Building and Environment 95 (2016) 189–198

Contents lists available at ScienceDirect

Building and Environment

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

Environmental emissions at foundation construction stage of buildings – Two case studies

Malindu Sandanayake, Guomin Zhang*, Sujeeva Setunge

School of Civil, Environmental and Chemical Engineering, RMIT University, GPO Box 2476, Melbourne VIC 3001, Australia

ARTICLE INFO

Article history:
Received 6 July 2015
Received in revised form
3 September 2015
Accepted 5 September 2015
Available online 9 September 2015

Keywords:
Greenhouse gas emission
Non greenhouse gas emission
Foundation
Construction
Buildings
Life cycle

ABSTRACT

Foundation construction involves heavy machine usage which contributes to greenhouse gas (GHG) and non-GHG emissions. The study aims to develop a model to estimate and compare emissions at foundation construction and demonstrate its application using two case studies. A process-based quantitative method is established to estimate emissions due to materials, transportation, and equipment usage. The results are analysed under five impact categories including Global Warming Potential, Acidification Potential, Eutrophication Potential, Photochemical Oxidant Formation Potential and Human Toxicity Potential. Analytical Hierarchy Process is employed to obtain weighting factors to assess impact categories under global and local perspectives. Results obtained an average GHG emission of 67%, 19% and 14% from materials, equipment and transportation respectively. This observation signifies the relative higher percentage of emission distribution of equipment and transportation in foundation construction compared to that in the total building construction. Considerable amount of non-GHG emissions such as Nitrous Oxides and Carbon Monoxides were recorded. Global Warming Potential remained the most prominent impact potential from all the perspectives considered, with an overpowering 75% contribution from global perspective. However, this relative importance is reduced to 33.74%–34.85%, with a relative increase in Photochemical Oxidant Formation and Eutrophication Potentials to 32.55% and 31.92% at regional and local perspective. Therefore emissions such as Nitrogen Oxides, Carbon Monoxides and Sulphur Dioxide should be given more consideration at the regional and local perspectives. Results also convey that the emission comparison perspective could change the focus of environmental impacts considerably.

1. Introduction

Buildings account for one-sixth of the world freshwater withdrawals, one quarter of wood harvest and two fifths of its materials and energy flows [1–4], and it is one of the seven dominant sectors that contributes greatly towards environmental emissions [5]. A systematic estimation of these emissions can be the initial step towards reduction of emission impacts. Many research studies have been undertaken on life cycle environmental effects of a building with a conclusion that the use phase of a building accounts for 80–90% while the construction phase is only responsible for 0.4–12% of the total emissions [2,5–10]. These results have shown that most of the current research focus on finding new technologies and regulations in reducing emissions at use phase of the building, paying less attention to other phases of the building such as material, construction and end-of-life phase [4,6,11,12].

Guggemos et al. in their studies highlighted the importance of assessing environmental impacts at the construction stage at an aggregate level [13]. As a critical step in the construction phase, foundation construction includes typical activities such as excavation, piling, and extensive concrete works. Utilisation of heavy construction machines and equipment are necessary to accomplish these activities. Therefore, emissions due to equipment usage could be relatively higher in foundation construction compared to other stages of construction. Another fact is that these emissions are released at a much shorter time span when compared to the whole structure construction. Although it is evident that emissions at foundation construction may be significant at an aggregate level, studies have seldom concentrated on emission levels at foundation construction stage separately [10,12,14]. There can be several reasons for this negligence. Difficulty in collecting on-site data is one of the major reasons. This difficulty can be in the form of getting

* Corresponding author.
E-mail address: kevin.zhang@rmit.edu.au (G. Zhang).

http://dx.doi.org/10.1016/j.buildenv.2015.09.002
0360-1323/

continuous site access, obtaining construction related documents and time consuming nature in data collection. Another reason is that after completion of the building, foundation is physically hidden from the environment and therefore given less exposure to receiving public criticism. Therefore, this research focused on estimation of environmental emissions in foundation construction.

2. Past research on building emission studies and research gap

With the concern of environmental sustainability, recent research effort has been extended from traditional focuses such as life cycle cost to environmental impact brought by building activities [15–17]. Initial research findings highlighted the importance of use phase emissions in a building [3,18,19]. Therefore many past studies concentrated on emission reduction possibilities at use phase to provide improved living conditions for inhabitants [20–22]. The results of these studies clearly signify that the use phase of the building is given more attention compared to other phases of the building. However few emission studies tried to investigate the importance of emission in other phases such as construction phase, material phase and end-of-life phase [10,13,23]. These studies conclude that emissions at other phases should be given more importance at an aggregate level.

