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Research article

# Socioeconomic determinants of China's growing $CH_4$ emissions

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ABSTRACT

Reducing $CH_4$ emissions is a major global challenge, owing to the world-wide rise in emissions and concentration of $CH_4$ in the atmosphere, especially in the past decade. China has been the greatest contributor to global anthropogenic $CH_4$ emissions for a long time, but current understanding towards its growing emissions is insufficient. This paper aims to link China's $CH_4$ emissions during 2005–2012 to their socioeconomic determinants by combining input-output models with structural decomposition analysis from both the consumption and income perspectives. Results show that changes in household consumption and income were the leading drivers of the $CH_4$ growth in China, while changes in efficiency remained the strongest factor offsetting $CH_4$ emissions. After 2007, with the global financial crisis and economic stimulus plans, embodied emissions from exports plunged but those from capital formation increased rapidly. The enabled emissions in employee compensation increased steadily over time, whereas emissions induced from firms' net surplus decreased gradually, reflecting the reform on income distribution. In addition, at the sectoral level, consumption and capital formation respectively were the greatest drivers of embodied $CH_4$ emission changes from agriculture and manufacturing, while employee compensation largely determined the enabled emission changes across all industrial sectors. The growth of $CH_4$ emissions in China was profoundly affected by the macroeconomic situation and the changes of economic structure. Examining economic drivers of anthropogenic $CH_4$ emissions can help formulate comprehensive mitigation policies and actions associated with economic production, supply and consumption.

## 1. Introduction

China is one of the countries most vulnerable to the adverse impacts of climate change. However, it is the largest $CO_2$ emitter in the world (Li et al., 2016). China' rapidly increasing $CO_2$ emissions have prompted the measures to address climate change and to achieve emission mitigation (Guan et al., 2018). The country's government has pledged to lower its $CO_2$ emissions per unit of GDP by 60–65% relative to the 2005 level and committed to peak its $CO_2$ emissions by around 2030. A series of energy and climate policies have been developed and implemented to ensure such mitigation targets. Nevertheless, most of these policies and actions have focused on the reduction of $CO_2$ emissions.

Methane ($CH_4$) is the second largest greenhouse gas (GHG) after $CO_2$, but is more active than the latter. For a time horizon of 20 years, $CH_4$ has greater short-term climate impacts than $CO_2$ with a Global Warming Potential 84 times larger than $CO_2$ (IPCC, 2014), while it is responsible for nearly one fifth of global warming (Montzka et al., 2011). In the recent decade, the atmospheric concentration of $CH_4$ has witnessed a disturbing surge (Saunois et al., 2016) to the extent that it has more than doubled compared with the level before the Industrial Revolution. The growth of $CH_4$ levels in the atmosphere has been largely driven by increasing emissions from human activities such as agricultural activities and fossil fuel extraction, and then mitigation of anthropogenic $CH_4$ emissions can generate direct effects on its atmospheric concentration (e.g., Ghosh et al., 2015; Nisbet et al., 2016).

China is the world's largest contributor of anthropogenic $CH_4$ emissions. To date, there are three national GHG inventories including $CH_4$ emissions reported by the Chinese government (CCDNDRC, 2017; Zhang et al., 2018a). According to the last official national GHG inventory, which was published in the first Biennial Update Report (BUR) on Climate Change submitted to the UNFCCC (CCDNDRC, 2017),

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China's total $CH_4$ emissions amounted to 55.9 Tg in 2012. Even by the lower GWP value of 21, this amount was equal to 1174 Mt $CO_2$-eq, much larger than the $CO_2$ emissions in some developed countries such as England and Japan. In view of the importance of $CH_4$ in the whole GHG emission inventories, China's significant $CH_4$ emissions have attracted considerable research in inventory compilation and analysis over the last decade. Some researchers and international institutions have published their own estimates for China's $CH_4$ emissions at the national scale (e.g., USEPA, 2012; Yang et al., 2014; Zhang and Chen, 2014; Zhang et al., 2014; Peng et al., 2016; Janssens-Maenhout et al., 2017). All unanimously reported that China's $CH_4$ emissions had witnessed dramatic increases over the past three decades (Zhang, 2011; Peng et al., 2016). Recently, the EDGAR database provided a consistent series of China's $CH_4$ emissions inventory covering 1970–2012 (EDGAR, 2017). Existing emission inventories have identified the surge in livestock, energy and waste-related $CH_4$ emissions in China, especially since 2005, as well as how this fast growing trend is unlikely to be reversed in the near periods (Yao et al., 2016). Given the severe challenges that increasing $CH_4$ emissions poses in mitigating GHG emissions, more attention should be paid to understanding and quantifying China's $CH_4$ emissions and to propose potential mitigation measures.

