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Mercury emissions embodied in Beijing economy

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ABSTRACT

Atmospheric mercury pollution is a severe threat to both environment and human health. For Beijing economy 2012, this paper compiles an exhaustive inventory for direct mercury emissions and performs an input–output analysis for indirect mercury emission connections. It's estimated that Beijing's direct atmospheric mercury emissions were 2.62 tonnes, mainly contributed by combustion of coal and cement production. Most sectors' indirect emission intensities are larger than direct ones, which indicates that there are considerable inter-sector mercury emission flows embodied in intermediate transactions. The economy avoided 5.30 tonnes of mercury emissions via trade, which double its direct emissions. Mercury emissions induced by Beijing's final consumption were 3 times as many as direct emissions and the largest part was due to capital formation. The results indicate that the end-of-pipe accounting couldn't fully capture urban economy's emissions. Our findings also provide insights for mercury emission mitigation from both the local and systematic perspectives. From the local perspective of direct emissions, the economy can adjust its energy structure and develop clean coal combustion technology as well as mercury removal devices. For the systematic perspective associated with indirect emissions, policy should be extended to manage consumption of the trans-boundary energy and resources.

1. Introduction

Atmospheric mercury is an extremely toxic pollutant which poses severe threats to human health and environmental security. Due to its wide distribution and long range transport, it can inflict damage on the whole world (Ci et al., 2011). During its complicated life cycle, inorganic mercury can be transformed into methylmercury, which is the culprit of Minamata disease. As the knowledge about the hazardous nature of atmospheric mercury continues to deepen, more and more efforts have been devoted to the research on atmospheric mercury emissions.

In recent years, much research has focused on the analysis for atmospheric mercury emissions directly released from anthropogenic sources. Under the UNEP-Chemicals and AMAP project, annual anthropogenic emissions of mercury into air were estimated as 1900 tonnes in 1995 (Pacyna and Pacyna, 2002), increasing to 1930 tonnes in 2005 (Pacyna et al., 2010) and 1960 tonnes in 2010 (UNEP, 2013). Muntean et al. (2014) evaluated global mercury emission inventory from 1970 to 2008, showing the emission hot-spots on gridded $0.1^\circ \times 0.1^\circ$ resolution maps. Moreover, Steenhuisen and Wilson (2015) allocated major point-source emissions in the 2010 AMAP inventory to some 4600 identified point source locations, most of which are in Africa, Asia, Australia and South America. In addition, mercury inventories at national scale were also compiled for important emitters like India (Laura et al., 2013), the United States (Pai et al., 2000), China (Wang et al., 2000; Wu et al., 2006), etc.

It's noted that most of these studies focused on the end-of-pipe mercury emissions, i.e., atmospheric mercury directly released by human activities. For a specific economy, mercury emissions of each sector in various regions are calculated separately. In fact, the

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socio-economy is a complex network, covering different sectors that interweave with each other via exchanging goods and services. For instance, according to direct accounting method, mercury emissions from Sector Construction are at very low level. However, it consumes large amount of electricity, cement, steel and other metals, whose production processes emit large amount of mercury emissions. That means Sector Construction's demand can induce indirect emissions, which happens on a product or service's supply chain. Given this, a more comprehensive approach which can cover both direct and indirect effects is in need to investigate the interrelationship of mercury emissions between sectors.

Input–Output analysis (IOA), proposed by Leontief (1936) in the late 1930s, is one of the most widely adopted methods for environmental emission investigations, as founded on the input–output table reflecting the complex interaction between different sectors. Along with the rising concern on environmental protection, IOA was extended to analyze environmental problems related to air pollution and energy consumption in the 1970s (House, 1977; Leontief, 1970; Leontief and Ford, 1972; Miernyk and Sears, 1974), which is named as environmentally-extended input–output analysis (EE-IOA). Henceforth, EE-IOA has been excessively used to evaluate GHG emissions (Guan et al., 2008), energy (Hannon, 2010; Jiang and Chen, 2011; Wu et al., 2015) and other ecological elements (Han et al., 2014, 2015) throughout the world. In recent years, embodiment analysis has been applied to investigate China's carbon emissions problem with IOA (Chen and Chen, 2010). Zhang et al. (2015) presented an inventory of non-CO_2 GHG emissions by the Chinese economy in 2005. Based on input–output table, embodied mercury emissions, defined as the sum of direct (on-site) and indirect (supply-chain) emissions (Chen and Han, 2015a,b; Chen et al., 2010a; Li et al., 2016a; Li et al., 2016b), can draw a holistic picture of anthropogenic mercury emissions.

