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Carbon emissions and their drivers for a typical urban economy from multiple perspectives: A case analysis for Beijing city

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HIGHLIGHTS

- The first comprehensive evaluation of sectoral CO_2 emissions from three perspectives for a city.
- Structural decomposition analysis from both the demand and supply side is conducted.
- Emission intensity, production input and output structure change contribute to CO_2 emission decrease in Beijing.
- Population, final demand/primary input level and structure change contribute to CO_2 emission increase in Beijing.
- Multiple accounting principles could support just and effective low-carbon city policies.

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ABSTRACT

Understanding carbon emission profile of cities from multiple perspectives is a prerequisite to design just and effective carbon reduction policies. Previous studies on CO_2 emissions by cities are usually confined to production or consumption-based perspective, while income-based perspective has been neglected. To fill the gap, direct emissions (a.k.a. production-based emissions), upstream emissions driven by final demand (a.k.a. consumption-based emissions) and downstream emissions enabled by primary input (a.k.a. income-based emissions) in an urban economy are comprehensively explored and compared for the first time, taking Beijing as a case. In the period of 2005–2012, *Manufacture of Nonmetallic Mineral Products/Construction/Processing of Petroleum, Coking, Processing of Nuclear Fuel* is identified as the key contributor to carbon emission by Beijing from the production/consumption/income-based perspective, respectively, indicating each perspective can unveil important information which the other methods fail to discover. Moreover, driving forces of CO_2 emissions change in Beijing are uncovered using the structural decomposition analysis (SDA) from both the demand and supply sides. Emission intensity, production input and output structure change contribute to CO_2 emission decrease in Beijing, which are largely offset by population, final demand/primary input level and final demand/primary input structure change, resulting in a net 3.9 Mt reduction during 2005–2012. While current policies continue to highlight end-of-pipe measures in cities, more attention should be paid to demand (e.g., encouraging low-carbon consumption) and supply side (e.g., controlling capital investment in enterprises with large income-based CO_2 emissions).

1. Introduction

As the center for population, transportation, energy consumption and business activities, cities are the major contributors to global CO_2 emissions. According to International Energy Agency, 71% of CO_2 emissions come from cities worldwide in 2006 and this share will increase to 76% in 2030 [1]. Among the important CO_2 sources, cities are responsible for 69% and 80% of EU and USA's carbon emissions [2,3], respectively. As the world's largest energy consumer, cities are responsible for 85% of China's total CO_2 emissions [4]. Regarding the

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vital role in global CO_2 emissions, cities are considered as key areas in strategies formulated for fighting against global climate change.

The first and fundamental step for proper mitigation policy design is to accurately quantify cities' carbon emissions. Currently, there are three different accounting principles that are widely used: production, consumption and income-based accounting [5–7]. Although each of the aforementioned accounting frameworks has its own merits, they have inherent blind spots (detailed reviews of each accounting principle are presented in Section 2.1). Under this circumstance, Steininger et al. [8] argued that carbon emissions accounting under multiple perspectives are suggested to support fair and effective mitigation strategies and identify some underlying reduction potentials. Moreover, the carbon emissions accounting under different perspectives can be combined as cornerstone for a shared-responsibility [9]. Notably, to the best of our knowledge, carbon emission accounting at urban scale from three different perspectives has not been found yet, as our reviews in Section 2.1 suggest that current studies on carbon emission accounting of cities are usually confined to one or two perspectives.

Beside the comprehensive perspectives on carbon emissions, the knowledge about how the carbon emissions change and their underlying drivers also have important policy implications. A prerequisite to meet the carbon mitigation targets without harming domestic competitiveness is to successfully identify the main drivers of the carbon emissions [10]. That is to say, a robust decomposition analysis on carbon emission driving factors will lead to appropriate policy design. Structural decomposition analysis (SDA) is usually coupled with input-output analysis, enabling it to take the effect of production structure into consideration [11]. As our review in Section 2.2 shows, however, most previous SDA studies are confined in demand-side perspective, little is known about the driving factors and their contributions from supply-side perspectives, especially those at city scale.

