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Analysis of industrial energy-related CO_2 emissions and the reduction potential of cities in the Yangtze River Delta region

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ABSTRACT

Cities are the main carbon dioxide (CO_2) emitters in China, and it is important to explore both the characteristics and reduction potential of their CO_2 emissions. This paper calculates the industrial energy-related CO_2 emissions (IECEs) of 17 cities in China's Yangtze River Delta (YRD) region from 2005 to 2014 and analyses the driving factors of CO_2 emissions using the Logarithmic Mean Divisia Index (LMDI). In addition, this paper predicts the CO_2 reduction potential of this group of cities for the period from 2015 to 2020. The results show that (1) during the sample period, industrial CO_2 emissions in the studied cities increased by a factor of 1.61. Economic output is the greatest contributor, followed by population size. Energy intensity and energy structure are the two main emission mitigation factors; (2) the driving factors of CO_2 emissions in the group of cities exhibit distinct spatial characteristics, indicating that future analyses of cities in this area should have distinctly different foci; and (3) the forecasting results show that under moderate and aggressive scenarios, CO_2 emissions in the studied cities can be reduced by 281.59 Mt and 711.90 Mt, respectively, by 2020.

1. Introduction

In recent years, anthropogenic climate change caused by the excessive emission of greenhouse gases (e.g., CO_2) has been regarded as a threat to human survival and development, and reducing emissions has become an increasingly important global issue (Guan et al., 2015; Hao et al., 2015; Song et al., 2015; Mi et al., 2017a). CO_2 is one of the main greenhouse gases, and the reduction of CO_2 can mitigate global warming and avoid associated hazards, such as sea level rise, increased desertification and others (Meng et al., 2016; Wang et al., 2016; Mi et al., 2017b; Zeng et al., 2017a).

China is one of the world's largest CO_2 emitter. Since China's 1978 economic reform, the country has achieved remarkable economic growth; however, energy consumption has increased with this economic growth (Yu et al., 2014; Mi et al., 2015a; Wang and Feng, 2017a), inevitably increasing CO_2 emissions. According to British Petroleum (BP) (British Petroleum, 2015), China became the world's largest emitter of carbon dioxide in 2006. In 2014, China's CO_2 emissions further reached 9.76 billion tons, accounting for 27.5% of global emissions (British Petroleum, 2015). Reducing CO_2 emissions could not only benefit sustainable development in China but also enhance China's national image (Liao et al., 2007; Jiang et al., 2016; Zeng et al., 2017b). To control CO_2 emissions, the Chinese government established a set of regional emission reduction targets in the 11th and 12th Five-Year Plan periods. However, China's different regions have extremely different levels of economic development, resource endowment, and economic structures, which lead to substantial variations in regional emissions characteristics (Chen et al., 2007; Zhang et al., 2009a; Liu et al., 2011; Wang et al., 2013; Guan et al., 2014). In this context, it is important for the government to consider the CO_2 emissions in each region individually to create regional strategies for reducing CO_2 emissions.

The Yangtze River Delta (YRD) region has the fastest growing economy, largest total economic output, and highest economic potential in China (Song et al., 2015). According to the National Bureau of Statistics, the gross domestic product (GDP) of the YRD region, which includes two provinces and one municipality, Suzhou, Zhejiang and Shanghai, reached 12.88 trillion Chinese Yuan, accounting for 20.26% of China's national economy in 2014. Economic development generally requires the consumption of considerable fossil fuel resources (Guan et al., 2008; Zhang et al.,

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2009b, 2014; Liao and Cao, 2013). Specifically, the YRD region's total energy consumption in 2014 reached 486.89 million tons of standard coal equivalent (Mtce), accounting for 12.16% of China's national energy consumption of 4002.99 Mtce and representing an increase of 166.75% over the 291.99 Mtce that the region consumed in 2005. Inevitably, high levels of CO_2 emissions are associated with the consumption of fossil fuels. Notably, industrial energy consumption in cities, which accounts for a large portion of the YRD region's total energy consumption, is a leading source of CO_2 emissions in this region (Song et al., 2015). Compared with the other two industrial regions of China, the Beijing-Tianjin-Hebei region and Pearl River Delta region, the cities in the YRD region emitted more industrial energy-related CO_2 in 2014 (as shown in Fig. 1). Therefore, analyses of the driving factors and emissions potential of industrial energy-related CO_2 emissions (IECEs) in these cities are inevitably needed to decrease CO_2 emissions and achieve the emissions reduction goals proposed in *Made in China 2025*) and the *Industrial Green Development Plan (2016–2020)*.

Under these conditions, this study focuses on answering the following questions. First, what are the major factors that influence the IECEs of each city in the YRD region? Second, how much potential do the cities in this region have to reduce IECEs? Third, what policy suggestions can be made to mitigate the industrial CO_2 emissions of cities in this region? To answer these questions, this study first constructs a factor decomposition model based on time series data and city panel data using the Logarithmic Mean Divisia Index (LMDI) method. This model allows us to decompose the sources of IECEs change into five components: the carbon intensity effect, the energy structure effect, the energy intensity effect, the economic output effect, and the population size effect. Then, this study conducts an empirical analysis of the annual driving effects of these factors in each city. Finally, the total potential reduction of studied cities is estimated.

