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Carbon implications of China's changing economic structure at the city level

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ABSTRACT

Carbon emissions are strongly related to economic development. China has entered a new phase of economic development – "New Normal" – in which large-scale and multidimensional changes are occurring in the economic structure. This study aims to estimate the carbon implications of these changes in the economic structure at the city level. We compiled a multiregional input-output (MRIO) model for China and used an environmentally extended input-output analysis (EEIOA) to estimate CO_2 emissions in Shanghai from both production and consumption perspectives. We found that consumption-based CO_2 emissions were more than 30% higher than production-based emissions in Shanghai. In recent years, both production- and consumption-based CO_2 emissions in Shanghai declined because of changes in China's economic development mode. The production-based emissions declined mainly due to changes in the production structure and energy mix, while the consumption-based emissions declined mainly due to changes in consumption patterns and domestic interregional emission flows.

1. Introduction

Energy-related carbon emissions are strongly related to economic development (Han et al., 2017; Zhang et al., 2017). China has enjoyed rapid economic growth over the past several decades. The growth rate of the average annual gross domestic product (GDP) exceeded 10% for a long period until the global financial crisis in 2008. The rapid economic growth was supported by high energy consumption, which generated significant greenhouse gas (GHG) emissions (Engström, 2016; Jarke and Perino, 2017). As a result, since 2006, China has become the largest CO_2 emitter in the world and has contributed more than 25% of global emissions (Liu et al., 2015; Mi et al., 2017c).

However, the global financial crisis significantly affected Chinese economic development (Long and Herrera, 2018; Overholt, 2010); the annual GDP growth rate declined from more than 14% in 2007 to less than 7% in 2016. The Chinese government introduced a large economic stimulus plan, including the domestic Four Trillion Yuan Stimulus Package, and established institutions and initiatives to expand foreign investment, including the Asian Infrastructure Investment Bank and the Belt and Road Initiatives. In recent years, China's economy has been unable to continue the double-digit economic growth of previous decades. Instead, the country has entered a "new normal" phase of socioeconomic development in which large-scale and multidimensional changes in economic structure are happening (Green and Stern, 2017; Mi et al., 2018). Specifically, China's production and consumption structure, export and import structure, urban-rural structure, interregional structure, and roles in international trade have changed under the new normal conditions (Mi et al., 2017a).

These structural changes in China's economy have major implications for energy consumption as well as carbon emissions. The Chinese government has made an international commitment to reach peak CO_2 emissions by approximately 2030. However, recent structural changes, along with increases in non-fossil energy production, have so dramatically affected coal consumption that China's carbon emissions have already started to flatten out — on some accounts, they have even been declining since 2013. Some recent studies have explored the carbon implications of China's changing economic structure at the national level. Mi et al. (2017a) used structural decomposition analysis (SDA) to estimate the impacts of the economic structural changes on the driving factors of China's CO_2 emission changes from 2005 to 2012. They found

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that changes in the production and consumption structure have become the strongest factor to offset China's CO_2 emissions in the new normal. Mi et al. (2017b) used the multiregional input-output (MRIO) model to estimate the impacts of changes in China's economic structure and its role in global trade on CO_2 emissions during the 2007–2012 period. The results showed that emission flow patterns have changed significantly since the global financial crisis, irrespective of domestic or foreign trade. Green and Stern (2017) tracked the recent changes in China's economy since 2000 and analysed their recent and future impacts on carbon emissions. They used the Kaya components approach to forecast that China's CO_2 emissions are likely to peak by 2025 due to structral tranformation in the country. Zhang et al. (2016) estimated the impacts of China's new policy directives on climate change outcomes in the new normal. They argued that China's CO_2 emissions will peak by approximately 2030 under China's new policies, which is different from the results of Green and Stern (2017).

However, these studies estimated national-level impacts of the changing economic structure on CO_2 emissions. To date, studies have seldom focused on the carbon implications at a city level. Therefore, a key contribution of this paper is to fill this research gap by estimating the carbon implications of China's changing economic structure in Shanghai, one of the most developed cities in eastern coastal China. It needs to be noted that Shanghai is a provincial-level city, with a population of over 24 million as of 2017. We selected Shanghai as an example for two reasons. First, Shanghai is one of the cities where economic structure changes fastest in China. Shanghai is always at the forefront of socioeconomic transformation in this country. The central government usually selects Shanghai to carry out pilot projects on economic transformation policies, such as the Shanghai Pilot Free Trade Zone. Second, Shanghai has closer economic connections with foreign countries compared to other regions in China. Due to its geographical location and government policy directives, Shanghai is well connected in international trade with a large amount of imports as well as exports. Therefore, the city is largely affected by global economic development.

