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Trade reshapes the regional energy related mercury emissions: A case study on Hubei Province based on a multi-scale input-output analysis

P. Zhang [a, b], Y.Y. Zhang [c], S.C. Ren [d], B. Chen [d], D. Luo [a, e], J.A. Shao [a, e], S.H. Zhang [a], J.S. Li [a, e, *]

[a] State Key Laboratory of Coal Combustion, Huazhong University of Science and Technology, Wuhan 430074, PR China
[b] China-EU Institute for Clean and Renewable Energy, Huazhong University of Science and Technology, Wuhan 430074, PR China
[c] Guangxi Key Laboratory of Power System Optimization and Energy Technology, Guangxi University, Nanning, Guangxi 530004, PR China
[d] Laboratory of Systems Ecology and Sustainability Science, College of Engineering, Peking University, Beijing 100871, PR China
[e] Department of New Energy Science and Engineering, School of Energy and Power Engineering, Huazhong University of Science and Technology, Wuhan 430074, PR China

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ABSTRACT

Recognized as a highly toxic air pollutant, atmospheric mercury is a grave threat to both human health and environment. The comprehensive understanding of Chinese regional mercury emissions is fundamental for proper mitigation policy design. However, previous researches on regional mercury emissions usually focus on the direct emissions and fail to uncover the effect of foreign and domestic trade. Therefore, this study constructs a multi-scale input-output model to investigate the regional fuel-related mercury emissions under the impacts of local consumption, domestic and foreign trade, using the case of Hubei Province, China. The results show that total emissions directly caused by fossil fuel use are 9.8 tons in 2007, of which coal accounts for more than 95%. Moreover, mercury emissions embodied in Hubei's final consumption are estimated to be 5.2 tons. Hubei, as a net exporter, has a trade surplus of 4.6 tons of energy-related mercury emissions, indicating that other regions home and abroad transfer large energy-related mercury emissions to Hubei via supply chains. This study has provided a useful tool for comprehensively understanding regional mercury emissions to support robust reduction policies formulation.

1. Introduction

Mercury emissions have become a significant environmental issue with global concerns (Kessler, 2013). Recognized as the culprit of Minamata Disease, mercury causes great harms to human beings, e.g., leading to the loss of children's IQ (Driscoll et al., 2013; Wang et al., 2010). Moreover, the atmospheric mercury can spread long distance through air (AMAP/UNEP, 2013), making it a pollutant with global importance. Human activities, such as energy combustion, artisanal and small-scale gold production and primary production of nonferrous metals, are the major contributors to the atmospheric mercury emissions (AMAP/UNEP, 2013). With the awareness of the growing damage caused by mercury emissions, the international community reached an agreement in 2013 and signed Minamata Convention aiming at reducing anthropogenic mercury emissions worldwide. Minamata Convention is regarded as a milestone for global mercury emission control, marking mitigating mercury emissions a legally binding target for the joint parties (Kessler, 2013).

As the knowledge on mercury emissions is the basis for guiding mercury reduction actions, the academic circles have devoted great efforts to mercury emission inventories. An early endeavor was conducted by Nriagu and Pacyna (1988), which complied an inventory of global mercury emissions. The results show the total emissions amounted to 3560 tons in 1983 and energy use was one of the leading contributors. Muntean et al. (2014) demonstrated the temporal and spatial variations of global mercury emissions from 1970 to 2008. And projections were made on the impacts of air quality and policies on global atmospheric mercury emissions in 2050 (Rafaj et al., 2013). As the largest individual mercury emitter in the world, China has always been the focal point and a number of efforts have been made to reflect the situation of China's mercury

* Corresponding author. State Key Laboratory of Coal Combustion, Huazhong University of Science and Technology, Wuhan 430074, PR China.
E-mail address: lijiashuo@hust.edu.cn (J.S. Li).

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emissions. In 1999 mercury emissions in China were estimated to be 536 (±236) tons, with non-ferrous metals smelting and coal combustion as the main sources (Streets et al., 2005). Under the UNEP (United Nations Environment Program) and AMAP (Arctic Monitoring and Assessment Program) project, the anthropogenic mercury emissions in China were estimated as 575 tons in 2010 (AMAP/UNEP, 2013). Wu et al. (2006) found out that nonferrous metals smelting and coal combustion together contributed about 80% of total mercury emissions in China during the period 1995–2003. Similar findings can be found in a series of studies (Hui et al., 2015, 2017). Only a few recent studies have paid attention to mercury emissions in sub-national regions (Wu et al., 2016; Zhang et al., 2015). As the success of mercury emissions reduction at global and national scale relies on each region and the situation in each region differs significantly, it is urgent to devote more efforts to investigate mercury emissions in sub-national regions.

