



# Quota-based carbon tracing model for construction processes in China

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## ABSTRACT

Carbon emissions contribute substantially to climate change. Many researchers believe that the construction industry can contribute significantly to carbon dioxide reduction through cleaner and more sustainable building production and construction, e.g. low energy building design and the use of low carbon materials. Nonetheless, the environmental impacts associated with construction process should not be underestimated. Despite that, as construction process is complex and involves many participants, the calculation of carbon emissions during the construction process is never an easy task. Divergence and limitation are found in both the system boundary and carbon sourcing method. This research aims to resolve the problem and facilitate construction managers to identify carbon emissions so as to optimize them through better construction arrangement. In this paper, the system boundary of the construction stage is first defined and the related activities being included in the construction process are identified. A methodology of establishing the sources of carbon emissions during the construction process based on a quota-based method of China is proposed. The calculation model for carbon emissions is established according to the traditional emission factor approach with some modifications. The carbon emitted during the construction process of a case teaching building is calculated using the proposed quota-based carbon tracing (QCT) model. The QCT model not only provides a systematic framework for the tracing of carbon emissions, it could also help construction managers identify low carbon construction methods and logistics schedule in order to maximize the carbon reduction opportunity during the construction stage.

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## 1. Introduction

Human activities, particularly the carbon dioxide (CO<sub>2</sub>) emitted from fossil fuel combustion, have driven the atmospheric greenhouse gas (GHG) concentration levels higher than at any time (IPCC, 2013) resulting in the warming of the earth at an alarming rate over the past century, with an average temperature increase by more than 0.8 °C per annum (1.5 °F) (NCA, 2014). In order to mitigate the effects of climate change, countries around the world have been making every endeavor to formulate relevant laws and measures to control and reduce the carbon emissions. For instance, the United States (US) has set targets to reduce GHG emissions in the range of 17% by 2020 and 26–28% by 2025 (DOE, 2016). Individual US states have taken drastic actions to reducing GHG emissions, such as California's Economy-wide Global Warming Solutions Act and the

nine-state Regional Greenhouse Gas Initiative that addresses the power sector emissions in the Northeast, as well as the renewable portfolio standards in 29 states and the energy efficiency resource standards in 20 states (TWH, 2016). The European Union (EU) has undertaken to reduce its GHG emissions by 80–95% compared with 1990 by 2050. To achieve the long-term overall climate target for 2050, Germany is striving to prevent most emissions in the energy sector and energy-related emissions in the building and transport sectors, as well as in industry and business (GOG, 2016).

Most of the carbon emissions in the construction sector are originated from energy consumption. Construction building consumes a large amount of energy and generates a great deal of CO<sub>2</sub> (Stern, 2006). Given the volume of new buildings to be constructed due to increasing urbanization and growing population, serious effort should be attributed to make the building production process more carbon conscious and sustainable (IPCC, 2014). In order to cut down on carbon emissions, energy efficient building design and low carbon materials are introduced to the building sector (Sharrard et al., 2008). The German government's Energy Concept

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calls for a virtually climate neutral building stock by 2050 (GOC, 2016). In France, the construction of new buildings should fulfill high energy and environmental performance, and a life cycle analysis (LCA) of the environmental impacts of a building is needed to help reduce its GHG emissions (GOF, 2016). The Canadian government has decided to achieve a low-carbon future through infrastructure investments by reshaping the economy to make it consistent with the low-carbon pathways (GOC, 2016). These methods contribute greatly to the carbon reduction during the project operation stage. However, one should not ignore the carbon emitted during the construction process.

Although some researchers argued that the emissions during the construction phase are negligible, others have found that the environmental impacts associated with construction activities are underestimated (Guggemos and Horvath, 2006; Acquaye and Duffy, 2010; Wang, 2014). Based on the input-output method, Acquaye and Duffy (2010) had selected a sample of 728 Irish construction firms for analysis and found that the Irish construction sector was responsible for 13.81 mtCO<sub>2</sub>e, comprising 2.37 mtCO<sub>2</sub>e (17%) of direct on-site emissions, 5.39 mtCO<sub>2</sub>e (41%) of upstream indirect domestic emissions and 5.75 mtCO<sub>2</sub>e (42%) of upstream indirect emissions outside the region. A case study on the life cycle carbon emissions analysis was conducted by Wang (2014), which has demonstrated that the construction work was responsible for about 3% of the total carbon emissions during the project whole life stages for a rehabilitation project in China and 10% for a new building project in Australia. Although this amount is comparative less substantial, but when taking the year as the basis for comparison, the carbon emitted on site per annum has shown a rising trend. The study by Guggemos and Horvath (2006) on the construction of commercial buildings also found that when considering the complete building over its life cycle, the construction phase consumed 2% of energy and released 1% of CO<sub>2</sub>, 7% of CO, 8% of NO<sub>x</sub>, 8% of PM<sub>10</sub> and 1% of SO<sub>2</sub>. This is due to the dominance of the long-term use phase of 50 years compared to a relatively short construction period of around 2 years in general. Scaling up to the national level, however, the impacts of construction projects become more significant. Irrespective of whether the focus is on the whole life cycle carbon emission analysis or carbon evaluation for construction industry itself, estimating the environment impacts during the construction process is imperative.

