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Consumption-based emission accounting for Chinese cities

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HIGHLIGHTS

- We calculate consumption-based CO_2 emissions for thirteen Chinese cities.
- Substantial differences exist between production- and consumption-based accounting.
- 70% of consumption-based emissions are imported from other regions in Chinese megacities.
- Capital formation is the largest contributor to consumption-based emissions.
- Production-based cities tend to become consumption-based as they undergo socioeconomic development.

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ABSTRACT

Most of China's CO_2 emissions are related to energy consumption in its cities. Thus, cities are critical for implementing China's carbon emissions mitigation policies. In this study, we employ an input-output model to calculate consumption-based CO_2 emissions for thirteen Chinese cities and find substantial differences between production- and consumption-based accounting in terms of both overall and per capita carbon emissions. Urban consumption not only leads to carbon emissions within a city's own boundaries but also induces emissions in other regions via interregional trade. In megacities such as Shanghai, Beijing and Tianjin, approximately 70% of consumption-based emissions are imported from other regions. Annual per capita consumption-based emissions in the three megacities are 14, 12 and 10 tonnes of CO_2 per person, respectively. Some medium-sized cities, such as Shenyang, Dalian and Ningbo, exhibit per capita emissions that resemble those in Tianjin. From the perspective of final use, capital formation is the largest contributor to consumption-based emissions at 32–65%. All thirteen cities are categorized by their trading patterns: five are production-based cities in which production-based emissions exceed consumption-based emissions, whereas eight are consumption-based cities, with the opposite emissions pattern. Moreover, production-based cities tend to become consumption-based as they undergo socioeconomic development.

1. Introduction

China has been the world's largest producer of CO_2 emissions since 2007. In 2013, its CO_2 emissions from fuel combustion totalled 8.5 billion tonnes, which accounted for a quarter of global CO_2 emissions [1,2]. China has prioritized climate change mitigation in the past decade, announcing in the 2014 "U.S.–China Joint Announcement on Climate Change" that its CO_2 emissions will peak by 2030. In addition, in its 2015 Intended Nationally Determined Contributions, China promised to decrease its CO_2 emissions per unit of GDP by 60–65% (based on 2005 levels) by 2030 [3].

Accompanying its rapid economic growth, China's urban population has increased dramatically during recent decades. The urban population grew to 750 million in 2014, increasing from approximately 300 million in 1990. Today, more than half of China's population lives in cities [4]. This rapid urbanization and industrialization have led to increased demands for energy and materials, which result in substantial emissions of greenhouse gases (GHG), including CO_2 [5,6]. Approximately 85% of China's

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CO_2 emissions are related to urban energy consumption, a rate that is much higher than that experienced in Europe (69%) or in the U.S. (80%) [7,8]. Therefore, cities are critical for implementing China's carbon emissions mitigation policies. There is an urgent need to understand China's urban CO_2 emissions, as such understanding is fundamental to proposing mitigation actions.

There are two approaches to measuring GHG emissions: production-based and consumption-based accounting [9–11]. Production-based CO_2 emissions are emissions caused by domestic production, including exports [12]. This approach accounts for CO_2 emissions at the point of production, without consideration of where goods are used or who ultimately uses them [13,14]. This approach is widely used in global climate change agreements, including the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. Conversely, under consumption-based accounting, all emissions occurring along the chains of production and distribution are allocated to the final consumers of products [15]. Pursuant to this approach, areas that import products are allocated the emissions related to their production. Therefore, consumption-based emissions include imports and emissions embodied in trade but exclude exports, whereas production-based emissions include exports and exclude imports [12]. Recent studies have compared the two approaches and demonstrated the advantages of consumption-based accounting [16–19]. For example, Steininger et al. [13] argued that a consumption-based climate policy approach can improve both cost-effectiveness and justice, while Guan et al. [20] indicated that consumption-based accounting helps mitigate global air pollution. Moreover, Larsen and Hertwich [21] argued that consumption-based accounting provides a more useful and less misleading indicator for assessing the performance of local climate actions. Finally, Peters and Hertwich [22] have noted that consumption-based accounting has many advantages over production-based accounting, such as addressing carbon leakage, promoting environmental comparative advantages, increasing options for mitigation, and encouraging technology diffusion.

