy Policy 110, 69-78.

Chen, G., Li, J., Chen, B., Wen, C., Yang, Q., Alsaedi, A., Hayat, T., 2016. An overview of mercury emissions by global fuel combustion: the impact of international trade. Renewable and Sustainable Energy Reviews 65, 345-355.

Chen, G., Shan, Y., Hu, Y., Tong, K., Wiedmann, T., Ramaswami, A., Guan, D., Shi, L., Wang, Y., 2019. Review on City-Level Carbon Accounting. Environmental Science & Technology 53, 5545-5558.

Chen, G.Q., Zhang, B., 2010. Greenhouse gas emissions in China 2007: inventory and input–output analysis. Energy Policy 38, 6180-6193.

Chen, S., Chen, B., 2015. Urban energy consumption: different insights from energy flow analysis, input–output analysis and ecological network analysis. Applied Energy 138, 99-107.

Chen, W., Wu, S., Lei, Y., Li, S., 2017b. Interprovincial transfer of embodied energy between the Jing-Jin-Ji area and other provinces in China: A quantification using interprovincial input-output model. Science of the Total Environment 584, 990.

Chen, Z.-M., Chen, G., 2013a. Demand-driven energy requirement of world economy 2007: a multi-region input–output network simulation. Communications in Nonlinear Science and Numerical Simulation 18, 1757-1774.

Chen, Z.-M., Chen, G., 2013b. Virtual water accounting for the globalized world economy: national water footprint and international virtual water trade. Ecological Indicators 28, 142-149.

Chen, Z., Chen, G., 2011a. An overview of energy consumption of the globalized world economy. Energy Policy 39, 5920-5928.

Chen, Z., Chen, G., 2011b. Embodied carbon dioxide emission at supra-national scale: a coalition analysis for G7, BRIC, and the rest of the world. Energy Policy 39, 2899-2909.

Chow, L.C.-h., 2001. A study of sectoral energy consumption in Hong Kong (1984–97) with special emphasis on the household sector. Energy policy 29, 1099-1110.

Costanza, R., 1980. Embodied energy and economic valuation. Science 210, 1219-1224.

CSDHK, 2018a. Census and Statistics Department Hong Kong Special Administrative. National Income Section (2)1. https://www.censtatd.gov.hk/hkstat/sub/sp250.jsp?tableID=036&ID=0&productType=8.

CSDHK, 2018b. Census and Statistics Department Hong Kong. https://www.censtatd.gov.hk/hkstat/sub/sp240.jsp?tableID=082&ID=0&productType=8.

CSDHK, 2018c. Census and Statistics Department Hong Kong. https://www.censtatd.gov.hk/hkstat/sub/sp250.jsp?tableID=036&ID=0&productType=8.

Dhakal, S., 2009. Urban energy use and carbon emissions from cities in China and policy implications. Energy policy 37, 4208-4219.

DSS, 2018. Department of Statistics Singapore. https://www.tablebuilder.singstat.gov.sg/publicfacing/createDataTable.action?refId=12359.

EMA, 2015. Energy Market Authority. https://www.ema.gov.sg/ourenergystory.aspx.

Fourcroy, C., Gallouj, F., Decellas, F., 2012. Energy consumption in service industries: Challenging the myth of non-materiality. Ecological Economics 81, 155-164.

Gadrey, J., 2010. The environmental crisis and the economics of services: the need for revolution. The handbook of innovation and services. A multi-disciplinary perspective, 93-125.

GaWC, 2018. https://www.lboro.ac.uk/gawc/world2018t.html.

Ge, J., Lei, Y., 2014. Carbon emissions from the service sector: an input-output application to Beijing, China. Climate Research 60, 13-24.

Guo, S., Chen, G., 2013. Multi-scale input-output analysis for multiple responsibility entities: carbon emission by urban economy in Beijing 2007. Journal of Environmental Accounting and Management 1, 43-54.

Guo, S., Shao, L., Chen, H., Li, Z., Liu, J., Xu, F., Li, J., Han, M., Meng, J., Chen, Z.-M., 2012. Inventory and input–output analysis of CO2 emissions by fossil fuel consumption in Beijing 2007. Ecological Informatics 12, 93-100.

Guo, S., Shen, G.Q.P., Yang J., Sun B.X., F., X., 2016. Embodied energy of service trading in Hong Kong. Smart and Sustainable Built Environment 4, 234-248.

Han, M., Chen, G., 2018. Global arable land transfers embodied in Mainland China's foreign trade. Land Use Policy 70, 521-534.

Hannon, B., Blazeck, T., Kennedy, D., Illyes, R., 1983. A comparison of energy intensities: 1963, 1967 and 1972. Resources and Energy 5, 83-102.

He, Q., He, W., Song, Y., Wu, J., Yin, C., Mou, Y., 2018. The impact of urban growth patterns on urban vitality in newly built-up areas based on an association rules analysis using geographical ‘big data’. Land Use Policy 78, 726-738.

Lenzen, M., Pade, L.-L., Munksgaard, J., 2004. CO2 multipliers in multi-region input-output models. Economic Systems Research 16, 391-412.

Li, J., Chen, G., Wu, X., Hayat, T., Alsaedi, A., Ahmad, B., 2014. Embodied energy assessment for Macao′ s external trade. Renewable and Sustainable Energy Reviews 34, 642-653.

Li, J.S., Zhou, H., Meng, J., Yang, Q., Chen, B., Zhang, Y., 2018a. Carbon emissions and their drivers for a typical urban economy from multiple perspectives: A case analysis for Beijing city. Applied Energy 226, 1076-1086.

Li, Y.L., Chen, B., Han, M.Y., Dunford, M., Liu, W., Li, Z., 2018b. Tracking carbon transfers embodied in Chinese municipalities' domestic and foreign trade. Journal of Cleaner Production 192, 950-960.

Li, Z., Galván, M.J.G., Ravesteijn, W., Qi, Z., 2017. Towards low carbon based economic development: Shanghai as a C40 city. Science of the Total Environment 576, 538-548.

Lin, B., Nelson, B.I., 2019. Determinants of industrial carbon dioxide emissions growth in Shanghai: a quantile analysis. Journal of cleaner production.

Liu, J., Chen, S., Wang, H., Campana, P.E., Yan, J., 2016. Evolution of China's urban energy consumption structure—a case study in Beijing. Energy Procedia 88, 88-93.

Meng, J., Mi, Z., Guan, D., Li, J., Tao, S., Li, Y., Feng, K., Liu, J., Liu, Z., Wang, X., 2018.

The rise of South–South trade and its effect on global CO 2 emissions. Nature communications 9, 1871.

Minx, J.C., Wiedmann, T., Wood, R., Peters, G.P., Lenzen, M., Owen, A., Scott, K., Barrett, J., Hubacek, K., Baiocchi, G., 2009. Input–output analysis and carbon footprinting: an overview of applications. Economic Systems Research 21, 187-216.

Nawab, A., Liu, G., Meng, F., Hao, Y., Zhang, Y., Hu, Y., Casazza, M., 2019. Exploring Urban Energy-Water Nexus Embodied in Domestic and International Trade: A Case of Shanghai. Journal of Cleaner Production.

NEA, 2013. National Energy Administration. www.nea.gov.cn/2013-01/28/c_132132808.htm.

NPCPRC, 2016. The National People's Congress of the People's Republic of China. China’s 13th Five Year Plan. www.npc.gov.cn/wxzl/gongbao/2016-07/08/content_1993756.htm.

Odum, H.T., 1983. Systems Ecology; an introduction.

Paloheimo, E., Salmi, O., 2013. Evaluating the carbon emissions of the low carbon city: A novel approach for consumer based allocation. Cities 30, 233-239.

Piaggio, M., Alcántara, V., Padilla, E., 2015. The materiality of the immaterial: service sectors and CO2 emissions in Uruguay. Ecological Economics 110, 1-10.

Quek, A., Ee, A., Ng, A., Wah, T.Y., 2018. Challenges in Environmental Sustainability of renewable energy options in Singapore. Energy policy 122, 388-394.

Sassen, S., 1991. The Global City: New York, London, Tokyo. 16 March 2015 at the Wayback Machine. Princeton University Press. ISBN 0-691-07063-6.

Schulz, N.B., 2010. Delving into the carbon footprints of Singapore—comparing direct and indirect greenhouse gas emissions of a small and open economic system. Energy Policy 38, 4848-4855.

SGPC, 2016. Singapore Press Centre. Singapore unveils latest plans for addressing climate change. https://www.gov.sg/resources/sgpc/media_releases/nccs/press_release/P-20160710-1.

SMSB, 2018. Shanghai Municipal Statistics Bureau.Shanghai Statistic Yearbook. http://www.stats-sh.gov.cn/tjnj/nje18.htm?d1=2018tjnje/E0401.htm.

Tang, M., Hong, J., Liu, G., Shen, G.Q., 2019. Exploring energy flows embodied in China's economy from the regional and sectoral perspectives via combination of multi-regional input–output analysis and a complex network approach. Energy 170, 1191-1201.

Tian, X., Chang, M., Shi, F., Tanikawa, H., 2017. Decoding the effect of socioeconomic transitions on carbon dioxide emissions: Analysis framework and application in megacity Chongqing from inland China. Journal of cleaner production 142, 2114-2124.

UNDESA, 2018. 2018 Revision of World Urbanization Prospects.

UNDESC, 2015. United Nations, Department of Economic and Social Affairs, Population Division. World Urbanization Prospects: The 2014 Revision, (ST/ESA/SER.A/366).

Webb, J., Hawkey, D., Tingey, M., 2016. Governing cities for sustainable energy: The UK case. Cities 54, 28-35.

WHO, 2015. World Health Organization. Global Report on Urban Health—Executive Summary. http://www.who.int/kobe_centre/measuring/urban-global-report/en/.

Wiedmann, T., 2009. Carbon footprint and input–output analysis–an introduction. Taylor & Francis.

Wiedmann, T., Wood, R., Minx, J.C., Lenzen, M., Guan, D., Harris, R., 2010. A carbon footprint time series of the UK–results from a multi-region input–output model. Economic systems research 22, 19-42.

WorldBank, 2018. https://data.worldbank.org/indicator/NV.SRV.TOTL.ZS?year_high_desc=true.

Wu, X., Chen, G., 2018. Coal use embodied in globalized world economy: From source to sink through supply chain. Renewable and Sustainable Energy Reviews 81, 978-993.

Wu, X.D., Guo, J.L., Han, M.Y., Chen, G.Q., 2018. An overview of arable land use for the world economy: From source to sink via the global supply chain. Land Use Policy 76, 201-214.

Zhang, B., Chen, G., 2014. Methane emissions in China 2007. Renewable and Sustainable Energy Reviews 30, 886-902.

Zhang, B., Qiao, H., Chen, B., 2015. Embodied energy uses by China's four municipalities: a study based on multi-regional input–output model. Ecological modelling 318, 138-149.

Zhang, B., Qiao, H., Chen, Z.M., Chen, B., 2016. Growth in embodied energy transfers via China's domestic trade: Evidence from multi-regional input–output analysis. Applied Energy 184, 1093-1105.

Zhang, Y., Lei, Y., 2017. Research on the Carbon Emissions of Beijing Residents Based on the Input-Output Model. Polish Journal of Environmental Studies 26.

Zheng, W., Shen, G.Q., Wang, H., Hong, J., Li, Z., 2017. Decision support for sustainable urban renewal: A multi-scale model. Land Use Policy 69, 361-371.

Zhu, Z., Liu, Y., Tian, X., Wang, Y., Zhang, Y., 2017. CO2 emissions from the industrialization and urbanization processes in the manufacturing center Tianjin in China. Journal of cleaner production 168, 867-875.

Appendix A

Table A1

Embodied energy in final consumption of service and non-service industries in the six global cities.