Additionally, previous studies on atmospheric mercury emissions were mainly investigated at global scale and national scale. However, little attention has been paid to mercury emission related issues at urban scale. In fact, cities, as centers of population, transportation, industries, which can cause large amount mercury emissions (Chen et al., 2014). Furthermore, cities are responsible for about 2/3 world's energy consumption, which is one of the major sources for mercury emissions (Chen and Chen, 2015b). In contrast to a large body of literature on GHG emissions (Chen and Chen, 2011; Li et al., 2013) or other environmental pollution (Han et al., 2015; Meng et al., 2016; Wang and Chen, 2016), rare has been done to analyze atmospheric mercury emissions at city scale.

Presented in the current study is a benchmark study on atmospheric mercury emissions for the capital city of China, Beijing, employing EE-IOA. Beijing is a megacity with population up to 20 million, and its gross industrial output value was 17.87 trillion RMB Yuan in 2012 (BMBS, 2013). However, the rapid economic (Chen and Chen, 2015a) development is gained at high costs (Yu et al., 2015), with more and more serious environmental problems emerged. Beijing's urbanization process is a vivid epitome of China's development (Chen, 2015; Ji and Chen, 2015). In January 2013, Beijing experienced several haze pollution episodes (Ji et al., 2014), which caused social panic. Besides heavy smog and $PM_{2.5}$ (Cao et al., 2014; Meng et al., 2015a, 2015b), atmospheric mercury is also a causative factor of Beijing's extremely bad air quality. Throughout the year of 2006 in Beijing, average HgP (particulate mercury) concentrations in $PM_{2.5}$ samples reached 0.27 ng/m^3, and coal combustion is the major source of HgP (Schleicher et al., 2015). However, the detailed inventory and the indirect effects induced by Beijing are still lacking. Under this circumstance, this research commits to investigate mercury emissions in Beijing economy, which will not only add knowledge on the current status of Beijing's mercury emissions but also be helpful for the policy-makers to formulate comprehensive reduction strategies.

The rest of the paper is structured as follows: Section 2 expounds the methodology applied in this study; Section 3 provides the accounting results and compares the direct and indirect emission intensities; Section 4 discusses relevant policy implications and conclusions are made in the final section.

2. Material and methods

2.1. Direct atmospheric mercury emissions accounting

In this paper, we focus on mercury emissions to air from anthropogenic sources, including combustion of fossil fuels, gold production, non-ferrous metal production, cement production, etc. The calculation of mercury emissions from each source is based on activity data in 2012 and corresponding emission factors, which can be referred to Li et al. (2015). The data sources and emission factors will be expounded in the following sections.

2.2. Environmentally-extended input–output analysis

According to Li et al. (2015) and Zhang et al. (2015), the basic row balance of input–output table is:

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

in which $X = [x_j]_{n\times 1}$, $X^{im} = [x_j^{im}]_{n\times 1}$, $A = [a_{ij}]_{n\times n}$, $F = [f_j]_{n\times 1}$. x_j is the total output of Sector j; n denotes the total number of economic sectors; X represents the total output; X^{im} denotes imports; F stands for final demand. A is the technology coefficients matrix.

Then we have

$$F - X^{im} = X - AX = (I - A)X \tag{2}$$

where I is the identity matrix.

According to studies (Chen and Zhang, 2010; Chen et al., 2010b), EE-IOA assumes that imports have the same embodied emission intensity as the local commodities (Weber et al., 2008). Therefore, the emission balance can be expressed as:

$$E^d + \varepsilon A\widehat{X} = \varepsilon\widehat{X} \tag{3}$$

in which E^d is the row of total direct mercury emission, ε denotes the total embodied emission intensity as a row vector, $\widehat{X}$ is a diagonal matrix transformed by total output vector X as (Miller and Blair, 2009):

$$\widehat{X} = \begin{bmatrix} x_1 & 0 & \cdots & 0 \\ 0 & x_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & \vdots & \cdots & x_n \end{bmatrix} \tag{4}$$

With Eqs. (2) and (3), the embodied emission intensity ε can be simply derived as:

$$\varepsilon = E^d\widehat{X}^{-1}(I - A)^{-1} = \varepsilon^d(I - A)^{-1} = \varepsilon^d L \tag{5}$$

where ε^d denotes direct mercury emission intensity and L is the Leontief inverse matrix.

Moreover, emissions embodied in trade balance (*EEB*) is also considered (Lin and Sun, 2010). First, mercury emissions embodied in imports (*EEI*), which reflects the amount of mercury emission avoided by imports, can be expressed as:

$$EEI = \varepsilon\widehat{X}^{im} \tag{6}$$

where $\widehat{X}^{im}$ stands for imports in diagonal matrix. Similarly, emissions embodied in exports (*EEE*) is:

$$EEE = \varepsilon\widehat{X}^{ex} \tag{7}$$

where X^{ex} denotes exports in diagonal matrix like $\widehat{X}^{im}$. Thus, mercury emissions embodied in trade balance (*EEB*) can be obtained as:

$$EEB = EEE - EEI \tag{8}$$

2.3. Data sources

The economic input–output table for Beijing economy in 2012 is provided by Beijing Statistical Bureau, which covers 42 economic sectors (seen in Table 1).

