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A multi-regional based hybrid method for assessing life cycle energy use of buildings: A case study

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ABSTRACT

Although sustainable development in the construction industry has attracted much attention, relevant studies on the regional scale analysis of industrial energy performance are still rare in China, especially for Guangdong province, which is currently on the frontier and fast track of national low-carbon development. In response, this study integrates a multi-regional input-output method with field-based operational data to quantify the total embodied energy consumption and energy transfers from the construction industry and assess the life cycle energy use of residential and office buildings in Guangdong Province. The results show that the embodied energy consumption of the provincial construction industry is localization dominant and fossil fuel oriented, which accounts for approximately 18.6% of the total regional energy consumption. The geographical connection and resource characteristic are the two factors that influence the interregional energy transmissions induced by construction activities in Guangdong province. The result of uncertainty analysis indicates that the mean value of energy intensities simulated by Monte Carlo simulation is highly consistent with the deterministic results. It is crucial to improve the accuracy of the input-output analysis by providing sufficient economic information. At last, a number of recommendations are given through the technology, product, and management aspects at the industrial and building levels. The local government and construction department can benefit from implementing such environment-friendly, technology innovative and multi-disciplinary solutions in the full-process management and improvement of energy reduction of buildings.

1. Introduction

The construction industry is attracting increasing attention as a significant contributor to global energy consumption and carbon dioxide (CO_2) emissions. The building sector consumed more that 40% of global primary energy and about 30% of global greenhouse gas emissions from human and economic activities in its materials production, construction, use, maintenance, and demolition phases (Baum and Council, 2007; Dixit, 2016; Dixit et al., 2012; Metz et al., 2007). In addition, the operational energy use of buildings accounts for 20%–40% of the total national energy consumption in developed countries (AIA, 2008; Pérez-Lombard et al., 2008). However, all these figures considered the building sector in a fragmental manner, either excluding energy consumed in building operations or ignoring energy embodied in the materials production and transportation phase. Meanwhile, as the largest primary energy contributor in the world, China faces enormous environmental challenges in the process of rapid urbanization, which has inevitably impeded the pace of sustainable and ecological development in the modernization of China. Apart from this, the construction sector consumes approximately 30% of the total national energy consumption, half of which is attributed to the building materials production process (Hong et al., 2016a, 2016c). There is also an imbalance of economy between the eastern coast and the western interior in China, where regions may differ regarding materials production, construction processes, and modes of transportation. Consequently, the life cycle energy simulation of buildings may be very different at the regional level. However, relevant discussions

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on the regional scale, such as potential significance and growing roles of the regional construction industry in the national energy conservation process are still rare studied.

On the other hand, Guangdong province, as one of the most important provinces regarding its GDP contribution and geographic location, also significantly influences the progress of sustainable construction in China. Table 1 summarizes the current sustainability achievements and the crucial role of Guangdong province in advancing sustainable development in China. It can be seen that apart from the economic contribution and high-speed urbanization, Guangdong is also on the frontier and fast track of low-carbon development in China, being a pilot area in several national energy conservation and emission reduction projects. Therefore, a success assessment of life cycle energy use of buildings in Guangdong province can contribute to the promotion of specific building energy codes, avoid the failure from traditional policy instruments, and provide engines of further energy optimization in buildings at the regional level. Such an understanding is also vital to further mitigate the increasing energy demands arising from the accelerated urbanization process and help local decision makers in developing effective energy reduction policies.