Despite that, construction process is complex as each project is composed of many activities. Most researchers define the life cycle research scope from a macroscopic point of view (Scheuer et al., 2003; Himpe et al., 2013; Zhang and Wang, 2015). When considering the exact construction process, these studies lacked the detail and a clear definition on the sources of carbon emissions. Yan et al. (2010) summarized four major sources of emissions on construction sites, namely building materials production and transportation; energy use of construction machines; energy use for processing resources; and disposal of construction wastes. Nonetheless, as carbon embedded in building materials should have been taken into account during the manufacturing process, there is a possibility of double counting. Besides, there is no exact agreement on what kinds of logistical actions should be considered when calculating the carbon emitted on site (Cole, 1998; Guggemos, 2003; Guggemos and Horvath, 2006). The discrepancy on the research range of carbon emissions during the construction stage may affect the accuracy of carbon emission assessment in the construction industry.

Furthermore, to evaluate the environment impact of construction work on site, it requires a large volume of data, viz. the types and efficiency of machines deployed as well as the respective fuel and electricity consumed. According to the LCA method (ISO, 2006a; b), establishing a life cycle inventory (LCI) of the studied

product is essential. Yet, this inventory does not include the data for construction work. Although several studies applied LCA to the construction phase, when it comes to evaluating the carbon emissions of construction behavior, the obstacle of data exchange between research institutes and the construction industry makes the research overly relying on other researcher's data (Chou and Yeh, 2015) or that from other countries (Wang, 2014). Researches used the available data without considering its practicality and local relevancy for carbon emission analysis. Without a credible emission data tracking and tracing method, the reliability of carbon emission analysis is questionable. Dong and Ng (2015) introduced a method of substituting local data using overseas life cycle inventories. Despite that, as construction process consists of hundreds or thousands of unit processes, collecting all the necessary site-specific data would consume considerable time and cost which renders it impracticable (Moreau et al., 2012). High-efficient technologies for evaluating the GHG emissions in the construction industry is proven to be hard to achieve.

In order to uncover the environmental impacts of the construction work on site, the research range is first defined in this paper. A quota-based carbon tracing (QCT) model is developed to estimate the carbon emissions of construction activities. Construction quota, which consists of a series information about construction activities, is used to track and trace the carbon emissions according to the detailed material and equipment consumption data. As a result, the respective carbon emissions on site can be systematically forecasted based on an emission factor approach. The calculation results would enable the adoption of carbon emissions benchmark at the bidding stage, thereby increase contractors' responsibility for carbon reduction. A case study of a teaching building project in China is presented to indicate the model assessment process and interpret the carbon emissions situation during different construction parts. The QCT model offers a more convenient, precise and efficient way for evaluating the work involved during the construction process. The model not only provides a systematic framework for tracing carbon emissions, it could also help construction managers identify low carbon construction methods and logistics schedule in order to maximize the carbon reduction opportunity during the construction stage.

## 2. Research background

### 2.1. Carbon emissions during the construction process

Currently, there is no consensus on the scope of the studies on carbon emissions during the construction process. Pacheco-Torres et al. (2014) proposed defining the scope of a building by including the materials production and building stages. The production stage includes raw material transportation and storage, material production and storage at the manufacturing plant. The building stage starts from the transportation of finished construction product from the manufacturer's warehouse to the construction site. Nonetheless, there is much argument on whether transportation outside the construction site should be taken into account in the construction process. Some researchers considered that the transportation of materials is part of construction process because the construction industry is highly dependent on imported materials (Fang and Ng, 2011; Noh et al., 2014). The energy consumption during the transportation process could take up around 20% of the industry's total (Smith et al., 2002). Therefore, the carbon emissions during that phase should be considered in the construction process (Guggemos, 2003; Guggemos and Horvath, 2006; Bribian et al., 2009). However, there are opinions suggesting that both the logistics and material production processes should be delineated from the construction process (Cole, 1998; Smith et al.,

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