Anthropogenic sources of mercury emissions in Beijing are listed in Table 2 with corresponding sectors and emission factors. Emission factors presented in this study come from Streets et al. (2005). Lacking emission factors of oil refineries and cremation, these two categories' emission factors are adopted from Rafaj et al. (2013). And emission factor of waste incineration is from Hu et al. (2012). In addition, activity data of each sources are collected from Beijing Statistical Yearbook (2013) (BMBS, 2013).

3. Results

3.1. Direct emissions

The direct atmospheric mercury emissions from local anthropogenic sources in Beijing are calculated as 2.62 tonnes in 2012. Fig. 1 displays the mix of the emissions from different anthropogenic activities. Combustion of fossil fuels is the largest emission source, contributing about more than half of the total direct emissions. The second largest source is cement production, accounting for 13.35%, closely followed by waste incineration (12.40%). Cremation and oil refineries have much less contribution, with a proportion of 5.43% and 4.10% respectively. Emissions from pig iron and steel production are the least.

Direct mercury emissions of 42 sectors in Beijing are depicted in Fig. 2. Sector 25 (*Electric Power/Steam and Hot Water Production and Supply*) emits 0.66 tonnes atmospheric mercury mostly by combustion of coal, which is the most mercury-intensive fuel. Also it's responsible for nearly a quarter of the total mercury emissions. The second largest emitter is Sector 13 (*Nonmetal Mineral Products*),

Table 1
Sectors for the economic input–output table for Beijing 2012.

Code	Sector
1	Farming, Forestry, Animal Husbandry, Fishery and Water Conservancy
2	Coal Mining and Dressing
3	Petroleum and Natural Gas Extraction
4	Ferrous and Nonferrous Metals Mining and Dressing
5	Nonmetal and Other Minerals Mining and Dressing
6	Food Processing, Food Production, Beverage Production, Tobacco Processing
7	Textile Industry
8	Garments and Other Fiber Products, Leather, Furs, Down and Related Products
9	Timber Processing, Furniture Manufacturing
10	Papermaking and Paper Products, Printing and Record Medium Reproduction, Cultural, Educational and Sports Articles
11	Petroleum Processing and Coking, Gas Production and Supply
12	Chemical Products Related Industry
13	Nonmetal Mineral Products
14	Smelting and Pressing of Ferrous and Nonferrous Metals
15	Metal Products
16	Ordinary Machinery
17	Equipment for Special Purpose
18	Transportation Equipment
19	Electric Equipment and Machinery
20	Electronic and Telecommunications Equipment
21	Instruments, Meters Cultural
22	Other Manufactures
23	Waste
24	Repair of Fabricated Metal Products, Machinery and Equipment
25	Electric Power/Steam and Hot Water Production and Supply
26	Gas Production and Supply Industry
27	Water Production and Supply Industry
28	Construction Industry
29	Wholesale, Retail Trade
30	Transport, Storage and Post
31	Hotels, Catering Service
32	Information Transmission, Computer services and Software
33	Financial Industry
34	Real Estate
35	Leasing and Commercial Services
36	Scientific Research and Development, Technical Services
37	Water conservancy, Environment and Public Facilities Management
38	Service to Households and Other Service
39	Education
40	Health, Social Security and Social Welfare
41	Culture, Sports and Entertainment
42	Public Management and Social Organization

Table 2
Emission factors from major sources and corresponding sectors.

Source category	Emission factor	Unit	Code	Sector
1. Combustion of fossil fuels			1–42	All sectors
Coal	0.02–0.43	g t^{-1}		
Oil	0.014–0.058	g t^{-1}		
Gasoline	0.058	g t^{-1}		
Diesel	0.058	g t^{-1}		
Kerosene	0.058	g t^{-1}		
Biofuel combustion	0.02	g t^{-1}		
2. Petroleum chemical industry & nonmetallic mineral products				
Oil refineries	0.001–0.02	g t^{-1}	11	Petroleum Processing and Coking, Gas Production and Supply
Cement production	0.040	g t^{-1}	13	Nonmetal Mineral Products
Lime production	0.04	g t^{-1}	13	Nonmetal Mineral Products
3. Pig iron & steel production	0.04	g t^{-1}	15	Metal Products
4. Waste incineration	0.343	mg kg^{-1}	22	Waste
5. Cremation	2.5	g/corpse	38	Service to Households and Other Service

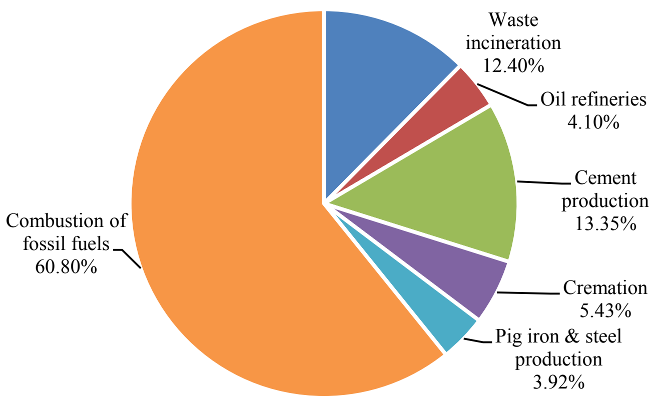

Fig. 1. Proportion of atmospheric mercury emissions.

because of production of cement and lime. Sector 30 (*Transport and Storage*) with large consumption of diesel and kerosene also contributed considerable amounts of mercury emissions, closely followed by Sector 23 (*Waste*) with waste incineration.

