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Research on the life-cycle CO_2 emission of China's construction sector

Zhengyan Zhang*, Bo Wang

College of Management and Economics, Tianjin University, Tianjin 300072, China

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ABSTRACT

To improve the accuracy and achieve a good level of detail, a process-based method was adopted in this paper to conduct a life-cycle CO_2 emission analysis of China's construction sector from 2005 to 2012 by quantifying the CO_2 emission during the six life-cycle stages, including building materials manufacturing, building materials transportation, building construction, building operation, building demolition as well as construction and demolition (C&D) waste disposal. The results indicate that the CO_2 emission of China's construction sector rose moderately from 2005, and has increased considerably since 2010. The total CO_2 emission mainly stems from building materials manufacturing stage (73%) and building operation stage (24%). The CO_2 emission from steel and cement account for the most of the CO_2 emission at building materials manufacturing stage (87%). The CO_2 emission of road transportation with 83% shares the highest proportion at building materials transportation stage. The CO_2 emission of centralized heating with 49% is the dominant source of CO_2 emission during building operation stage. The CO_2 emission at construction and demolition (C&D) waste disposal stage is mainly generated from demolition waste with 86%. These findings could provide references for measures to take targeted at various life cycle stages.

1. Introduction

Global Warming is considered to be the most significant environmental problem ever faced by mankind, and it is also one of the most complex challenges in the 21st century [1]. The main cause of Global Warming is the emission of greenhouse gases, particularly carbon dioxide [2]. The construction sector is the second largest carbon dioxide emitter, accounting for roughly 33% of the total global carbon dioxide emission [3]. In the member nations of European Union, the energy used by buildings is about 50% of the total energy consumption, and the CO_2 emission released from buildings through life cycle is almost 50% of the total quantity [4,5]. But compared to other sectors, there is a huge potential of energy saving in the construction sector at a relatively low cost. The IPCC's fourth report predicts that by 2030, the global construction sector is expected to reduce 6 billion tons of CO_2 equivalents per year, being the most potential sector for CO_2 emission reduction [6]. Therefore, how to control and reduce CO_2 emission from buildings has become a hot topic of discussion at home and abroad in recent years.

As the world's largest emitter of CO_2, China is facing great pressure to reduce CO_2 emission. The data from US Energy Information Administration (EIA) showed that CO_2 emission of global energy consumption was 32,578.654 million tons in 2011, of which 8715.307 million tons came from China [7]. As the pillar industry of the national economy, the construction sector consumes about 28% of the total energy consumption in China, and the percentage continues to show a trend of rapid growth [8]. Therefore, analyzing the CO_2 emission from China's construction sector at a macro-level and identifying the main sources of CO_2 emission have vital significance for improving energy efficiency and reducing CO_2 emission of the construction sector. Furthermore, the mitigation of CO_2 emission from the construction sector will greatly help China to achieve the energy saving and emission reduction targets.

The aim of this paper is to propose a method to estimate the life-cycle CO_2 emission of China's construction sector from 2005 to 2012. The specific objectives are: (1) to define the scope of the study for life-cycle CO_2 emission of the construction sector; (2) to establish a suit of formulas to calculate the CO_2 emission at each stage of the entire life cycle; (3) to interpret and analyze the results obtained by the above method.

2. Literature review

Research on the life-cycle CO_2 emission of buildings can be divided into micro-level research and macro-level research. The existing literature mainly focuses on micro-level studies. Some of them focuses on single building. For example, Shao et al. [9] performed a method of systems accounting to calculate the CO_2

* Corresponding author at: No. 92 Weijin Road, Nankai District, Tianjin, China.
E-mail address: zzyccq@163.com (Z. Zhang).

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Table 1
CO_2 emission quantification studies on buildings.