The few emission studies that concentrated on construction phase focused only on a particular emission source [12,24,25]. Table 2 summarises past emissions studies on buildings in the life cycle phases and indicates that most of the emission studies at construction phase considered material optimisation options and neglected other emission sources such as equipment usage and transportation. This can be due to lack of inventory, uniqueness of construction technique and modelling issues. Moreover, majority of these studies are directed only towards evaluation of greenhouse gases (GHG) emissions with little attention given to non-GHG emissions [12]. Nevertheless, heavy equipment usage at foundation construction can result in considerable amounts of non-GHG emissions due to partial combustion of fuel which can have adverse effects on human health even if present in smaller amounts. Thus, the study intends to evaluate both GHG and non-GHG emissions at the foundation construction stage. Methodologies for evaluation of these emissions are explained in the following section.

3. Methods

3.1. Scope and system boundary

3.1.1. Emission substances considered

Australian Greenhouse gas accounts (AGGA) factors report describes Carbon dioxide (CO_2), Nitrous Oxide (N_2O) and Methane (CH_4) emissions as major GHG emissions from stationary and mobile machines [26]. Therefore, the present study considered CO_2, N_2O and CH_4 emissions from transport vehicles and equipment usage and hereon GHG emissions refer to these three emissions.

Apart from GHG emissions, non-greenhouse gas emissions such as Carbon Monoxide (CO), Nitrogen oxide (NO_x) and particulate matter (PM) are often emitted during the fuel combustion of stationary equipment and transport vehicles [10,13,27,28]. Thus the case study considers selected non-greenhouse gas emissions that are frequently found in fuel combustion of equipment and transport vehicles. Material stage considers embodied emissions of materials. Table 1 shows the emission substances considered for each stage in construction phase.

Table 1
Emission substances considered in different stages of construction.

Stage	Emission substances included
Material stage	CO_2
Equipment usage stage	CO_2, CH_4, N_2O, CO, NOx, PM, Sulphur dioxide (SO_2)
Transportation stage	CO_2, CH_4, N_2O, CO, NO_x, Sulphur dioxide (SO_2)

3.1.2. System boundary for the study

An ideal system boundary for emissions in construction phase should include embodied emissions from materials, emissions due to machines and equipment usage, transportation of machines and equipment, transportation of labour and disposal of construction waste [12]. Although this system boundary seems to be the most accurate, some studies argue that the system boundary for the construction phase should exclude embodied emissions due to materials [10,13]. Since one of the objectives of the study is to understand the significant emission sources in the construction phase, embodied emissions of materials are also included in the study. Both the construction projects included in the case study analysis are located in central building district and therefore public transportation is used as the mode of labour transportation. The practical difficulty of tracking these emissions forced the exclusion of emissions due to labour transportation from the system boundary of the study. Thus, embodied GHG emissions of materials (E_M), emissions due to machines and equipment usage (E_{EQ}) and emissions due to transportation of materials and equipment (E_T) are considered as the emission sources for this study.

3.2. Quantitative approach selection

Based on ISO 14044, Life Cycle Assessment (LCA) is a powerful tool to evaluate environmental impacts of buildings throughout its life cycle [29]. LCA describes three distinct methods namely input–output, process based and hybrid approach that can be used to evaluate the environmental emissions of a product or process over its life cycle.

The applicability of these methods differs according the purpose of the study, assumptions and limitations and data availability. Input–output analysis is a top-down economic approach which evaluates the effects of different industry sectors considering the economy as a whole [30,31]. This method is an effective way of estimating emissions when it is difficult to obtain process specific data. Many studies have used input–output analysis to evaluate the embodied emissions of materials as it is often difficult to obtain the upstream process data. Process based analysis is a bottom-up approach to evaluate environmental emissions considering the activities in the process. This approach requires high quality data to obtain more conclusive results. If this requirement can be accomplished, a process based approach could be the best approach to evaluate emissions. Hybrid based approach is a more comprehensive analysis which uses a combination of the above two approaches. Two types of hybrid analyses are often used in emission studies on buildings, i.e., input–output based hybrid analysis and process based hybrid analysis. Process based hybrid analysis uses process data to perform the analysis and input–output data to fill in the gaps wherever there is lack of process data. On the contrary, an input–output based hybrid analysis evaluates the whole system using input–output method and the known process based results are then subtracted from the total value to obtain the missing values. These are then added to the known process based results to get the whole impacts of the process. For more comprehensive information on hybrid analysis methods refer to the works done by Treloar [32–34]. However, in case of a specific case study analysis a process based analysis is the most effective method to evaluate