Environmental Impact Assessment Review 68 (2018) 1–9

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

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

# A comparative method of air emission impact assessment for building construction activities

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ARTICLE INFO

*Keywords:*
Environmental impacts
Emissions
Buildings
Construction
Case study

ABSTRACT

Different construction activities may indicate distinct environmental impacts due to their uniqueness. Ability to assess and compare the environmental impacts from different construction activities can aid the process of minimising emissions at different building construction processes. The study presents a comparative impact assessment methodology to evaluate environmental impacts at different activities during the building construction stage. Significant impact related construction activities for five major impact categories namely global warming potential (GWP 100), acidification potential (AP), Eutrophication potential (EP), Photochemical oxidation formation potential (POFP) and Human toxicity potential (HTP) are compared from the global, regional and local perspectives. A case study of a residential building in Australia is used to demonstrate the application of the functions of the developed method. The results of the case study indicated that the method can be effectively used to compare environmental impacts of different construction activities at different geographical perspectives considered. The method can be used by designers and contractors in comparing impacts of various construction activities to identify the most emission effective construction processes.

## 1. Introduction

With the rising concern on the environmental impacts from pollutant emissions and resource usages in a building life cycle, there is a contemporary requirement for developing more environmental friendly buildings (Yan et al., 2010). Initial research studies were concentrated on minimising embodied emissions of materials and emissions at the use phase of a building (Alcorn, 2003; Alcorn & Baird, 1996; Chau et al., 2007; Chau et al., 2012; Sartori & Hestnes, 2007; Cole, 1998). With the introduction of sustainable materials and energy efficient building service options in a building, the construction stage has become the inevitable focus of interest to reduce emissions from buildings (González & García Navarro, 2006; Sandanayake et al., 2016; Yan et al., 2010; Sandanayake et al., 2015; Sandanayake et al., 2017). However, lack of comprehensive data and generic methodology has restricted researchers to estimate life cycle impacts in spite of the theoretical framework provided in ISO 14040 and ISO 14044 (Verbeeck & Hens, 2010; Mao et al., 2013; ISO14040, 1997; ISO14044, 2006).

Several impact studies attempted to measure the environmental impacts at the construction stage of a building. Li et al. proposed a LCA based environmental impact assessment model for construction processes (Li et al., 2010) which was applied to earthwork construction to understand the impact variations. The results indicated steel as an impact substance contributes to the maximum impacts while pit support activity is the governing factor that contributes to environmental impacts. Gangolells et al. developed a method for predicting the environmental severity of construction processes (Gangolells et al., 2009). They defined the significance of environmental impacts in terms of the impact duration, probability of occurrence and impact scale. The limitation of this method is that it requires expert knowledge for each time to evaluate the impacts of construction processes. A few other studies concentrated on evaluating impacts from construction materials. Chau et al. evaluated impacts on building materials and building service components of commercial buildings using 8 case studies in Hong Kong (Chau et al., 2007). The life cycle impacts of materials soon after installation and after 50 years were estimated for over 30 building materials. A limitation of the study is that it did not include foundation and formwork in the calculations. Upton et al. estimated greenhouse gas (GHG) emissions and impacts of using wood in construction of buildings (Upton et al., 2008). The results of the study indicated that 27% emissions can be saved by using wood on building construction. However the study is highly case sensitive with lots of assumptions and uncertainties.

A considerable amount of research was conducted only to evaluate emissions associated with the construction stage of a building. Guggemos et al. in their emission study compared environmental

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http://dx.doi.org/10.1016/j.eiar.2017.09.003
Received 11 December 2016; Received in revised form 12 September 2017; Accepted 12 September 2017

emissions from concrete and steel buildings (Guggemos & Horvath, 2005). The results of the study signified that concrete buildings are responsible for higher emissions at the construction stage while steel buildings accountable for higher emissions from the whole building life cycle perspective. Mao et al. conducted a comparative study on prefabrication and conventional construction techniques of buildings to measure GHG emissions (Mao et al., 2013). The study concluded that adopting 10.5% prefabrication materials can achieve a GHG reduction of 15.3%. Yan et al. in a similar study estimated GHG emissions from building construction using a case study in Hong Kong (Yan et al., 2010). They found out that the embodied emissions from materials govern the total GHG emissions with a contribution of 82–87% of the total GHG emissions. Further analyses also recommended emission reductions by using recycled materials. Hong et al. revealed the importance of considering human activities and materials used in lesser quantities in construction stage emission studies (Hong et al., 2015). The findings indicated that materials with negligible weight (0.1%) can have a GHG reduction of 2–3%.