As for direct emission intensity (also depicted in Fig. 2), Sector 23 (*Waste*) rather than Sector 25 holds the top position, with an intensity of 140.39 kg/billion RMB, due to its extremely low economic output value but relatively high emissions. Sector 3 (*Petroleum and Natural Gas Extraction*) has the second largest intensity, followed by Sector 13. Though with lots of direct mercury emissions, Sector 25 and Sector 30 have low emission intensities due to their large amount of economic outputs.

3.2. Embodied emissions

Total embodied mercury emissions is calculated as 25.05 tonnes, nearly ten times as many as direct emissions. Embodied emission intensity, i.e., direct and indirect emission intensity, of each sector is depicted in Fig. 3. Sector 23 (*Waste*) has the largest embodied emission intensity with a value of 160.33 kg/billion RMB, and its indirect emission intensities are the third largest among all sectors. The second highest sector is Sector 3 (*Petroleum and Natural Gas Extraction*) with only 28.67 kg/billion RMB, which is so far behind Sector 23. Sector 11 (*Petroleum Processing and Coking, Gas Production and Supply*) has the third highest indirect mercury emissions for each unit of output. In addition, the average of sectoral

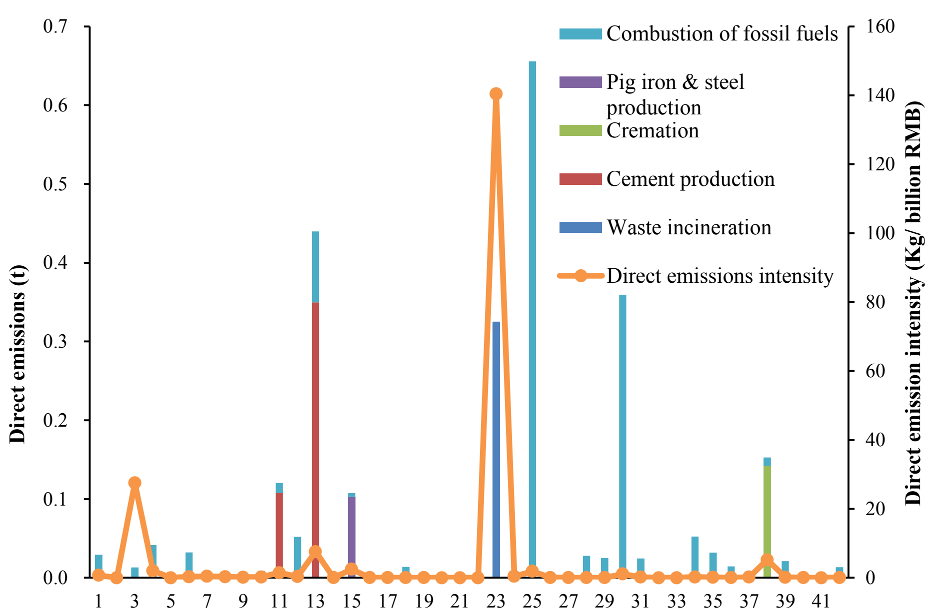

Fig. 2. Sectoral direct emissions and intensities.