	Government Consumption (Mtoe)		**Investment Consumption (Mtoe)**		**Household Consumption (Mtoe)**		**Total Consumption (Mtoe)**	
	Service	Non-service	Service	Non-service	Service	Non-service	Service	Non-service
Hong Kong	1.08	0.07	0.77	4.13	4.35	9.62	6.20	13.82
Singapore	1.28	0.00	0.67	5.21	3.43	3.41	5.38	8.62
Shanghai	2.50	0.02	2.62	18.80	6.40	14.18	11.52	33.00
Beijing	8.48	0.02	6.38	14.06	7.20	11.40	22.06	25.48
Tianjin	0.94	0.08	3.48	21.17	3.14	7.45	7.55	29.38
Chongqing	1.65	0.01	1.33	18.83	2.47	7.68	5.44	26.53

Table A2

Concordance of sectors for Chinese MRIO and GTAP database.

No.	**Sectors for GTAP database**	**No.**	**Sectors for Chinese MRIO**
1	Paddy rice	1	Agriculture
2	Wheat		
3	Cereal grains nec		
4	Vegetables; fruit; nuts		
5	Oil seeds		
6	Sugar cane; sugar beet		
7	Plant-based fibers		
8	Crops nec		
9	Bovine cattle; sheep and goats; horses		
10	Animal products nec		
11	Raw milk		
12	Wool; silk-worm cocoons		
13	Forestry		

14	Fishing		
15	Coal	2	Coal mining
16	Oil	3	Petroleum and gas
17	Gas		
18	Minerals nec	4	Metal mining
		5	Nonmetal mining
19	Bovine meat products	6	Food processing and tobaccos
20	Meat products nec		
21	Vegetable oils and fats		
22	Dairy products		
23	Processed rice		
24	Sugar		
25	Food products nec		
26	Beverages and tobacco products		
27	Textiles	7	Textile
28	Wearing apparel	8	Clothing, leather, fur, etc.
29	Leather products		
30	Wood products	9	Wood processing and furnishing
31	Paper products; publishing	10	Paper making, printing, stationery, etc.
32	Petroleum; coal products	11	Petroleum refining, coking, etc.
33	Chemical; rubber; plastic products	12	Chemical industry
34	Non-metallic minerals	13	Nonmetal products
35	Ferrous metals	14	Metallurgy
36	Metals nec	15	Metal products
37	Metal products		
38	Motor vehicles and parts	17	Transport equipment
39	Transport equipment nec		
40	Electronic equipment	19	Electronic equipment
41	Machinery and equipment nec	16	General and specialist machinery
		18	Electrical equipment

		20	Instrument and meter
42	Manufactures nec	21	Other manufacturing
43	Electricity	22	Electricity and hot water production and supply
44	Gas manufacture; distribution	23	Gas and water production and supply
45	Water		
46	Construction	24	Construction
47	Trade	26	Wholesale and retailing
		27	Hotel and restaurant
48	Transport nec	25	Transport and storage
49	Water transport		
50	Air transport		
51	Communication	28	Leasing and commercial services
52	Financial services nec		
53	Insurance		
54	Business services nec		
57	Dwellings		
55	Recreational and other services	29	Scientific research
56	Other services (government)	30	Other services

Appendix B

The detailed process of double deflation method

China's input-output tables are usually based on current prices, but the overall level of prices in different years is usually different, and the price changes in different sectors are also distinct in different years. Therefore, the original monetary value in the official input-output tables includes the influence of price fluctuations in different years. In order to eliminate the influence of such price fluctuations, this paper used the price "double deflation method" to make the invariable price input-output table. The constant price input-output tables constructed in this study are based on 2012 prices. Assuming that the price index of each sector in a given year is p_i, and the price index of each department in the base year is b_i, $d_i = b_i / p_i$ is defined as the subtraction factor of a certain sector, then the subtraction factor d_i of each sector can constitute a vector .

$$Z_d = diag(d) \times Z \quad \text{(B-1)}$$

$$Y_d = diag(d) \times Y \quad \text{(B-2)}$$

$$X_d = diag(d) \times X \quad \text{(B-3)}$$

Where diag (d) denotes transforming the vector into a corresponding diagonal matrix. , Y and X represents the products that are used as intermediate use, the products that are used as final use and the total outputs, respectively. $_d$, Y_d and $_d$ denotes the new matrix obtained after the double deflation process. After filling these new data to the corresponding positions of the original input-output tables, the constant price input-output tables can be obtained.