Sub-national regions have got engaged in domestic and foreign supply chains more deeply due to regional integration and economic globalization. Numerous studies have verified that substantial resources and pollutant emissions can be transferred through domestic and international trade (Chen et al., 2017b, 2018a, 2018b, 2018c; Li et al., 2016; Meng et al., 2016a, 2016b). However, previous studies on Chinese regional mercury emissions fail to fully reflect the impact of international and domestic trade simultaneously, not to mention most of the existing regional studies are confined in the framework of production-based perspective which neglects the effect of trade. There have already been a few researches which tried to elucidate the impact of trade on urban mercury emissions by using single-region/scale input-output (IO) analysis (Jiang et al., 2016; Li et al., 2015). However, these singe-scale IO-based researches made an assumption that the commodities imported from other domestic and foreign regions share the same embodied emission intensities with the local products, which might be inconsistent with the real situation, since sectors in different regions usually have different energy structures and emission intensities. Another study investigating virtual mercury flows within China has taken domestic trade into consideration, but overlooking the impact of foreign trade on local mercury emissions (Liang et al., 2016).

To fill the gap, this study selects Hubei Province of China, as a case to study the impact of both international and domestic trade on its energy-related mercury emissions in 2007, by constructing a multi-scale IO model. Hubei is known as “the thoroughfare leading to nine provinces” and plays an important role in the rise of central China. Rapid growth of Hubei's economy leads to large amounts of energy consumption. Consequently, the increasing energy-related mercury emissions will become a major concern. In addition, it is noted that Hubei exports large quantities of energy-intensive commodities such as electro-mechanical products, new and high technology products, plastics, ships and steel every year (Li et al., 2013), which indicates that a significant quantity of emissions are induced to meet domestic and foreign demands. Thus, Hubei provides a typical provincial economy to investigate the trade impacts on energy-related mercury emissions in sub-national regions. The rest of the paper is organized as follows: Section 2 describes the methodology and materials employed in this study; Section 3 summarizes the detailed results, including the direct and indirect results; relevant policy implications are discussed in Section 4, and in the final section conclusions are drawn.

2. Method and materials

2.1. Mercury emission inventory

According to method adopted in previous studies (Chen et al., 2017a; Guan et al., 2014; Jiang et al., 2016; Li et al., 2017a, 2017b; Liang et al., 2016), the compilation of emission inventory in this research is based on the energy consumption statistics of different industrial sectors and their corresponding emission factors. Energy-related mercury emissions can be calculated as follows:

$$E_{r,i} = A_{r,i} \times EF_{r,i} \tag{1}$$

In this equation, E stands for atmospheric mercury emissions, while A means activity data or product consumption and EF is the corresponding emission factors, r and i represent different regions and sectors, respectively.

2.2. Multi-scale IO table compilation

The model adopted in this research is the widely-used *Chenery-Moses* model (Evans, 1955; Moses, 1955). The basic assumption of this model is that the trade flows between regions are only decided by the starting region and final destination. Xia et al. (2015) have applied this model to assess energy consumption in Beijing. To calculate the trade flows among different regions, a trade coefficient is introduced. The trade coefficient of sector i from region r to region s (Tc_i^{rs}) can be calculated as:

$$Tc_i^{rs} = \frac{Tf_i^{rs}}{P_i^s} \tag{2}$$

In this equation, Tf_i^{rs} is the trade flow of sector i from region r to region s. P_i^s is the total production of sector i transported to region s, which can be derived from the equation $P_i^s = \sum Tf_i^{rs}$.

With regard to two specific regions s and r, the ratio of each kind of products from region r to region s can be described through a diagonal matrix:

$$Tc^{rs} = \begin{bmatrix} Tc_1^{rs} & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & \cdots & Tc_n^{rs} \end{bmatrix} \tag{3}$$

where n is the number of involved sectors in this research.

In this research, the regions chosen are Hubei province, rest of China (ROC) and rest of the world (ROW). With matrixes:

$$Tc = \begin{bmatrix} Tc^{11} & Tc^{12} & Tc^{13} \\ Tc^{21} & Tc^{22} & Tc^{23} \\ Tc^{31} & Tc^{32} & Tc^{33} \end{bmatrix} \tag{4}$$

and

$$A = \begin{bmatrix} A^1 & 0 & 0 \\ 0 & A^2 & 0 \\ 0 & 0 & A^3 \end{bmatrix} \tag{5}$$

among which A^s is the direct consumption coefficient matrix of region s ($s = 1,2,3$). The multi-regional input-output (MRIO) table can be acquired through equation:

$$X = TcAX + TcF \tag{6}$$

where X and F are the total output vector and final demand vector of three-scale sectors, respectively.

2.3. Embodied atmospheric mercury emissions

For sector i in a specific region s, the IO balance of atmospheric mercury in economic flow is illustrated in Fig. 1. Z_{ij}^{sr} is the intermediate input flow between different regions, i.e., the economic flow from sector i in region s to sector j in region r; f_{it}^{sr} means the