In China, $CH_4$ emissions are directly related to economic production such as energy extraction and supply (Zhang et al., 2014), rice cultivation and livestock farming (Wang et al., 2017b), and waste management services (Du et al., 2017, 2018b). Besides mitigating $CH_4$ emissions on the production side, it is essential to understand the role of socioeconomic activities in anthropogenic emissions and reveal the opportunities available for mitigation (Zhang et al., 2015; Zhou et al., 2018). It is widely acknowledged that resource extraction and environmental emissions are induced by final consumption demand (Liu et al., 2010; Wu and Chen, 2017; Tang et al., 2018). Environmentally extended input-output analysis (EEIOA) facilitates a deeper appreciation of sector-specific direct/visible and indirect/hidden emission requirements (Miller and Blair, 2009). By using the Leontief demand-driven input-output models, a series of studies have been performed to measure consumption-based accounting of GHG emissions at different scales (Feng et al., 2015; Hawkins et al., 2015). An increasing amount of literature has focused on China's $CO_2$ emissions embodied in final consumption and international trade (e.g., Chen and Zhang, 2010; Feng et al., 2012; Yuan et al., 2018). Particularly, Zhang and his colleagues (Zhang and Chen, 2010; Zhang et al., 2015, 2018a) have conducted a series of studies on the embodiment analysis of $CH_4$ emissions in China. Environmental emissions can also be driven by primary inputs. Higher income translates to higher consumption capacity and greater demands for environmental resource inputs. The Ghosh supply-push input-output model can capture the linkages of value-added with primary inputs, which has been used to estimate the enabled emissions of $CO_2$ and air pollutants driven by the value added using the income-based accounting method (e.g., Liu et al., 2010; Zhang, 2010; Marques et al., 2013; Liang et al., 2016a, b; Liu and Fan, 2017). Furthermore, the method of structural decomposition analysis (SDA) enables researchers to examine the driving forces of resources, emissions and other physical quantities (e.g., Hoekstra and Van Den Bergh, 2002; Su and Ang, 2012, 2017; Arto and Dietzenbacher, 2014; Malik et al., 2016; Deng and Xu, 2017; Wang et al., 2017a). By using this method, energy, air pollutants and carbon emissions in China have been widely analyzed (e.g., Kagawa and Inamura, 2004; Peters et al., 2007; Guan et al., 2008, 2009; 2014; Zhang, 2009; Xu et al., 2011; Zhang and Qi, 2011; Feng et al., 2012, 2017; Xie, 2014; Zeng et al., 2014; Deng et al., 2016; Yuan and Zhao, 2016; Jiao et al., 2017; Liu and Liang, 2017; Mi et al., 2017a, 2017b; Shi et al., 2017; Wei et al., 2017; Zhao et al., 2017; Du et al., 2018a; Zhang et al., 2018b). Despite of the existing literature on GHG emissions accounting, the current understanding of China's $CH_4$ emissions from both consumption- and income-based perspectives is insufficient.

Exploring and explaining the socio-economic drivers behind China's growing anthropogenic $CH_4$ emissions is of critical importance for three reasons. First, China has not only been the largest $CH_4$ emitter in the world, its level of emissions has also increased constantly. Identifying major emission drivers provides guidance on further mitigation. Second and more importantly, the world-wide rise in $CH_4$ emissions over the last decade is poorly understood. Unlike $CO_2$ emissions, there is an ongoing dispute over the determinants of the surging atmospheric $CH_4$. Various sources have been suggested to be responsible for this increase, such as agricultural activities in Asia (Schaefer et al., 2016), feedback effects from tropical wetlands (Nisbet et al., 2016), and declines in hydroxyl radicals (Turner et al., 2017), yet no consensus has been reached. Surprisingly, explaining $CH_4$ emission growth with socio-economic factors barely draws any attention from researchers, even though atmospheric $CH_4$ is closely associated with human activities. Third, $CH_4$ monitoring is especially inadequate. Although some developed countries have refined their $CH_4$ measurement equipment to monitor emissions from various sources, upgrading to better equipment for monitoring individual sources is costly for developing countries. Therefore, analyzing the socio-economic drivers of $CH_4$ emissions and their corresponding mitigation potentials is not only meaningful but is also a practical option for most developing countries with limited resources.

This paper aims to shed light on the issue of China's anthropogenic $CH_4$ emissions, and explore the socioeconomic determinants of its growing emissions from 2005 (the baseline for China's emission reduction commitment) to 2012 based on the EEIOA and SDA methods. Key sectors and driving forces for embodied and enabled $CH_4$ emissions in China are identified by using income-based accounting and consumption-based accounting, where the former involves a supply-side SDA and the latter a demand-side SDA. The main contribution of our work is to reveal the supply- and demand-side impacts on anthropogenic $CH_4$ emissions arising from structural changes in the economy. Finally, we discuss the development of emission trend and future mitigation policies, especially in the economic “new normal”.

## 2. Methodology and data sources

### 2.1. Consumption-based accounting and structural decomposition analysis

Consumption-based accounting covers the embodied $CH_4$ emissions caused by final demand (e.g., rural and urban consumption, government consumption, investment and export) and relocates the emission responsibility to final consumers. Performing structural decomposition on embodied emissions can provide a comprehensive understanding towards the socioeconomic determinants of $CH_4$ emissions from the demand side. According to the principle of EEIOA model, $e$ denotes a row vector of sector-level $CH_4$ emissions and $x$ denotes the sector-level output vector, the $CH_4$ emissions embodied in final demand, $u$, can be calculated as

$$u = (e'\hat{x}^{-1})(I - Z\hat{x}^{-1})^{-1}\hat{y} \quad (1)$$

where $Z$ is the inter-sectoral transaction matrix denoting the monetary relationship among different sectors of the economy; $y$ is the vector of final demand for each sector; and the operator ˆ represents a diagonalizing matrix. The term $e'\hat{x}^{-1}$ stands for a vector of sector-level $CH_4$ emission intensities, and $(I - Z\hat{x}^{-1})^{-1}$ is the Leontief inverse matrix. Since $y$ represents the final demand, $(I - Z\hat{x}^{-1})^{-1}\hat{y}$ can be interpreted as the inputs from each sector to produce the final demand. Thereafter, embodied $CH_4$ emissions induced by any given final demand category such as consumption, can be obtained through Equation (1).

We consider five factors, i.e. population, production efficiency, production input structure, consumption structure and absolute consumption volume, for analyzing the determinants of embodied $CH_4$ emissions. Consequently, the $CH_4$ emissions embodied in final demand can be decomposed into five terms by rewriting Equation (1) into: