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Exploring the driving forces of energy-related CO_2 emissions in China's construction industry by utilizing production-theoretical decomposition analysis

Miao Wang [a], Chao Feng [b,*]

[a] School of Management, Xiamen University, Xiamen 361005, China
[b] School of Economics and Business Administration, Chongqing University, Chongqing 400030, China

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ABSTRACT

The construction industry is one of the largest energy consumers and CO_2 emitters in China. This paper primarily aimed to explore the driving forces of energy-related CO_2 emissions (ECE) from the construction industry. Adopting a comprehensive decomposition approach, this study decomposes the changes in ECE into eight factors. The main results provide the following findings. (1) Industrial activity was the largest factor pushing the growth of CO_2 emissions, driving up CO_2 emissions in all years and contributing to a 174.65 Mt CO_2 emissions increase in total. (2) In contrast, advances in industrial output technology represented the dominant factor inhibiting CO_2 emissions, cumulatively reducing CO_2 emissions by 99 Mt. (3) The effects of potential energy intensity changes and industrial output technical efficiency fluctuated in different years but exerted positive effects on CO_2 emissions over the entire period. (4) Additionally, changes in spatial structure, energy-saving technology, and energy consumption structure as well as energy usage efficiency all contributed to emissions reductions to varying degrees. The CO_2 emissions of the construction industry increased in all provinces, while emissions changes and their factor effects varied distinctly across provinces.

1. Introduction

As the need for international climate change negotiation and national sustainable development has increased, China has set energy-saving and emission-reduction targets. The construction industry is one of the pillar industries in China (Xue et al., 2015). Since the beginning of the new century, China's construction industry has witnessed enormous development. It has become an important industry in material production in China's economy and an important force for stimulating economic growth. In 2014, the Chinese construction industry achieved 4479 billion yuan in gross output value, with a growth rate of 9.76% compared with a year ago.[1] However, simultaneously, as a resource-intensive industry, the extensive growth mode of the construction industry has not achieved substantial transformation during these years. Significant resource consumption, energy consumption and CO_2 emissions as well as other environmental pollution problems have severely affected the healthy expansion of China's construction industry. Recently, along with the acceleration of the urbanization process in China, the construction industry's energy consumption and CO_2 emissions have dramatically increased. Under these circumstances, energy savings and emission mitigation in China's construction industry are of great significance to the sustainable development of China's economy.

Clarifying the development situation of China's construction industry and investigating the major forces influencing its CO_2 emissions could provide valuable information for policy makers in instituting emission-reduction policies. The contributions of this paper mainly cover three aspects. (i) This study employed a comprehensive decomposition approach, which provides three new factors (i.e., industrial output technical efficiency, industrial output technology change, and spatial structure) to explore the driving factors behind the construction industry's growing CO_2 emissions. (ii) To provide a more comprehensive understanding of the information on CO_2 emissions and factor impacts in China's construction industry, this study calculated and analyzed both

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* Corresponding author.

E-mail addresses: bigmiao613@126.com (M. Wang), littlefc@126.com (C. Feng).

[1] The data were calculated by current prices, the original data were obtained from the China Statistical Yearbook.

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additive and multiplicative decomposition results. (iii) Considering the large differences existing among Chinese provinces, this study not only conducted an empirical analysis at the national level but also carried out decomposition analysis for 30 Chinese provinces.

Accordingly, the structure of this paper is organized as: Section 2 presents the literature review. Section 3 introduces the methodology and data. Section 4 presents an overview of China's construction industry. Section 5 discusses the decomposition results at both the national and provincial levels. Section 6 draws the research conclusions and proposes corresponding policy recommendations.

2. Literature review

With the growing concern over the issue of energy savings and emission reduction, numerous researchers have been absorbed in exploring and quantifying the driving factors affecting environmental changes. Technically, such research can be done by decomposing the aggregate environmental changes into several factors by utilizing the decomposition method. Structural decomposition analysis (SDA) and index decomposition analysis (IDA) are two well-known decomposition methods. Rose and Casler (1996) reviewed the theoretical foundation and major features of the SDA method. Examples of SDA studies are Peters et al. (2007), Xie (2014), and Mi et al. (2016), among others. This method is conducted on the basics of input-output table (Mi et al., 2015; Wang et al., 2017a). However, this tables are not available yearly (Su and Ang, 2012; Mi et al., 2017a), which limits its use. The IDA method is based on the index number concept (Ang and Zhang, 2000; Hoekstra and Van den Bergh, 2003). Compared with SDA, the IDA method has relatively low data requirements (Lin and Liu, 2015a,b). Ang (2004) reviewed the various IDA methods and concluded that the Logarithmic Mean Divisia Index (LMDI) was preferential, owing to its theoretical foundation, ease of use and result interpretation, among others. Examples of LMDI studies and their research objects are listed in Table 1.

