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The impact of trade on fuel-related mercury emissions in Beijing—evidence from three-scale input-output analysis

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ABSTRACT

For urban economies heavily dependent on trade, a systems analysis incorporating the effect of trade is demanded to investigate their overall energy consumption and environmental emissions. A three-scale input–output analysis which distinguishes local, domestic and international activities is presented in this study to evaluate the embodiment fluxes of fuel-related mercury emissions by China's capital city in 2010, in light of the mercury intensities for the average world and national economies. The results show that Beijing's embodied mercury emissions resulting from final fuel consumption were 7.79 t in 2010, more than 3/4 of which were attributed to domestic and international imports. These findings indicate that Beijing outsourced the majority of its fuel-related mercury emissions to regions via trade. Owing to the large-scale infrastructure construction, capital formation contributed the largest amount of embodied mercury emissions among all the final consumption types. This study suggests that multi-scale governance and comprehensive mitigation strategies are urgently needed to alleviate Beijing's mercury pollution, as the local emissions reduction depends on the overall abatement at national and international scale. The present study not only brings insights to Beijing's air pollution control but also can be used as a reference for other urban economies with heavy dependence on trade.

1. Introduction

Under the trend of economic globalization and regional economic integration, mankind has been confronted with a key problem: the growing impact of trade on the global environment [1,2]. In the last decade, the role of trade in shifting environmental emissions has attracted global attention. Due to the hot debate on who should take the responsibility for GHG emissions embodied in trade, a large body of literatures have investigated the impact of trade on GHG emissions displacement based on different approaches [3–5]. Evidence shows that the so-called GHG emission reduction goals in developed economies were achieved by displacing emission-intensive industries to developing economies. Lately, trade related air pollution has become a new research focus [6–11]. Peters and Hertwich reported that the amount of air pollutants embodied in imports was 2/3 of Norway's domestic emissions [12]. Regarding the poor air quality in China, Guan et al. analyzed the primary $PM_{2.5}$ emissions by China, and demonstrated that China's $PM_{2.5}$ emissions were largely driven by exports to OECD countries [13]. Lin et al. investigated the relationship between China's air pollution and China-US trade and found that China-to-US exports contributed to about 21% of China's export-related air pollution [14]. These studies verified that the same phenomenon of GHG emission transfer also happened to air pollution.

Half a century ago, the notorious Minamata Disease started to raise global concerns about mercury pollution. Since then, substantial evidence has been collected to prove that mercury is adverse both to human beings and ecosystems. Given its high toxicity and global long-range transport potential, mercury is regarded as a global pollutant causing adverse effects not only on living organisms at the major emissions spots, but also on those in remote regions [15,16]. In the wake of the painful lesson from the Minamata Disease, many efforts have been dedicated to protecting human health and our environment

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from the threat of anthropogenic mercury emissions. In 2013, a global treaty on mercury pollution proposed by the United Nations was signed by 87 countries including China [17]. This convention can be viewed as the first crucial step towards tackling mercury emissions via international cooperation.

To manage and reduce anthropogenic mercury emissions, it is vital to identify and characterize the various emission sources. Generally, there are two main types of mercury emission sources: natural sources such as forest fires and volcano eruptions, anthropogenic sources such as energy combustion. Human activities have significantly raised the amounts of mercury in the atmosphere, especially since the beginnings of industrialization in the early 19th century [18]. Among all human activities, fossil energy combustion—especially coal combustion—is reported as one of the largest anthropogenic sources, contributing a large proportion of the global mercury released to air [19]. This conclusion is supported by a series of studies on mercury air emissions at global scale [20–22]. At the national scale, fossil energy combustion is also verified as the main contributor among countries with the highest mercury emissions. For instance, the USA emitted 158 t of mercury into the atmosphere in 1999, with about 30% coming from energy combustion [23]. As the Polish economy heavily depends on electricity and heat produced by coal, the large amount of mercury emitted by fossil fuel makes Poland one of the largest emitters in Europe [24]. In recent decades, India's fast-growing economy has led to massive demand for energy, which is primarily met by burning coal. Consequently, coal combustion is responsible for the majority of mercury emissions into the atmosphere in India [6]. As the largest individual emitter of atmospheric mercury worldwide, China contributes about 1/3 of the global total mercury emissions [25]. Meanwhile, China is also the biggest coal consumer in the world [26]. As a result, atmospheric mercury emissions from energy combustion attracted wide attention and a certain number of related investigations were conducted (e.g. [27,28]). Although there are differences among them, these investigations reached a similar conclusion: that coal combustion is the primary anthropogenic source of mercury emissions in China [29,30]. These aforementioned studies, which have constructed detailed inventories on energy-related mercury emissions, provide essential information to guide efforts to reduce mercury emissions in those concerned regions.

However, some common limitations can be found among the existing studies on fuel-related mercury emissions. First, the aforementioned studies merely focused on mercury emissions at global and national scale, while research on the urban scale has been lacking. As a matter of fact, urban regions are the major fossil energy consumers worldwide, contributing to over 2/3 of global energy consumption [31]. Therefore, the knowledge about mercury emissions caused by urban energy consumption is vital to policy design against global mercury emissions. Second, these aforementioned studies are carried out under the framework of direct accounting, i.e., focusing exclusively on the direct mercury emissions from various sources (i.e., mercury emitted by direct energy consumption of end-users) within the territorial boundary. The direct accounting method is usually confined to direct emissions from fossil fuel combustion within territorial boundary.

In recognition of the leakage problem brought about by direct accounting, an approach called IOA was proposed to account for the holistic (direct and indirect) effects. The indirect effect refers to ecological elements such as environmental emissions, resources consumption induced by intermediate products which are passed on to other sectors before they are finally consumed [32–35]. As the IOA facilitates deeper appreciation of the total embodied emissions (including both direct and indirect emissions) of a specific economy, it has been widely accepted and applied as a method for benchmarking environmental emission accounting. With regard to the merit of IOA, many studies concerning mercury emissions have been conducted focusing on different scales. At the global scale, Liang et al. [36] and Li et al. [37] adopted the IOA to account mercury emissions embodied in international trade and national final consumption, respectively. At national scale, Liang et al. applied this approach to investigate the driver of mercury emissions by China [38]. Following that, Liang et al. portrayed a full picture of virtual mercury flows between provincial regions in China, in light of multi-region IOA [39]. Of particular relevance, one latest IOA-based study reported on the mercury emissions caused by an urban economy [40]. Compared with the mercury emission research in the framework of direct accounting, these IOA studies provide more comprehensive mercury emissions information and a new perspective to cope with the atmospheric mercury pollution.

However, the current IOA-based mercury emission studies are still far from sufficient, due both to the large number of urban economies and their dominant role in global energy consumption. Additionally, it is worth noting that these mercury emission studies used conventional environmentally-extended IOA, which assumes that local production and imports have the same embodied emission intensities and subjectively attributes the emission responsibility to the final consumption [41]. Consequently, these studies cannot identify the mercury emissions shifts accompanied with both domestic and international trade. In light of the ecological and general systems theory developed by Odum [42,43], Chen and his group have developed a unified method called systems IOA to account for various ecological elements consumption by economies at different scales [4,44–50]. Moreover, this method has also been applied to elaborate the role of trade in influencing the GHG emissions by Beijing by using a three-scale IOA which identifies the emission intensities at urban, national and international scale [45]. Given that, the current study also employs three-scale IOA to systematically account the mercury emissions embodied in Beijing's domestic and foreign trade. The details of the three scale IOA will be elaborated in Section 3.

The remainder of this article is organized as follows: Section 2 presents the case description of Beijing as a typical urban economy; Section 3 provides an introduction of the a systems accounting method called three-scale input-output analysis (IOA) and data source; Section 4 presents the results; Section 5 discusses policy implications and suggestions to reduce energy-related mercury emissions; conclusions are provided in Section 6.

2. Case description

Urban economies, which cover about 2% of global land while hosting half of the world's population [51] and accounting for 67% of energy consumption worldwide [52], show heavy dependence on trade. Due to the limited resources and large populations, urban regions have to import large quantities of commodities from both domestic and foreign regions to sustain their development. For instance, cities need to import life necessities such as food and water to satisfy urban residents. The processes such as food production and transportation inevitably require fossil energy input and therefore lead to emission of pollutants. Additionally, owing to the differences in industry specialization, a specific urban economy's demand on some resources and products might be satisfied by imports from other domestic and foreign economies. The steel building construction in Beijing might be produced in other provinces or even foreign nations. The production process of imported steel burns fossil energy, which causes mercury emissions outside Beijing. Thus, urban economic sectors not only directly emit pollutants by consuming coal and oil, but also induce indirect air pollution by importing energy-intensive production from other domestic and foreign regions. Under the circumstance, a series of questions arise: How does domestic and international trade impact the holistic picture of a typical urban economy's air pollution? What is the quantity of pollutants which are displaced from the urban scale to national and global scale? Is there any option to solve the air pollution in urban regions by involving national and global scale?

To answer these questions, this manuscript selects China's capital city—Beijing, a typical urban economy, to analyze the impact of trade