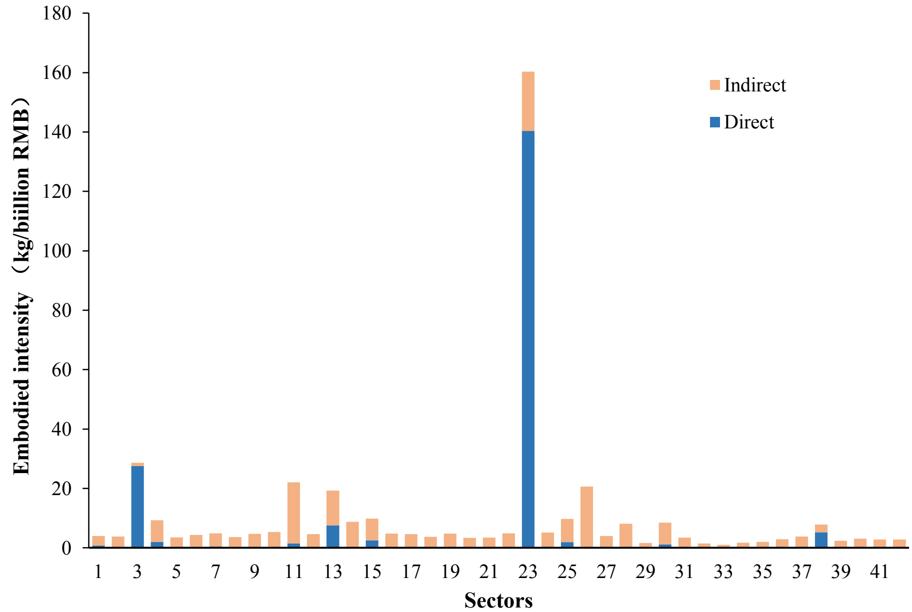

Fig. 3. Embodied mercury emission intensities by sectors.

embodied mercury emission intensity is 10.00 kg/billion RMB, much larger than the average of direct emission intensity of only 4.64 kg/billion RMB.

It's noted that many sectors' embodied mercury emission intensities contain a large part of indirect emission intensities, except for several sectors like Sector 3, 23 and 38 (*Service to Households and Other Service*). Fig. 4 clearly shows the dominance of indirect emission intensity. Sector 20 (*Electronic and Telecommunications Equipment*) has nearly 100% indirect emission intensity out of embodied intensity. Due to the large demand of mercury-intensive commodities, service sectors have higher proportions of indirect emission intensities.

3.3. Emission embodied in trade

Emissions embodied in exports (*EEE*) and imports (*EEI*) of each sector are illustrated in Table A1. Beijing's total *EEE* amounts to 68.98 tonnes with 94.73% for domestic exports while only 5.27% due to foreign exports. Sector 3 (Petroleum and Natural Gas Extraction), as the largest exporter, emits 29.32 tonnes embodied mercury, followed by Sector 12 (*Chemical Products Related Industry*) and 15 (*Metal Products*) with 10.23 tonnes and 7.28 tonnes emissions. As for *EEI*, Beijing has avoided 74.28 tonnes of mercury emissions through importing goods and services from other regions. Different with *EEE*, only 45.96% of total *EEI* are linked to domestic sources while 54.04% are from aboard. Sector 3, 12 and 15

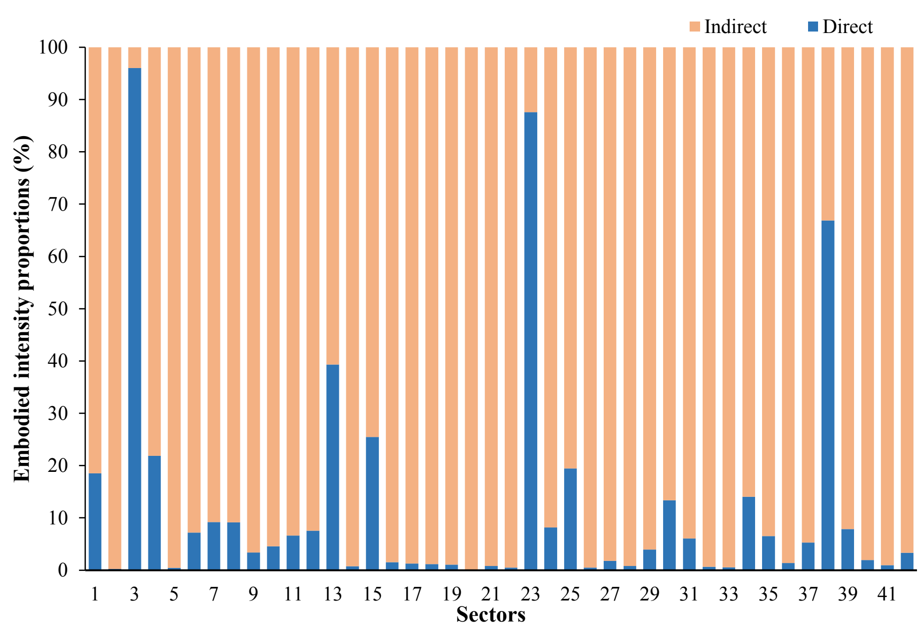

Fig. 4. Proportion of embodied mercury emission intensities.

(*Construction Industry*) are also the three largest importers, contributing nearly 70% of the total *EEI*.

Together with *EEE* and *EEI*, net mercury emissions embodied in trade balance (*EEB*) amount to −5.30 tonnes, which means Beijing is a net importer of mercury emissions. *EEB* of each sector are depicted in Fig. 5. Obliviously, most sectors of primary (Sector 1) and secondary industries (Sector 2 to 29) have negative value of *EEB* while sectors with positive *EEB* are concentrated in tertiary industries (Sector 30 to 42). It can be explained by Beijing's economic structures. Due to the lack of natural resources, industries in Beijing rely heavily on import of raw materials and products from other regions, which helps Beijing to avoid local mercury emissions. Seen from each sector, Sector 3 is still the largest net importers, with 1.92 tonnes net imported emissions. In contrast, Sector 36 (Scientific Research and Development, Technical Services) has the largest net exported mercury emissions due to Beijing's high-tech industrial clusters.

