Journal of Cleaner Production xxx (2017) 1–13

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Reprint of: Uncertainty analysis for measuring greenhouse gas emissions in the building construction phase: a case study in China

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ARTICLE INFO

Article history:
Received 17 June 2015
Received in revised form
19 April 2016
Accepted 19 April 2016
Available online xxx

Keywords:
Uncertainty analysis
Life cycle assessment (LCA)
Greenhouse gas (GHG) emissions
Building construction phase

ABSTRACT

Uncertainty analysis is useful in determining whether the results of life cycle assessment are sufficiently reliable and valid when making optimal decisions. However, only a few studies have measured carbon emissions by considering the inherent uncertainty during building construction phase that may result in the misinterpretation of critical parameters. To address such weakness, a multi-method-based uncertainty analysis framework was developed in view of the basic characteristics of the construction practice. This framework integrated the deterministic and probabilistic approaches to facilitate the uncertainty assessment in quantifying carbon emissions and to provide insights into the sensitive construction activities from the uncertainty perspective. The developed framework was examined through a mix-use project in Guangzhou China. Results showed that the uncertainties in the measurement method and geographic representativeness are the major uncertainty sources for the building construction phase. The total greenhouse gas emission for the target building was 8791.5 tonnes of carbon dioxide equivalent with a 9.8% coefficient of variation, which was in line with the result calculated by the deterministic method and with the result extrapolated based on the data collected from China. The results of the scenario analysis showed that the proportion of 1% in contribution analysis and the coefficient of variation of 18% in uncertainty analysis can be regarded as the baseline for determining the critical input parameters. This study lends a useful tool for monitoring the uncertainty of LCA studies in the construction practice. In addition, this framework can facilitate to avoid the misinterpretation of the final results during the decision-making process. Although this study focuses on Chinese construction industry, it also provides good references for measuring uncertainty of greenhouse gas emissions of construction industries around the world.

1. Introduction

The carbon dioxide (CO_2) emissions related to the residential and commercial building sector have been a global concern. As the primary contributor of global greenhouse gas (GHG) emissions, the construction industry plays a significant role in global warming. The Intergovernmental Panel on Climate Change asserts that the building sector contributed 40% to the total energy consumption and 25% to the global total CO_2 emissions (IEA, 2007; Metz et al., 2007). In China, the situation is significantly urgent owing to its accelerated urbanization. According to the 12th Five-Year Plan, the urbanization rate in China will reach a historic high of 51.5% in 2015. As the result of such extensive construction, the growth rate of energy consumption in buildings is more than 10% in past decades (Chang et al., 2014), producing large amount of CO_2 emissions. Therefore, the negative effects of extensive building constructions on China's environmental sustainability should be evaluated. In fact, the carbon emissions generated from building construction activities have been extensively studied in China. At the national level, the GHG emissions from the construction sector have been quantified using a series of macro-level analysis techniques, such as input–output (I–O) analysis and structural path analysis (Chang et al., 2014; Chen and Zhang, 2010; Liu et al., 2012). At the project level, numerous studies have investigated the carbon emissions

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http://dx.doi.org/10.1016/j.jclepro.2017.05.146
0959-6526/

from different types of buildings. As the major building type, residential buildings play a significant role in GHG emissions. Gao (2012) measured the embodied carbon footprint of residential buildings by conducting an empirical study of 17 buildings in Jiangsu province. Liu et al. (2009) quantified the life cycle CO_2 emissions of residential communities in China. Regarding office buildings, Wang et al. (2016) employed two case studies to illustrate the current GHG emission reduction performance of Chinese green buildings. Yao (2013) developed a benchmark for the carbon emissions from office buildings based on life cycle assessment theory. The current research hotspot for GHG emission quantification lies in investigating the influence of innovative construction techniques such as precast construction (Aye et al., 2012; Mao et al., 2013). In sum, previous research provides relevant insights into the current GHG emission status of the construction sector from the industrial and project perspectives. Nonetheless, the uncertainties generated during modeling are yet to be extensively looked into.

As an effective tool in the decision-making process for saving energy and reducing emissions, life cycle assessment (LCA) is widely used in the construction industry for environmental quantification. Theoretically, the outcome of an LCA analysis should be reliable and valid for decision makers to make optimal decisions. However, in the construction practice, the uncertainty of the inherent data affects the accuracy of LCA results. As such, the importance of uncertainty analysis behind the LCA results has been emphasized in recent years (Ciroth et al., 2002; Geisler et al., 2005; Sonnemann et al., 2003; Sugiyama et al., 2005). Therefore, the present study establishes a multi-method-based analytical framework to simulate the uncertainty that emanates from the computational process in the construction industry. This study aims to accurately assess the GHG emissions from buildings and to contribute to the literature from three aspects. First, this paper develops a multi-method-based analytical framework that can systematically identify the uncertainty sources and that can quantify the uncertainty bundled in construction activities. This framework can reinforce the importance of measuring uncertainties in LCA studies and can avoid the misinterpretation of the final results during the decision-making process. Second, the integration of qualitative and quantitative assessment methods provides a possible solution for assessing the uncertainty of LCA studies in the construction practice. This method also provides a sufficient understanding on the uncertainty related to building construction. Third, this paper identifies the critical parameters that influence the GHG emissions during building construction in the context of China.

