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Geographic sources and the structural decomposition of emissions embodied in trade by Chinese megacities: The case of Beijing, Tianjin, Shanghai, and Chongqing

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ABSTRACT

Based on a structural decomposition analysis within a multi-regional input-output analytical framework, this study analyzes and compares the changes in and geographic sources of the emissions embodied in trade (EET) at the city level. It also examines how and why the EET changed in four Chinese mega-regions between 2002 and 2010. One finding is that the geographic sources of Beijing's, Tianjin's, and Shanghai's emissions embodied in exports (EEE) are mainly located in the provinces of the Tianjin-Hebei-Henan areas and the east coast regions of China, whereas the geographic sources of Chongqing's EEE are primarily concentrated in the southeast of China and central China. Conversely, Beijing's, Tianjin's, and Shanghai's emissions embodied in imports (EEI) are strongly associated with the provinces of Northern and North Central China, whereas Chongqing's EEI are mainly related to the southeast of China and the Hebei-Henan areas. Another important finding is that a megacity's EEE are most affected by demand in the other regions and production in the local city, whereas its EEI are largely determined by demand in the local city and production in the other regions.

1. Introduction

With the implementation of the eleventh five-year plan, promoting urbanization development has become the public economic policy priority for the Chinese government. In this context, urban advancement has clearly sped up, which has accordingly led to the rapid development of the Chinese urban economy. The latest statistics indicate that the urbanization rate (urban population size) increased from 39% (502 M) in 2002 to 55% (750 M) in 2014 and currently maintains an annual growth rate of around 2% (6%) in China (CCSY, 2014). By 2030, the urbanization rate (urban population size) is projected to increase to approximately 60% (880 M) in China (United Nations, 2014). Meanwhile, a further study shows that cities account for 90% of China's GDP, and they have a share of around 75% of China's energy consumption and 85% of greenhouse gas (GHG) emissions (Dhakal, 2009, 2010). An even more serious concern is that the projected rate of growth in urbanization and the accompanying increases in the standard of living are steadily driving high growth in energy consumption and thus in CO_2 emissions in urban areas (Dhakal, 2010; Parshall et al., 2010; Schulz, 2010; Bai et al., 2014; Feng et al., 2014; Chen et al., 2016). Proactive initiatives have been taken to promote energy conservation and emissions reduction at the city level, both of which have received considerable attention.

Although trade plays a crucial role in regional economic development by providing a mechanism to efficiently allocate resources (i.e., labor, energy, and so forth) in the process of economic globalization (Amin, 1999; Czarnitzki and Hottenrott, 2009), a prominent side effect is the geographical separation between the production of emissions and the consumption of emissions in the production of consumable items. Trade also provides a mechanism for consumers to shift the environmental impacts associated with their consumption to other regions (Weber et al., 2008; Peters and Hertwich, 2008a; Sato, 2014; Scott and Barrett, 2015; Zhong et al., 2015; Chen et al., 2016a, 2016b). Some of the commitments to emissions reduction that would otherwise belong to the consumer

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are transferred to the producer of a traded good (Batabyal and Nijkamp, 2003; Schulz, 2010). Recently, the climate policy implications stemming from using a consumption-based approach instead of a more conventional production-based approach have been discussed, whereas more attention has been given to the impact of emissions embodied in trade (EET) on the city's carbon emissions and its reduction obligation assignments (Schulz, 2010; Feng et al., 2014; Hermannsson and McIntyre, 2014; Li et al., 2014a,b; Choi, 2015; Hu et al., 2016).

At present, studies on the urban scale of EET primarily focus on three aspects, which are discussed in the following section. However, few studies focus on a complete comparison and analysis of the sources and flows of different cities' embodied carbon emissions, and, more importantly, less emphasis is placed on comparing the changes in embodied carbon emissions in different cities and exploring the driving forces on such changes in a specific period, which may lead to less valuable insights for policy makers. Parshall et al. (2010) and Dhakal (2010) observed that the growth in carbon emission from the expansion of urban residents' consumption could be partially offset by reductions in emissions through measures such as reducing the local energy intensity or improving energy efficiency, but from the perspective of embodied emissions, the question is whether these measures are also effective for EET and whether the effects differ across cities. Furthermore, another important question is to what extent changes in a city's EET are affected by changes in trade. Understanding the driving forces for the transfer of environmental impacts, particularly CO_2 emissions associated with production and consumption, may contribute to enabling stakeholders to effectively implement future climate and environmental policies at the city level.