In this study, we analyse the carbon emissions in Shanghai city from both consumption and production perspectives. There are two approaches to calculate carbon emissions of a region: production- and consumption-based accounting (Su and Ang, 2014, 2017). Under production-based accounting, emissions are distributed to the regions where these emissions are emitted (Cai et al., 2017; Fernández-Amador et al., 2017; Peters, 2008). This accounting is more widely adopted by policy makers. For example, the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol have both adopted production-based accounting (Dong, 2017). By comparison, under consumption-based accounting, also known as the carbon footprint approach, all emissions that occur along the chains of production are allocated to the final consumers of the products (Ang and Choi, 1997; Wiedenhofer et al., 2017). Therefore, emissions embodied in one region's imports belong to the consumption-based emissions of the region. Consumption-based emissions are usually calculated using environmentally extended input-output analysis (EEIOA) (Peters et al., 2011; Yu et al., 2017). Most studies of consumption-based emissions are conducted at the global or national levels. Recently, some studies used EEIOA to analyse carbon emissions for Chinese cities from a consumption perspective. For example, Mi et al. (2016) used an input-output model to estimate consumption-based carbon emissions for 13 cities in China. They found that large differences existed between consumption- and production-based accounting for all cities examined. Feng et al. (2014) calculated consumption-based emissions of four cities in China and estimated the spatial distribution of the emissions within China that were caused by consumption in the four cities.

In this study, we construct production-based carbon emission inventories for Shanghai from 2000 to 2015 and estimate consumption-based carbon emissions for 2007, 2010, and 2012. We use a global MRIO model that combines China's MRIO with a global MRIO model that is based on the Global Trade and Analysis Project (GTAP). Based on the global MRIO model, we use the EEIOA approach to estimate consumption-based emissions in Shanghai and emission flows between Shanghai and other regions.

2. Literature review

The relationships between economic structure and carbon emissions have been analysed via three approaches, including econometrics, decomposition analysis, and optimization model. First of all, many researchers applied econometric approaches to estimate the relationships between economic structure and carbon emissions. Ahmad et al. (2016) combined autoregressive distributed lag (ARDL) and vector error correction model (VECM) to analyse the relationships among carbon emissions, energy consumption and economic growth in India. Kofi Adom et al. (2012) used ARDL approach to estimate the short-run causal relationships and the long-run equilibrium relationships between industrial structure and carbon emissions for three African countries. Niu et al. (2011) used panel data based econometric approaches to evaluate the causality between energy consumption, GDP growth and carbon emissions for eight Asia-Pacific countries from 1971 to 2005.

Second, the decomposition analysis is widely used to analyse the relationship between economic structure and carbon emissions. Mi et al. (2017a) used structural decomposition analysis (SDA) method to analyse the impacts of China's economic structure changes on carbon emissions during 2005–2012. Mi et al. (2017b) used SDA approach based on MRIO table to estimate the impacts of economic structure changes on interregional carbon emission flows within China between 2007 and 2012. Chang and Lahr (2016) combined SDA and linkage analysis to identify the key factors and sectors that affected carbon emissions in China. Hoekstra et al. (2016) used SDA to estimate the contributions of international sourcing to global CO_2 emission growth.

Third, some researchers developed optimization models to estimate impacts of economic structure on carbon emissions. Mi et al. (2015) developed an optimization model based on input-output analysis to analyse the impacts of industrial structure changes on energy consumption and carbon emissions in China. Yu et al. (2016) developed a dynamic multi-objective optimisation model to estimate the impacts of industrial structure on energy consumption in China.

3. Methodology and data

3.1. Construction of the production-based carbon emission inventory

Production-based carbon emissions are calculated using the Intergovernmental Panel on Climate Change (IPCC) reference approach (Liu et al., 2015; Shan et al., 2017). In this study, we focus on CO_2 emissions caused by energy consumption in economic sectors. We do not consider emissions caused by industrial processes, such as the production of cement and lime. According to the IPCC approach, the formula for calculating CO_2 emissions from energy consumption is (Mi et al., 2017b)

$$C = E \times V \times F \times O, \tag{1}$$

where C represents the fossil fuel-related CO_2 emissions, E represents the energy consumption associated with different fuel types (expressed as a physical unit), V is the net calorific value of differ-