The remainder of this paper is organized into six sections. Following the Introduction, Section 2 presents an overview of the recent uncertainty analysis in LCA studies. Section 3 establishes a multi-method-based uncertainty analytical framework by considering the basic characteristics of building construction. To overcome the data gap in traditional construction projects, this study collected input data based on an extended system boundary, considering onsite miscellaneous works and construction-related human activities. The focus was directed toward data inaccuracy analysis rather than the lack of data. The study mainly focused on the parameter uncertainty given that it is most sensitive to the final result. Section 4 applies the uncertainty analysis framework for measuring GHG emissions to a real building case. Section 5 discusses the proposed approach along with policy implications, and Section 6 presents the conclusions.

2. Overview of uncertainty analysis in LCA studies

Various researchers have investigated the sources of uncertainty based on LCA analysis. Weidema and Wesnæs identified five indicators, including data reliability, completeness, temporal correlation, geographical correlation, and technological correlation, to evaluate the additional uncertainty caused by data availability and quality (Weidema, 1998; Weidema and Wesnæs, 1996). Huijbregts et al. (2001) classified these indicators into two groups, namely, data inaccuracy and lack of data. With the development of LCA methodology, recent studies have determined that uncertainty not only comes from input parameters but also from the initial assumptions and the selected methodology. Geisler et al. (2004) identified uncertainty sources according to the different phases of LCA. These researchers regarded the measurements of elementary flows, temporal and spatial correlations, and production process as the uncertainty sources in life cycle inventory analysis (LCIA) phases. Huijbregts et al. (2003) emphasized that in addition to the uncertainties from input data, LCA outcomes can also be influenced by selected scenarios and mathematical models. Basset-Mens et al. (2004) quantified uncertainty by considering the variability in the LCA in pig farming systems. The uncertainty sources included technical performance, emission factors, and the functional unit. After reviewing 24 LCA studies focusing on quantitative uncertainty analysis, Lloyd and Ries (2007) concluded that uncertainty and variability come from three LCA modeling components, namely, input data, normative choice, and model, whereas Cellura et al. (2011) categorized the uncertainty sources in LCA analysis as methodological choices, initial assumptions, and quality of data. Williams et al. (2009) divided uncertainty types into data, cutoff, aggregation, temporal, and geographic uncertainty to conduct uncertainty analysis for a hybrid LCA model. Gavankar et al. (2015) focused on the communication of uncertainty in LCAs than on the technical aspects and summarized five criteria to facilitate uncertainty communication. In sum, previous works addressed three different uncertainty sources significant in LCA-related studies. These sources are parameter, model, and scenario uncertainties in which the parameter uncertainty is the most sensitive to the final LCA outcome (Huijbregts et al., 2003).

Assessment tools vary in terms of uncertainty types, and they can generally be divided into qualitative and quantitative approaches. The data quality index (DQI) is the most commonly used qualitative assessment method because of its high applicability and feasibility. The data quality evaluation matrix (Weidema, 1998) and the transformation matrix (Kennedy et al., 1996) are the two most efficient tools used in DQI assessment. However, DQI remains limited in terms of its assessment accuracy due to the subjective determination of data quality. Although the quantitative analysis techniques are complemented for the current qualitative uncertainty assessment methods to minimize variations, the results still tend to be underestimated as specified by Coulon et al. (1997). Considering the aforementioned limitations in the application of qualitative approaches in uncertainty analysis, quantitative approaches have been introduced based on data availability. Basson and Petrie (2004) adopted a set of statistical methods to differentiate and identify both the technical and valuation uncertainties in the LCA analysis of a coal-based power station. Canter et al. (2002) conducted uncertainty analysis in LCA for four beverage delivery systems. The group applied DQI to evaluate the uncertainty of target input data, which were first selected according to their individual contributions, and used Monte Carlo simulation (MCS) to obtain the overall uncertainty and model variance. May and Brennan (2003) performed uncertainty analysis by implementing three steps: gravity analysis to determine data contribution, uncertainty analysis, and sensitivity analysis. Imbeault-Tétreault et al. (2013) outlined an analytical approach for uncertainty analysis to mitigate the resource intensity in MCS and validated this quantitative method in a real case to reveal its importance in uncertainty calculation. Herrmann et al. (2014) established an LCA classification

Please cite this article in press as: Hong, J., et al., Reprint of: Uncertainty analysis for measuring greenhouse gas emissions in the building construction phase: a case study in China, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.05.146