The remainder of this paper is structured as follows. Section 2 presents the literature review. Section 3 describes the methodology and data sources. Section 4 discusses the empirical results. Section 5 summarizes the findings and provides policy recommendations.

2. Literature review

Since the 1980s, global warming has become an important issue worldwide, and many studies have attempted to identify the factors that influence carbon emissions by applying a variety of approaches (Rhee and Chung, 2006; Mi et al., 2015b). Among them, decomposition analyses of carbon emissions have been popular in academia; using this approach, many studies have been conducted

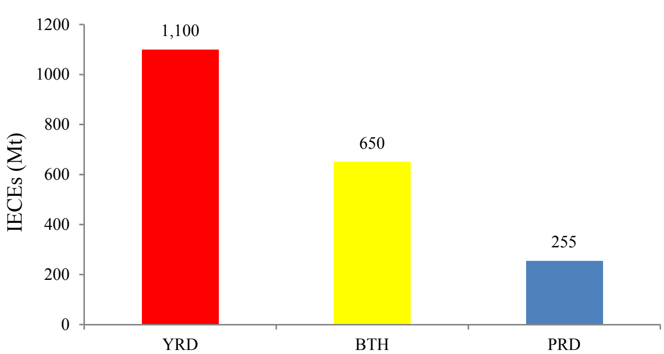

Fig. 1. Industrial energy-related CO_2 emissions in three industrial areas in 2014. Note: YRD= Yangtze River Delta region; BTH= Beijing-Tianjin-Hebei region; PRD= Pearl River Delta region.

on energy consumption and carbon emissions. In these studies, two types of decomposition analysis approaches were commonly used: structural decomposition analysis (SDA) and indexed decomposition analysis (IDA). The former method decomposes index changes using the input-output tables of specific years depending on the input-output model used for quantitative economic assessment. This method was proposed by Chang and Lin (1998) to analyse the drivers of industrial CO_2 emissions changes in Taiwan from 1981 to 1991. Subsequently, many scholars have applied this method to analyse CO_2 emissions (Chang et al., 2008; Su and Ang, 2012; Geng et al., 2013; Tian et al., 2013). The latter method, which was first used by Hulten (1973) to study energy issues, is capable of assessing factors that drive changes in carbon emissions to provide relevant suggestions for mitigation. Because of the accessibility of data, the IDA approach is more widely applied than the SDA approach (Ang, 2004) and has been expanded by many researchers (Boyd et al., 1988; Howarth et al., 1991; Liu and Ang, 2007).

The LMDI approach was first proposed by Ang and Choi (1997). It is considered a very good IDA approach because of its theoretical foundation, adaptability, ease of use and interpretation of results (Ang, 2004). Compared with other IDA approaches, the LMDI method has several practical advantages from an application perspective, including perfect decomposition, the additive property of results and consistency in aggregation (Ang, 2005). Because of these advantages, the LMDI method is favoured by many researchers and used in many areas, such as energy supply and demand (Wang et al., 2014; Chong et al., 2015), energy-related gas emissions (Chang et al., 2008; Wang and Feng, 2017b), material flow and dematerialization (Wood et al., 2009; Pothen and Schymura, 2015), national energy efficiency trend monitoring (Inglesi-Lotz and Pouris, 2012; Shahiduzzaman and Alam, 2013) and cross-country comparisons (González et al., 2014).

In the context of energy-related gas emissions, increasing CO_2 emissions in China have attracted considerable research attention, and many studies have been conducted to explore the associated driving factors using the LMDI approach. These studies are mainly conducted from sectoral and regional perspectives to identify the driving factors of carbon emissions in different sectors and regions. For example, Liu et al. (2007) analysed the changes in industrial carbon emissions from 36 industrial sectors in China from 1998 to 2005 based on a time series decomposition of the LMDI method. Xu et al. (2012) analysed the changes in energy consumption and CO_2 emissions in China's cement industry and the associated driving factors from 1990 to 2009 by applying the LMDI method. Lin and Long (2016) employed the LMDI approach to explore the driving factors of carbon emission changes in China's chemical industry using both time series data and provincial panel data. Using the LMDI decomposition method, Xie et al. (2016) decomposed the CO_2 emission changes in China's petroleum refining and coking industry into five categories and compared their different contributions.

In addition to studies conducted at the sector level, some researchers have explored carbon emissions from a regional perspective. For example, Zhao et al. (2010) identified and quantitatively analysed the main factors responsible for industrial carbon emissions in Shanghai from 1996 to 2007 using the LMDI method. Xu et al. (2014) decomposed carbon emissions into energy structure, energy intensity, industry structure, economic output, and population scale effects, and analysed the factors that influence carbon emissions due to fossil energy consumption at the country level. Song et al. (2015) analysed the effects of economic scale, population size, energy intensity, and energy structure on carbon emissions in the YRD region from 1995 to 2010. Chen et al. (2016) used the LMDI method to decompose industrial carbon emissions from energy consumption into four factors and analysed their