This study aims to develop a hybrid method to evaluate the life cycle energy performance of buildings in Guangdong province by also considering geographical features and technological differences, thus providing a holistic understanding of energy use behavior of both regional construction industry and buildings. A multi-regional input-output (MRIO) model is therefore applied to manifest the geographical boundary and technological differences between Guangdong province and other regions. This method provides a solution to quantify inter-sectoral and inter-regional energy flows from a top-down perspective (Chen and Chen, 2013; Hong et al., 2016a). By taking account of regional characteristics and sectoral differences, MRIO model has been extensively studied within different research scopes. Most of the studies have focused on quantifying energy consumption and carbon emissions embodied in international trade (Chen and Chen, 2011a, 2011b; Hertwich and Peters, 2009; Hong et al., 2017; Lenzen et al., 2004, 2013). These studies measured environmental burdens from a global perspective while remaining the challenge of understanding sustainable strategies from a regional level. In particular in the context of China, the relevant studies are relatively rare. Guo et al. (2012) applied an MRIO model to quantify CO_2 emissions and simulate the basic emission flows in China. Su and Ang (2014) developed a hybrid multi-region model to provide insights for interregional CO_2 emissions. Chen and Chen (2015, 2016) conducted a series of investigations by combing MRIO method and network analysis. At the regional level, they developed a hybrid network model to track interregional carbon flows in the Jing-Jing-Ji Area. At the urban level, by employing energy flow analysis, input-output (I-O) analysis, and ecological network analysis, they quantified urban energy consumption of Beijing to reinforce a better understanding of sustainable energy use from different insights.

In this study, two types of buildings, namely residential buildings and office buildings, are considered in life cycle energy quantification in Guangdong province due to their increasing importance in achieving sustainable construction in the construction industry. According to the International Energy Agency (IEA), the residential and commercial sectors accounted for almost 40% of the final energy use in the world, with the major part of this energy being consumed in buildings (Birol, 2010). In fact, the total floor area of office buildings completed in China increased from 69.3 million m^2 in 2000 to 204.9 million m^2 in 2012, representing an annual increase rate of 10.4% over the past decades (NBSC, 2013). The completed gross floor area of residential buildings in 2012 accounted for 65.4% of all completed building floor area and is responsible for more than 60% of the total economic output of the construction industry (NBSC, 2013). Such a rapid growth rate has a significant effect on the amount of energy used in both the production process and the daily operation of buildings. Therefore, this study utilized a multi-regional based hybrid method to provide geographical and methodological solutions for a life cycle energy assessment of buildings at the regional level. The specific objectives are as follows:

(1) To quantify the total energy consumption and energy transfers of provincial construction industry from the sectoral and regional perspectives;
(2) To develop a multi-regional based hybrid method to assess life cycle energy consumption of buildings at the regional level;
(3) To provide specific policy implications by considering the energy consumption features of buildings in Guangdong province.

The remainder of this paper is organized as follows: Section 2 describes the basic methodology and data collection process in the study, Section 3 discusses the energy simulation results of the provincial construction industry as a whole and the specific results for residential and office buildings. An examination of effects from data quality, sector aggregation, and result's reliability is presented in Section 4. The implications for policy are discussed in Section 5, while Section 6 concludes the study.

2. Methodology

2.1. Hybrid model development

This study utilizes a multi-regional input-output (MRIO) model to simulate the embodied energy consumption of the construction industry in Guangdong province and calculate embodied energy intensity for residential and office buildings. The construction industry defined in the MRIO table is composed of building construction, civil engineering construction, installation and

Table 1
Current role of Guangdong province in achieving sustainable construction in China.

Aspect	Source	Content
Economic contribution	Guangdong Statistic Yearbook 2016	The construction and real estate industries together contributed 10.4% of provincial GDP in 2015.
Urbanization rate	Annual Report of Housing and Urban-Rural Development in Guangdong Province	The urbanization rate in Guangdong province reached the highest in China in 2013, increasing from 16.3% in 1978 to 67.8% in 2013.
Low carbon strategy	National Development and Reform Commission	● The first batch of selected localities in "low-carbon province and low-carbon city" national experimental project ● Largest number of ecological towns in China
Green building strategy	● Annual Report of Housing and Urban-Rural Development in Guangdong Province ● The Ordinance on Energy Conservation of Buildings in Guangdong Province	● In 2014, Guangdong had 151 green buildings with the completed floor area of 16.5 million square meters. ● One of the top provinces (2nd) with the largest cumulative and annual floor areas of green buildings in China.