3.4. Emissions embodied in Beijing's final consumption

Mercury emissions embodied in Beijing's final consumption amount to 7.92 tonnes in 2012, which is divided into 5 categories: rural household consumption (2.25%), urban household consumption (30.38%), government consumption (16.34%), capital formation (47.33%) and inventory increasing (3.70%). Capital formation is the main contributor to the total mercury embodied emissions because of Beijing's huge investment, nearly 41.44% of the GDP in 2012 (BMBS, 2013). In addition, mercury emissions embodied in urban household consumption are more than 13 times as many as that induced by rural household consumption. Moreover, urban household's per capita mercury embodied emissions are still more than 2 times larger. Without doubt, urban residents' more energy and material-intensive lifestyle results in much more mercury emissions.

The distribution of sectoral mercury emission embodied caused by final demand is shown in Fig. 6. Almost 40% of the total embodied emissions in final consumption are attributed to the consumption of commodities provided by Sector 28 (*Construction Industry*). More specifically, capital formation has the significant contribution. It can be explained that ongoing urbanization of Beijing, buildings spring up and large amount of mercury intensive products such as energy, cement and steel are consumed, which leads to high embodied mercury emission intensity. Likewise, Sector 34 (*Real Estate*) is ranked at 3rd with 0.95 tonnes embodied emissions while Sector 32 (*Information Transmission, Computer services and Software*) is at 3rd, far below Sector 26. Notably, Sector 42 (*Public Management and Social Organization*), 40 (*Health, Social Security and Social Welfare*) and 36 (*Scientific Research and Development, Technical Services*) are the main contributors of emissions embodied in government consumption.

4. Discussion

This study presents a holistic picture on mercury emissions in Beijing from both the local and systematic perspectives, based on both direct accounting and IOA. The rapid urbanization, has endured heavy air pollution in Beijing in recent decades (Chen and Chen, 2014; Chen and Lu, 2015). The government should take steps to mitigate air pollutants like atmospheric mercury to make the environment a safe place for the urban residents. Comprehensive suggestions integrating direct and indirect effects are proposed for mercury emission reduction in Beijing, in light of the findings in this study.

4.1. Direct emissions reduction

From this study, Beijing's direct mercury emissions mainly originate from fossil fuel combustion and cement production. Currently, tertiary industry including finance, wholesale and retail, tourism, culture creativity and other service industries are the backbone of Beijing economy, while the proportions of the first and second industries decrease year by year. In the 12th Five-Year Plan issued by Beijing Municipal Development and Reform Commission, Beijing set the tone of green development, which is "Optimize Primary Industries, Strengthen Secondary Industries and Expand Tertiary Industries". In addition, "reducing emissions of sulfur

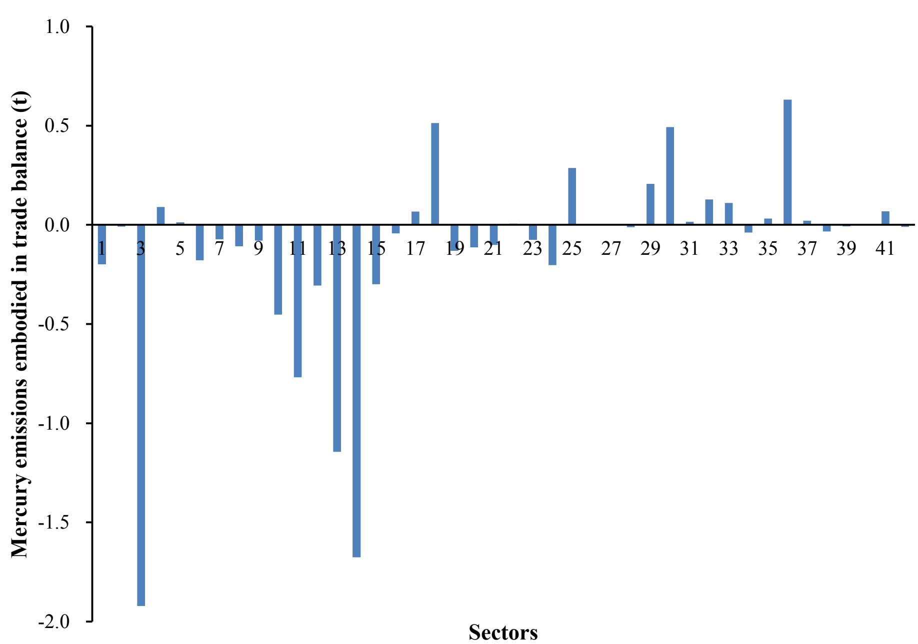

Fig. 5. Mercury emissions embodied in trade balance.

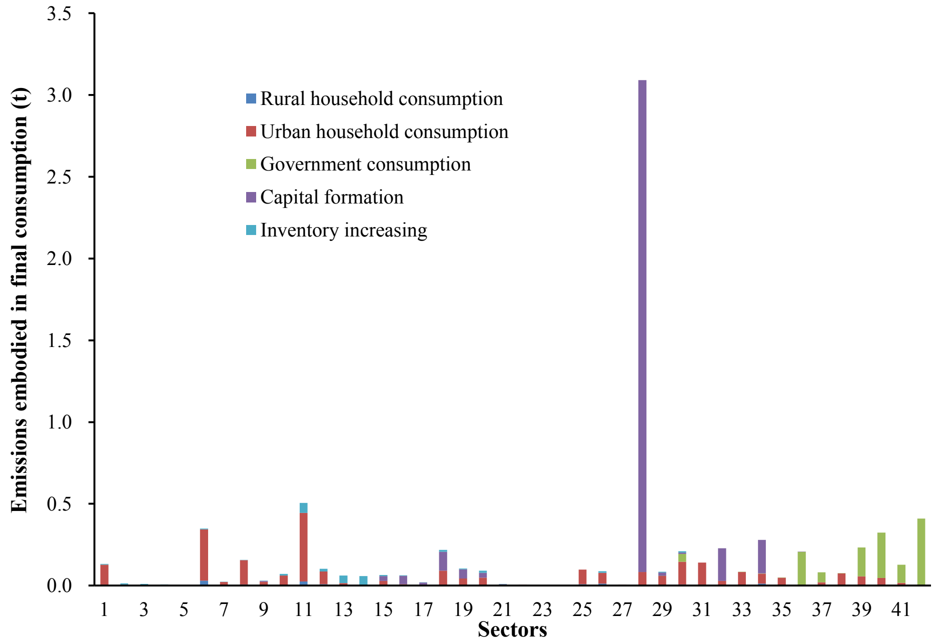

Fig. 6. Emissions embodied in final consumption.

dioxide, nitrogen oxide and other pollutants" is also proposed as mandatory target for a safer and cleaner environment (Beijing Municipal People's Congress, 2011).

Guided by this green development strategy, Beijing will control the burning of fossil fuels for the clean air, especially the combustion of coal. Coal used in Beijing is mostly imported from other regions in China (Wu et al., 2016a, 2016b). Thus, in order to reduce energy-related mercury emissions, Beijing can change the structure of energy consumption, e.g., importing more clean energy such as natural gas to replace coal. In addition, coal power plants and factories with coal boilers should install effective mercury removal devices, e.g., electrostatic precipitator devices, cyclones (Streets et al., 2005) and low-cost functional sorbents (Lee et al., 2006; Sun et al., 2013), or upgrade the outdated control technology.

Cement production as well as waste incineration has the parallel importance for direct mercury reduction in Beijing. Therefore, it's also vital to close down obsolete production facilities and gradually reduce the local production of cement. Meanwhile, with more advanced science and technology, e.g., bioleaching, which is a biological process to remove mercury (Díaz-Tena et al., 2016), the emission control will be more effective and efficient.

4.2. Indirect emissions reduction

Due to the lack of indigenous energy and other natural resources and its large population, Beijing relies heavily on other regions. According to Clean Air Plan (Beijing Municipal People's Government, 2013), Beijing will import more electricity and natural gas to reduce burning of coal in the future. In addition, some energy-intensive manufacturing sectors and polluting industries will be reallocated to other regions (usually a less developed region) via administrative measures, e.g., the relocation of Shougang Group for the 2008 Olympics. Besides consuming large amount of energy and resource from other regions, Beijing has also transferred its polluting industries to the nearby areas, which will exacerbate the heavy indirect embodied emissions. The result in this study shows that Beijing's indirect embodied emissions were as large as 25.05 tonnes. Moreover, due to the limited data availability, this study made an assumption that local embodied emission intensities are the same as intensities of domestic imports and foreign imports (Chen and Zhang, 2010). In fact, domestic emission intensity is larger because Beijing has tighter restrictions on emissions of air pollution like mercury and coal takes a smaller percentage in Beijing's energy consumption structure, which results in underestimation of indirect embodied mercury emissions induced by Beijing (Li, 2015).

In order to reduce the indirect embodied mercury emissions, Beijing should design comprehensive and reasonable policies to manage its consumption of energy and resource in trans-regional context. Mercury emissions of other regions induced by Beijing should also be taken into consideration. Moreover, a clear division of responsibilities between producer and consumer is in urgent need. Additionally, Beijing could also take actions in areas with high emission reduction potential. In this study, most sectors, especially sectors of tertiary industries, have higher indirect embodied mercury emissions. High tax rate and strict regulations can be considered as tools to control the high consumption of mercury-intensive products and services in sectors like construction and transport. Although with relatively low embodied emissions, household consumption has considerable potential for reducing emissions of mercury. The government can encourage residents to adopt energy-efficient lifestyle. Meanwhile, the government can also take advantages of science, technology and economy to strengthen financial and technical support for research projects on efficient use of energy and resources as well as procedures and technology with fewer emissions.

