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Carbon emissions and policies in China's building and construction industry: Evidence from 1994 to 2012

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ABSTRACT

Since 2013, China has become the largest emitter of CO_2 in the world. Among all emission sources, the building and construction industry contributes significant amounts due to its massive use of materials and equipment. However, emissions quantity, growth trends, and influencing factors have yet to be fully investigated. This study aims to calculate construction carbon emissions in China from 1994 to 2012 by identifying the longitudinal impact of seven key driving factors and evaluating the effectiveness of construction emissions policy. The data were collected from publicly accessible statistical yearbooks in China, and analyzed by the Logarithmic Mean Divisia Index (LMDI) to decompose incremental emission changes. Key findings include: (1) carbon emissions of China's building and construction industry reached 115 billion kg in 2012 and contributed 3.4% to the country's emissions; (2) on average, the annual emissions increase for the last 19 years was 6.9%, during which time “building materials consumption” contributed the most (63%) to the total increase of carbon emissions, while “energy intensity” offset the largest amount (54%) of total emissions mitigation; (3) in 2012, construction carbon intensity was far less (only 13.1%) than that of the national intensity level; and (4) the construction industry has met or surpassed most of the domestic emission-reduction targets in both the short- and mid-term, but there is uncertainty on whether long-term targets can be achieved. This research provides new scientific evidence of carbon emissions in China's building and construction industry from a decomposition method and raises new challenges for industry-specific emission regulations.

1. Introduction

Global warming caused by greenhouse gas (GHG), especially CO_2 emissions (hereinafter interchangeably used with carbon emissions), continuously threats the existence of human and ecological environment and has caused a series of global concerns, such as rising sea levels, crop failures, desertification, and pest proliferation. To limit the global average temperature to below 1.5 °C–2 °C compared with the pre-industrial level and to reach the peak of global GHG emissions as soon as possible, a 40–70% reduction in global GHG emissions must be ensured by 2050 [1]. To achieve this target, international countries have made commitments to cut domestic carbon emissions.

In 2013, the world's total carbon emissions were 754.2 billion, while China accounted for 14.4% (108.6 thousand billion kg) [2]. In 2014, China surpassed the United States (U.S.) to become the world's largest emitter of greenhouse gases, accounting for about 23.4% of global GHG emissions [3]. Among total energy consumption in China, the building sector contributes to 10.5 to 11.3 thousand-billion kg of coal equivalent and accounts for 28–30% of China's total carbon emissions [4]. The construction phase accounts for 5.5–5.9% of a building's life-cycle carbon emissions [5], and the embodied energy of building materials including cement, iron, steel and so on consumes around 16% of total energy consumption of the country [6]. Though the percentage of carbon emissions might seem small, amounts could reach high levels given the amount of total national emissions as the base [2].

In addition, carbon emissions from the construction industry in China have yet been fully investigated and would involve challenges in developing and evaluating relevant policies for the building and construction industry. Therefore, this paper aims to compute and track national levels of carbon emissions for the

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construction industry in China from 1994 to 2012 and to identify the most influential factors that affect the change in the quantity of emissions. A time-series decomposition technique was used to decompose the aggregated emissions into incremental contributions by different factors. The results could promote a further understanding of construction emissions quantities and future emissions trends to shape more effective policies for the construction and built environment.

The structure of the study is as follows. Section 2 reviews existing studies for carbon emissions calculation and decomposition methods and Section 3 delineates the research method and data collections. Section 4 discusses total construction emissions, contributing factors to the change in emissions, and the effectiveness of current and future emission policies. Section 5 concludes and suggests future works.

2. Literature review

2.1. National levels of carbon emissions

The building industry is projected to contribute more than 31% of carbon emissions to total global emissions by 2020 and 52% by 2050 [7]. In Europe, the building and construction industry accounts for over 40% of total energy consumption [8], and contributes almost 50% of carbon emissions released in the atmosphere [9]. During the life cycle of a building, the embodied energy- and construction-related energy may take up between 10% and 60% of total energy used [10]. In Australia, around a quarter (23%) of total GHG emissions is the result of the energy demand from the building sector [11]. In the United States (U.S.), construction activities are responsible for 40% of carbon emissions of non-transportation mobile sources [12] and emissions from construction equipment and plants account for more than 50% of most types of emissions [13]. Energy consumption estimates for the construction sector in the U.S. are 2.6–3% of the country's entire energy consumption [14]. In the United Kingdom, construction sector related activities account for an estimated 47% of total CO_2 emissions [15], and emitted 42.6 Mega tonnes of CO_2e ($MtCO_2e$) in 2011, among which approximate 10 $MtCO_2e$ associated with construction operational activities and 22 $MtCO_2e$ attributed to material production [16]. In Korea, carbon emissions in the building sector comprise 23% of the country's total emissions [17].