Author	Year	Method			Research level	
		Process	I/O	Hybrid	Micro	Macro
Seo and Hwang	2001			√	√	
Gerilla et al.	2007			√	√	
Nässén et al.	2007		√			√
Gustavsson et al.	2010	√			√	
Yan et al.	2010	√			√	
Acquaye and Duffy	2010		√			√
Chang et al.	2010		√			√
You et al.	2011	√			√	
Yu et al.	2011	√			√	
Monahan and Powell	2011	√			√	
Van and Xu	2012	√			√	
Cuéllar-Franca and Azapagic	2012	√			√	
Li et al.	2013	√			√	
Mao et al.	2013	√			√	
Wang et al.	2013		√			√
Shao et al.	2014			√	√	
Biswas	2014	√			√	
Mao et al.	2014	√			√	
Dong et al.	2014		√			√
Onat et al.	2014		√			√

emission of six case buildings in E-town, Beijing. Gustavsson et al. [10] studied the life cycle primary energy use and CO_2 emission of an eight-storey wood-framed apartment building. Yan et al. [11] calculated the GHG emission during the construction of a building in Hong Kong. Li et al. [12] estimated the life-cycle carbon efficiency of a five-storey brick-concrete residential building in China at its design phase through calculating the carbon emission at each stage and the life-cycle value. Biswas [13] assessed the life cycle GHG emission and the energy consumption of the Engineering Pavilion at Curtin University in Western Australia.

Some micro-level research focuses on the comparison of the CO_2 emission from different buildings. You et al. [14] made a comparison to examine the differences of CO_2 emission between masonry-concrete and steel-concrete buildings. Yu et al. [15] quantified the energy use and carbon emission of a bamboo-structure residential building and made a comparison with a typical brick-concrete building. Gerilla et al. [16] evaluated the energy usage and air emissions (CO_2, SO_x, NO_x, SPM) of wood and steel reinforced concrete housing construction in Japan. Monahan and Powell [17] and Mao et al. [18] compared the carbon emission of buildings built by both traditional and modern construction methods. The results showed that the buildings adopting modern construction method produced less carbon emission per square meter than those adopting conventional construction method. Bastos et al. [19] made a life-cycle energy and GHG analysis of three representative residential building types in Lisbon. Seo and Hwang [20] compared the entire life cycle emissions of single family house, apartment and multifamily house, including manufacturing, construction, operation and demolition stage. Van and Xu [21] calculated the embodied energy and embodied GWP (Global Warming Potential) of five single-storey retail buildings in Canada using ATHENA® EIE for Buildings v4.0.64. Cuéllar-Franca and Azapagic [22] estimated the life cycle GWP of three most common types of house in the UK-detached, semi-detached and terraced.

For macro-level research, which studies all buildings of a region for a certain period of time, the literature is relatively less. Nässén et al. [23] and Acquaye and Duffy [24] calculated CO_2 emission from construction sector in Sweden and Ireland respectively. Chang et al. [25] analyzed environmental emissions (CO_2, SO_2, NO_x, PM) of construction projects in China. Wang et al. [26] compared the output and demand emissions of CO_2 among eight sectors including the construction sector, identifying the in-depth characteristics of the inter-sectoral linkages of CO_2 emissions. Dong et al. [27] calculated three carbon accounts of Beijing, including territory account (TA), production account (PA) and consumption account (CA). Onat et al. [28] assessed carbon emission of U.S. residential and commercial buildings.

Table 1 shows some attributes (date, research level, type of method used) of the above quoted studies.

There are three main approaches to assess carbon emission: process-based, economic input–output analysis-based and hybrid economic input–output analysis-based. From Table 1 we can find that micro-level studies often used process-based method, which is a bottom-up method developed to assess the environmental impact of goods and services according to their production process [18]. While an economic input–output analysis-based method was usually adopted by macro-level research, this method is a top-down method considering not only the direct environmental impact of a product or a service, but also all indirect impacts involved in the supply chain [11].

But using the economic input–output analysis-based method to calculate the CO_2 emission of the construction sector has its limitations. (1) The calculation of the amount of CO_2 emission is based on the input–output table which is updated every five years in China. So it is impossible to calculate every year's indirect CO_2 emission of the construction sector; (2) In order to facilitate the analysis of statistical data, a large number of industrial sectors have to be merged, which will bring some significant errors; (3) Economical data must convert to physical data; (4) The energy supply sector is double counted [29,30]. Therefore, this study applies process-based method to assess CO_2 emission of China's construction sector from 2005 to 2012, in the hope of measuring every year's CO_2 emission of the construction sector in a more reasonable way and achieving a good level of detail.

3. Method

3.1. Scope of the study

In this paper, the life cycle of buildings is divided into 6 stages. The total emission is the sum of the CO_2 emission from each stage:

$$Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 \quad (1)$$

where Q is the total amount of CO_2 emission from China's construction sector, Q_1, Q_2, Q_3, Q_4, Q_5, and Q_6 are respectively the amounts of the CO_2 emission from