5. Conclusions

A holistic embodied mercury emission accounting of Beijing in the year of 2012 is presented to provide insights for proper policy design, in light of the EE-IOA. Direct atmospheric mercury emissions amounted to 2.62 tonnes in Beijing, which mainly came from combustion of and coal cement production. Based on EE-IOA, most sectors' embodied emission intensities are revealed larger than direct emission intensities, with the direct and indirect inputs from other sectors. Beijing is a net importer of mercury emissions avoiding 5.30 tonnes emissions via domestic and foreign trade. Also, emissions embodied in Beijing's final consumption were7.92 tonnes and the largest part was capital formation.

Schemes for mercury emissions mitigation from the perspectives of direct and indirect emission are also discussed in this study. Guided by green development strategy, Beijing will decrease its direct emissions by energy structure adjustment and reducing local production of cement as well as burning coal with clean technology. For indirect emissions, policy should be made to manage Beijing's consumption of energy and resource under multi region structure with the clear division of responsibilities between emissions producer and consumer.

With EE-IOA and the concepts of embodied emission intensity, a clear atmospheric mercury accounting is provided for Beijing, a typical urban economy. Here we once again emphasize the importance of indirect emissions induced by cities, which indicates considerable inter-sector mercury emissions flows embodied in intermediate transactions. We hope that the present study will contribute to the solution of Beijing's environmental problem, as well as to mercury emission studies for other urban economies.

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Appendix A

Table A.1
The mercury emissions embodied in trade (in tonnes).

Sector code	Foreign import	Domestic import	Total import	Foreign export	Domestic export	Total export	Trade balance
01	0.32	0.24	0.56	0.01	0.35	0.36	−0.20
02	0.13	1.14	1.26	0.01	1.24	1.26	−0.01
03	30.86	0.38	31.24	0.15	29.17	29.32	−1.92
04	0.94	0.32	1.27	0.00	1.35	1.36	0.09
05	0.01	0.13	0.14	0.03	0.12	0.15	0.01
06	0.16	0.88	1.04	0.02	0.84	0.87	−0.18
07	0.04	0.22	0.25	0.01	0.17	0.18	−0.07
08	0.03	0.26	0.30	0.04	0.15	0.19	−0.11
09	0.02	0.14	0.15	0.01	0.06	0.07	−0.08
10	0.06	1.64	1.70	0.04	1.21	1.25	−0.45
11	2.00	9.01	11.00	0.85	9.39	10.23	−0.77
12	0.40	2.06	2.45	0.13	2.01	2.15	−0.31
13	0.09	1.84	1.93	0.09	0.70	0.79	−1.14
14	1.89	7.07	8.96	0.19	7.09	7.28	−1.68
15	0.06	0.55	0.61	0.10	0.22	0.31	−0.30
16	0.28	0.37	0.66	0.11	0.50	0.61	−0.04
17	0.18	0.19	0.37	0.10	0.34	0.44	0.07
18	0.74	0.83	1.57	0.14	1.94	2.08	0.51
19	0.14	0.56	0.70	0.09	0.48	0.57	−0.13
20	0.27	1.16	1.43	0.28	1.03	1.31	−0.11
21	0.12	0.06	0.18	0.02	0.07	0.08	−0.10
22	0.00	0.25	0.25	0.00	0.25	0.26	0.01
23	0.26	0.04	0.29	0.02	0.20	0.22	−0.08
24	0.00	0.21	0.21	0.00	0.00	0.00	−0.20
25	0.00	1.89	1.89	0.00	2.17	2.17	0.29
26	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	0.00	0.01	0.01	0.00	0.00	0.00	−0.01
29	0.00	0.60	0.60	0.07	0.73	0.80	0.21
30	0.64	1.68	2.33	0.45	2.37	2.82	0.49
31	0.03	0.23	0.26	0.03	0.25	0.28	0.02
32	0.02	0.00	0.02	0.06	0.09	0.15	0.13
33	0.01	0.01	0.02	0.01	0.12	0.13	0.11
34	0.00	0.04	0.04	0.00	0.00	0.00	−0.04
35	0.03	0.05	0.09	0.08	0.04	0.12	0.03
36	0.29	0.00	0.29	0.46	0.46	0.92	0.63
37	0.00	0.01	0.01	0.00	0.03	0.03	0.02
38	0.00	0.03	0.03	0.00	0.00	0.00	−0.03
39	0.05	0.00	0.05	0.01	0.04	0.04	−0.01
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
41	0.04	0.04	0.08	0.01	0.13	0.14	0.07
42	0.01	0.01	0.02	0.01	0.00	0.01	−0.01
Total	40.14	34.14	74.28	3.64	65.35	68.98	−5.30

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