To limit carbon emissions and to save energy in the construction and built environment, a series of assessments have been established globally. Among these assessments, two dominant approaches—at both the macro and micro level—have been applied in estimating construction carbon emissions [18]. At the macro level, input–output modeling and life cycle assessments have been most commonly used. Nässén et al. [19] accessed the direct and indirect energy use and carbon emissions of the building industry in Sweden with input–output modeling. Lu et al. [20] evaluated the effectiveness of three carbon policies to control carbon emissions in the U.S. construction industry. Chen and Zhang [21] analyzed the carbon emissions of China in 2007 based on a multi-scale, input–output approach.

However, little study has been performed to estimate the carbon emissions associated with construction activities in China. Most existing studies have focused on calculating emissions from an individual building. For instance, Gustavsson et al. [22] used bottom-up analytical techniques to calculate the life-cycle, primary-energy use and carbon emissions of an eight-story, wood-framed apartment building in Sweden. Kneifel [23] estimated life-cycle energy savings, carbon emissions reduction, and the cost effectiveness of energy efficiency of a new commercial building using an integrated design approach. Suzuki and Oka [24] quantified the total amount of energy consumption and life-cycle carbon emissions of office buildings in Japan using the input–output method. Yet these studies do not provide adequate implications for industry-level aggregated emission policymaking. The abovementioned literature highlights the research gap identified in the study of national levels of construction carbon emissions. This gap hinders the future development of an effective low-carbon policy for the construction and built environment.

2.2. Carbon decomposition analysis

To develop an effective low-carbon policy, the impact of key contributing factors should also be quantified. Previous studies have discussed several techniques to decompose aggregated carbon emissions from the entire industry into individual contributing impacts. The Index Decomposition Analysis (IDA) method was first applied to electricity-consumption decomposition in Britain and the U.S. in the early 1980s. Since then, it has been widely used in energy-related carbon emissions for the economic sector as well as energy-consuming sectors [25]. The IDA can be further classified into many forms, such as the Arithmetic Mean Divisia index (AMDI) method [26], the Logarithmic Mean Divisia Index method [27], the Laspeyres index method [28], and the Shapley/Sun (S/S) method [29].

Among these methods, the Logarithmic Mean Divisia Index method (LMDI), a brand of IDA, is an analytical tool developed from energy studies that uses aggregated data of different sectors, especially those sectors that contain fewer elements and time-series data [30]. The LMDI has features such as full decomposition, a lack of residuals, ease of use, and consistent results. Based on those advantages, the LMDI has been widely applied for studying carbon emissions at national levels. For instance, Lv et al. [31] used the LMDI to decompose the historical carbon-emissions volume in China and analyzed the country's carbon intensity from 1980 to 2010. Li [32] used a distance function approach to decompose the change of CO_2 emissions in China. González et al. [33] tracked the European Union carbon emissions through a LMDI decomposition analysis of changes in carbon emissions from 2001 to 2010.

Researchers also used the LMDI to decompose emissions in various industries, such as commerce and manufacture. Liu et al. [34] analyzed the change of China's industrial carbon emissions from the final fuel usage of 36 industrial sectors over the period of 1998–2005. Xu et al. [35] analyzed CO_2 emissions in China's cement industry. Jeong and Kim [36] decomposed Korean industrial manufacturing GHG emissions from 1991 to 2009 using the LMDI method. Rogan et al. [37] decomposed gas consumption in the Irish residential sector. Nag and Parikh [38] analyzed the commercial energy-consumption evolution patterns in India from 1970 to 1995 in terms of primary energy requirements, final energy consumption, and implications for overall carbon intensity.

So far, there have been some attempts to use the LMDI in China's built environment, such as the study by Zhao et al. [39], which decomposed China's urban residential energy consumption. Zha et al. [40] used IDA to investigate the driving forces of residential CO_2 emissions in China, and Cai et al. [41] decomposed China's building energy consumption. However, these studies focused on the building operational phase or on natural gas consumption and did not provide a decomposition of the construction operational carbon emissions. Therefore, this study selects the LDMI as a decomposition tool to investigate construction activities related emissions.

3. Research method and data collection

“Gate-to-gate” approach is selected to define the system