In addition to the two aforementioned decomposition methods, some studies have recently carried out decomposition analysis based on the production-theory framework. For instance, Pasurka (2006) decomposed NO_x and SO_2 emission changes by coal-fired electric power plants within a joint production framework. Wang (2007) used output distance functions to study the changes of energy productivity in twenty-three OECD (organization for economic cooperation and development) countries. Following this line of research, Zhou and Ang (2008) proposed that decomposing CO_2 emission changes by using the Shephard input distance functions in a joint production. The most significant advantage of PDA is providing production technology-related and efficiency-related components (such as technology change, technical efficiency change, and others). Note that only energy consumption was taken as an input in the research of Zhou and Ang (2008).

Table 1
LMDI studies and their research objects.

Studies	Research objects
Liu et al. (2007)	Industrial CO_2 emissions
Timilsina and Shrestha (2009)	Transport sectoral CO_2 emissions in Latin American and Caribbean countries
Baležentis et al. (2011)	Energy intensity in Lithuania
Zhang and Guo (2013)	Rural residential commercial energy consumption in China
Cansino et al. (2015)	CO_2 emissions in Spain
Song et al. (2015)	Carbon emissions in the Yangtze River Delta region
Robaina-Alves et al. (2016)	The carbon dioxide emissions in Portuguese tourism
Xu et al. (2017)	Carbon intensity in China
Wang et al. (2017)	Decoupling indicator between CO_2 emissions and GDP in China
Zhou et al. (2017)	China's industrial carbon emissions
Wang and Feng (2018a)	Energy consumption of China's nonferrous metal industry
Zou et al. (2018)	Irrigation water demand in the Heihe River basin of Northwest China
Moutinho et al. (2018)	CO_2 emissions in the current top 23 countries in terms of renewable energies
Goh et al. (2018)	Global carbon intensity of electricity

Subsequently, Zhang et al. (2012) presented an alternative decomposition technique to identify the factors that influence CO_2 emissions. In their study, they incorporate both the labor force and capital stock into the input and decompose CO_2 emission changes into nine components. Using a similar approach, Zhang et al. (2013) investigated the carbon emission changes in twenty-five OECD countries and China, and in this study, they decomposed the changes of carbon emission into ten factors. Note that this approach can identify the effects of change in the structure and input ratio on carbon emission changes. Wang et al. (2015) also conducted a decomposition analysis of China's CO_2 emissions based on a modified PDA model. As previously mentioned, the LMDI method cannot reveal the impacts of technology-related factors. As a result, some researchers have combined the PDA and IDA methods. The combined decomposition approach not only can reveal the impacts of some technology and efficiency factors on CO_2 emission changes but can also solve out the inconformity of structural effects. Examples of such decomposition studies include Lin and Du (2014), Du et al. (2017), Li et al. (2017), Liu et al. (2017), Wang et al. (2018a), and Wang et al. (2018b).

Regarding China's building construction industry, several studies have attempted to explore the driving forces of energy consumption or CO_2 emissions. For example, Cai et al. (2014) and Zhou and Chen (2015) used LMDI method to identify the driving factors affecting the energy consumption change of China's building industry. Zhang et al. (2015a,b) also used LMDI method to analyze the drivers of the building energy consumption of the commercial sector. Hong et al. (2017) applied the SDA method to quantify the effects of the driving forces led to the energy increase in this industry. Moreover, Lin and Liu (2015a,b) adopted a three-dimensional LMDI method to analyze the economic factors of CO_2 emissions in China's commercial and residential buildings. Lu et al. (2016) used LMDI to identify the longitudinal impacts of seven key factors of carbon emission in China's building and construction industry. Jiang and Li (2017) calculated the direct and indirect carbon emissions in China's building industry and then applied LMDI to investigate the drivers of carbon emission change. Ma et al. (2017a) proposed an IPAT–LMDI model approach to identify the drivers affecting national building energy savings. Ma et al. (2017b) adopted an extended STIRPAT model to evaluate the driving forces affecting carbon emissions in Chinese public buildings.

Summarizing the previous literature, we find that although several researchers have used the LMDI, SDA, or STIRPAT (i.e., stochastic impacts by regression on population, affluence, and technology) method to investigate the driving forces of energy consumption/CO_2 emissions from China's construction industry, some omissions still exist. More specifically, the LMDI and SDA methods can quantify the factor effects of energy consumption or CO_2 emissions, but they cannot investigate technology-related factors. The extended STIRPAT model can investigate the impact of technological advancement; however, the STIRPAT only can reveal the relative responses of these factors to energy consumption/CO_2 emissions. Considering that this study aims at revealing the quantitative impact of various driving factors, the STIRPAT model is not suitable either. As previously mentioned, the