In the present study, a structural decomposition analysis (SDA) within a multi-regional input-output (MRIO) analytical framework is used to study the driving forces of EET changes at the urban scale. Regrettably, however, this analysis has not been done earlier. Nevertheless, SDA has been used to analyze carbon emissions and energy intensity indices for a specific country or group of countries based on the regional input-output models (De Nooij et al., 2003; Alcantara and Duarte, 2004; Du et al., 2011; Yamakawa and Peters, 2011; Feng et al., 2012; Xu and Dietzenbacher, 2014). Moreover, based on the regional input-output method, a number of studies have focused on a region's CO_2 emissions embodied in trade and on the interregional or international transfer of carbon emissions (Davis and Caldeira, 2010; Guo et al., 2012a,b,c; Chen et al., 2013; Feng et al., 2013, 2014; Xu and Dietzenbacher, 2014; Zhang et al., 2014; Chen et al., 2016, 2016a, 2016b; Hu et al., 2016). Clearly, the methodological limitations of using only the SDA method or regional input-output analysis prevent a better understanding of the changes in the EET and the corresponding determining factors of these changes at the city level. Hence, in order to enable related stakeholders to effectively develop targeted regional environmental and energy policies, this study contributes to filling this gap by combining SDA with MRIO models to analyze the changes and geographic sources of EET at the city level and by examining how and why EET changes in four Chinese mega-regions between 2002 and 2010. Additionally, this study makes comparisons and examines whether the sources of EET growth differ between these mega-regions.

In this analysis, four Chinese municipalities (i.e., Beijing, Tianjin, Shanghai, and Chongqing) are selected as the case for calculating the embodiment of emissions from 2002 to 2010. Two accounting approaches (the production accounting approach and the consumption accounting approach) for CO_2 emissions are applied here and compared (Peters and Hertwich, 2008a, 2008b). In addition, the sources and flows of these cities' EET and the changes in the EET of these mega-regions between 2002 and 2010 have also been analyzed. It should be noted that three kinds of driving forces, such as changes in terms of emission intensities, production technology, and demand for final products, are discussed in the structural decomposition analysis of our study.

The remainder of this paper is organized as follows. The following section summarizes the literature, and Section 3 presents some important background information on our case study. The details of the methodology and the data are presented in Section 4. Section 5 discusses the calculation results. Uncertainty analysis is given in Section 6. Finally, the conclusions and future work are presented in Section 7.

2. Literature review

At present, studies concerning a city's embodied energy consumption and, thus, EET can be divided into three primary types. The first type focuses on the embodied energy consumption and the corresponding EET in one city in one year, such as Trondheim, Norway, in 2000 (Larsen and Hertwich, 2009); Melbourne, Australia, in 2001 (Baynes et al., 2011) and 2009 (Wiedmann et al., 2015); Lisbon, Portugal, in 2002 (Rosado and Ferrão, 2009); Beijing, China, in 2002 (Zhou et al., 2010), 2005 (Ji et al., 2014), 2007 (Guo et al., 2012a,b,c; Chen et al., 2013), and 2010 (Li et al., 2016); Xiamen, China, in 2007 (Vause et al., 2013) and 2010 (Lin et al., 2015); and Haninge, Sweden, in 2008 (Wu, 2011). Remarkably, Vause et al. (2013) observed that Xiamen was a net exporter in 2007. The emissions embodied in domestic exports from Xiamen to other regions of China and those resulting from the local Xiamen economy's demand for local production accounted for approximately 78% and 22% of the total emissions embodied in production, respectively. Moreover, Li et al. (2016) observed that Beijing's total energy consumption in 2010 was mainly energy embodied in domestic trade.

The second type of study focuses on variation characteristics of the embodied energy consumption and emissions in a city in a specific period (Schulz, 2010; Li et al. 2014a,b; Zhang et al., 2014). Notably, Schulz (2010) examined the volumes and trends of GHG emissions embodied in the products traded in Singapore from 1960 to 2000 and found 25 Mt of GHG equivalents per year in the early period of the time series as well as steady growth. Li et al. (2014b) found that although the embodied energy intensity dropped sharply from 2000 to 2011, the net embodied energy in trade from other regions to Macao more than doubled in 2011 as compared to that in 2000.

The third type focuses on comparing and analyzing the embodied energy consumption and emissions in different cities in one year (Feng et al., 2013, 2014; Hermannsson and McIntyre, 2014; Zhang et al., 2014; Choi, 2015; Liu et al., 2015; Chen et al., 2016, 2016a; Hu et al., 2016). It is worth noting that from the perspective of the four Chinese mega-regions of Beijing, Shanghai, Tianjin, and Chongqing, Feng et al. (2014) observed that 50% of consumption-based emissions in Chongqing and more than 70% of consumption-based emissions in Beijing, Shanghai, and Tianjin came from regional trade from other regions of China in 2007, and they further argued that in order to promote low carbon development in China, stakeholders should pay more attention to the consumption patterns of China's urban residents. As for the three US metropolitan areas of Atlanta, San Francisco, and Seattle, Choi (2015) observed that EET accounted for 63–73% of total GHG emissions pertaining to these urban economies and then suggested that promoting sustainable consumption behavior in the urban areas might be beneficial to redirect metropolitan development patterns toward low carbon emissions.

Although previous studies have provided an important basis for policy makers to figure out the impact of trade on a city's carbon