Hence, this study aims to fill the knowledge gaps by evaluating the production, consumption and income-based carbon emissions simultaneously and the major driving forces from supply and demand-side perspectives, using the case of the capital city of China, Beijing. After the United States' withdrawal from the 2015 Paris Agreement, many researchers stated that China, the world's largest direct carbon emitter, can and will lead on climate change [12]. In order to reach emission peak before 2030, China has taken low-carbon cities a priority in mitigating climate change, which has been emphasized in many national plans, such as *National Plan on Climate Change (2014–2020)* and *Work Plan for Controlling Greenhouse Gas Emission during the 13th Five-Year Plan Period (2016–2020)*. Many Chinese cities, including Beijing, have promised to reach the carbon emissions peak around 2020. In order to build a low carbon urban economy as well as play a leading exemplary role for the whole nation, the Municipal Government of Beijing has promised to reach the carbon emissions peak in 2020 or even earlier [13]. As Beijing's carbon mitigation has entered a new stage, it is urgent to draw a holistic picture of Beijing's carbon emissions and furthermore, to identify the driving factors from different perspectives, based on the latest data. It is expected that the study will bring new insights for carbon emissions mitigation actions as well as enlarging the possibilities for future climate policies for Beijing, or even other global cities fighting against the climate change.

The rest of this study is organized as follows: Section 2 reviews the recent advances in multiple accounting principles and structural decomposition analysis at city level; methodology and data adopted in this paper are elaborated in Section 3; Section 4 presents the detailed results; some discussions and policy implications are illustrated in Section 5; finally, conclusions are drawn in Section 6.

2. Literature review

2.1. Multiple accounting principles

Multiple accounting principles in this study include production, consumption and income-based accounting. The production-based accounting focuses on the carbon emissions emitted within the administrative boundaries, including those caused by exports production [5]. This approach is widely used in global climate change agreements, including the Kyoto Protocol and Paris Agreement. Though most of the previous production-based researches are developed at national scale, city-level emission inventory has attracted ever-increasing attentions [14–16]. Kennedy et al. [17] constructed the greenhouse gas inventories for 22 global cities and investigated the underlying characteristics. Hoornweg et al. [18] reviewed per capita emissions of 100 cities to identify the hotspots for effective mitigation efforts. Besides, emission inventory for many Chinese cities has also been compiled. Sugar et al. [19] provided a comprehensive and detailed emission inventory for Beijing, Tianjin and Shanghai, which are among the highest per-capita emissions in global cities. Yu et al. [20] has drawn the similar conclusion that highly urbanized Chinese cities generated higher per-capita emissions than their European counterparts. Wang et al. [21] and Shan et al. [22] compiled 12 and 20 Chinese cities, respectively. Fang et al. [23] investigated the relationship between urban form and carbon emissions in 30 provincial capital cities. All these studies provide preliminary information for understanding the role of cities in global climate change. However, the adequacy of production-based perspective has also been questioned for it causes carbon leakages which lead to the serious issue of policy efficiency [24,25]. For example, household in cities consumes a huge amount of electricity produced in the power plants that may not locate in the city boundary, while the production-based perspective neglects the upstream carbon emissions caused by electricity generation [26].

Given the insufficiency of production-based accounting, many researchers argue that besides the direct emissions, carbon emissions embodied in goods and services consumed by the economy but produced in other places should also be taken into consideration [5,27]. Consequently, the consumption-based perspective, which is able to cover the upstream carbon emissions, is suggested as a supplementary for the production-based perspective for benchmarking cities' carbon emission inventory [28,29]. For example, Minx et al. [30] evaluated the carbon footprint of citied in UK, which was proved to be determined by socio-economic rather than geographic and infrastructural factors. Long et al. [31] used a multi-regional input-output model to estimate the indirect emissions induced by Tokyo, Japan. Many attentions have also been paid to Chinese cities, among which Beijing, Tianjin, Shanghai and Chongqing are always on the list [32,33]. A most updated and comprehensive consumption-based accounting database for 13 Chinese cities was constructed by Mi et al. [34]. Besides, more advanced models are developed to assess the consumption-based emissions of cities by taking the domestic and foreign supply chains into consideration, such as multi-scale input-output model [35,36], city-centric global multi-regional input-output model [37]. A consistent conclusion reached in most of these studies is that cities, especially those heavily rely on service industries, have higher consumption-based carbon emissions than their production-based emissions, indicating that final consumption in cities can displace carbon emissions in other regions. Peters and Hertwich [38] as well as many other researches [39,40] have highlighted the advantages of consumption-based accounting over production-based accounting in addressing carbon leakage, increasing reduction potential and improving policy fairness. Jacob and Marschinski [41], however, argued that consumption-based accounting maybe misleading for policy makers, as the potential consequences of the trade restriction or adjustment are hard to evaluate.

It should be pointed out that before purchasing goods and services, final consumers should first earn income as suppliers. The supply of primary inputs such as wages and taxes would enable carbon emissions by downstream users via product sale chain, which are usually named as income-based emissions [7]. The accounting for income-based emissions can provide important information for carbon emission reduction policymaking from the supply side. Compared to the large