There are numerous studies on consumption-based carbon emissions at the global and national levels [23]. Peters and Hertwich [22] calculated CO_2 emissions embodied in international trade among 87 countries. They found that 53 billion tonnes of CO_2 emissions in 2001 were embodied in international trade and that developed countries were net importers of emissions. Hertwich and Peters [24] quantified consumption-based greenhouse gas emissions for 73 nations and 14 aggregated world regions. At the global level in 2001, 72% of greenhouse gas emissions were related to household consumption, 18% to investment and 10% to government consumption. Davis and Caldeira [25] used a fully coupled multi-region input-output (MRIO) model to construct a consumption-based CO_2 emissions inventory of 113 countries and regions. The results showed that 62 billion tonnes of CO_2 were traded internationally, which accounted for 23% of global emissions. These CO_2 emissions were mainly exported from China and other emerging markets to developed countries. Peters et al. [26] developed a global database for consumption-based CO_2 emissions for 113 countries. In most developed countries, consumption-based emissions increased faster than territorial production-based emissions. Under consumption-based accounting, net CO_2 emissions transferred from developing countries to developed countries grew from 4 billion tonnes in 1990 to 16 billion tonnes in 2008.

At the national level, Wood and Dey [27] applied a consumption-based approach to calculating Australia's carbon footprint and found that emissions embodied in exports were much higher than those embodied in imports and that Australia's total carbon footprint was 522 million tonnes (Mt) in 2005. Nansai et al. [28] applied a global link input-output model to analyse Japan's carbon footprint. Wiedmann et al. [29] and Barrett et al. [30] both calculated the UK's consumption-based greenhouse gas emissions and found that consumption-based carbon emissions were rapidly increasing and that there was a widening gap between production- and consumption-based emissions. Feng et al. [31] tracked carbon emissions embodied in products in the Chinese provinces; these authors found that 57% of total emissions were related to goods and services that were used outside of the province in which they were produced. For example, 80% of the emissions embodied in goods used in the highly developed coastal provinces were imported from less developed areas.

Studies of emission inventories for cities are limited, and most are focused on production-based accounting. Dhakal [8] compiled energy usage and emissions inventories for 35 provincial capital cities in China. The results showed that these 35 cities accounted for 40% of China's energy consumption and CO_2 emissions and that the carbon intensity for these cities decreased throughout the 1990s. Hoornweg et al. [32] analysed per capita GHG emissions for several large cities and reviewed emissions for 100 cities. They showed that annual per capita emissions for cities varied from more than 15 tonnes of CO_2 equivalent to less than half a tonne. Sugar et al. [33] provided detailed GHG emission inventories for Beijing, Shanghai and Tianjin and found that Chinese cities are among the world's highest per capita emitters when compared with ten other global cities. Liu et al. [34] analysed features, trajectories and driving forces of GHG emissions in four Chinese megacities (Beijing, Tianjin, Shanghai and Chongqing) from 1995 to 2009. The emission inventories compiled in this paper include both direct emissions and emissions from imported electricity. Creutzig [35] used data from 274 cities to explore the potential for urban mitigation of global climate change. The results showed that urban energy use will grow threefold between 2005 and 2050, if current trends in urban expansion continue.

Few studies have researched consumption-based emissions for cities [36,37]. Hasegawa et al. [38] constructed a multi-region input-output table among 47 prefectures in Japan and estimated their consumption-based carbon emissions. They found that production-based emissions differed great from consumption-based emissions. Moreover, the ratio of carbon leakage to carbon footprint was more than 50% on average at the regional level. Almost all previous studies of consumption-based emissions in Chinese cities focus on the same four megacities, i.e., Beijing, Shanghai, Tianjin and Chongqing. Dhakal [39] used a consumption-based approach to analyse the carbon footprints of four Asian megacities, including Beijing and Shanghai. Feng et al. [40] also analysed consumption-based carbon emissions in the four Chinese megacities and found that urban consumption imposed high emissions on surrounding regions via interregional trade. In this study, we use an input-output model to construct consumption-based CO_2 emissions for thirteen Chinese cities.

2. Method and data

2.1. Input-output model for consumption-based accounting of carbon emissions

The input-output model is one of the most widely used methods of analysing consumption-based carbon emissions [41]. The method is divided into single-region input-output and multi-region input-output (MRIO). In this study, we use the single-region input-output model. Some studies have summarized the input-output model and its applications [42,43]. Dietzenbacher et al. [44] compiled eight experts' views on the future of input-output. As mentioned above, the method has been widely used in environmental research [45] on energy consumption [46–48],