On the contrary, there are well developed LCA based environmental impact assessment tools that have the capacity to assess building impacts. The Building Environmental and Economic Sustainability (BEES) software is developed by United States National Institute of Standards and Technology, which measures both environment impacts as well as cost of a product before producing an overall score (Lippiatt, 1998). The environmental performance calculation is a cradle to grave approach, and the approach considers material acquisition, product manufacture, transportation, installation, operation and maintenance and recycling in the assessment process. According to the general LCA methodology, it is required to follow a three-step procedure before interpretation of results. The BEES model can assess six impact categories: global warming potential, acidification potential, nitrification potential, natural resource depletion, indoor air quality, and solid waste (Lippiatt, 1998). Since it uses US average data it does not include local impact indicators such as human health potential. ENVEST 2 is the first UK based environmental impact design software to evaluate impacts of a building at the early design stage (Seo, 2002). It simplifies a complex design process for easy evaluation of environmental impacts. Developed by Building Research Establishment (BRE), it is a web based tool which enables larger data sharing options for companies to benchmark complicated designs. ENVEST 2 uses four major assessment criteria in the impact assessment. Instead, OGIP and Eco-quantum tools use comprehensive assessment to estimate impacts at buildings (Kellenberger & Althaus, 2009; Haapio & Viitaniemi, 2008; Forsberg & von Malmborg, 2004). One advantage of these tools is that they provide optimisation options for comparing impact variations (Zabalza Bribián et al., 2009). Modeling complexities and lack of in-depth level analyses are limitations of these tools.

However, none of these studies or tools have made attempts to perform a thorough investigation of environmental impacts at various construction stages in a building, especially in different construction activities. Moreover, there applicability to Australian conditions are not considered. These previous studies also lack a comprehensive system boundaries or derived for few types of buildings and emission sources. Besides most of the emission studies have only concentrated on estimation of pollutant emissions with very few studies have made attempts to portray the entire environmental profile by evaluating the impacts. Consequently, the current study intends to bridge the previous research gaps by addressing two major objectives. Firstly, it aims to estimate the overall environmental impact profiles at the construction stage of a building using a case study of commercial building construction. Secondly, a comprehensive impact assessment is performed for various construction activities within the construction stage. The significance of these environmental impacts is determined at global, regional and local perspectives based on the geographical location considered. The ascertained impacts at various construction activities will aid the contractors and designers to identify the construction activities that involve significant environmental impacts and plan accordingly to minimise them.

## 2. Study scope and system boundary

### 2.1. System boundary

The ISO 14040 has no consented methodology to define the scope or system boundary for considered study (ISO14040, 1997). Therefore, it is vital to address the system boundary before commencing the analysis. For this study, the major environmental impacts associated with construction materials, energy use, equipment usage and transportation are examined at the construction stage of a building. The impacts at the operation and demolition stages are not considered. Even though embodied emissions from materials are considered to be an upper stream life cycle stage, recent studies have highlighted the relevance of inclusion of embodied emissions from materials in construction stage emission studies (Yan et al., 2010; Mao et al., 2013; Hong et al., 2015). Moreover, other impacts such as solid waste, land depletion and portable water usage are associated with construction activities, the major objective of the study is to evaluate and compare environmental impacts of air emissions. Thus, the scope of the study considers the environmental impacts from air emissions at different construction activities of a building. As shown in Fig. 1, the system boundary includes embodied emissions from materials, emissions from equipment, transportation emissions and electricity usage emissions.

### 2.2. Functional unit

The functional unit of the study is set to $m^2$ of the construction area. The functional unit is chosen to maintain the uniform comparative basis of impact assessment.

## 3. Methodology

### 3.1. Emissions evaluation

The emissions at the construction stage are exclusive because they involve both greenhouse gas (GHG) and non-GHG emissions. These emissions are evaluated using emission models and the emission factor inventories are chosen to achieve consistency in measurement. According to the IPCC report GHG emissions consist of six major pollutant types mainly involving carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) emissions (IPCC, 2007; Reveised, 2006). However, studies have shown that $CO_2$ emissions are dominant in construction activities as a result of fossil fuel combustion (Mao et al., 2013) Therefore, the study considers $CO_2$ as GHG emissions in this study. Non-GHG emissions include emission substances like carbon monoxide (CO), nitrogen oxides ($NO_x$), sulphur dioxides ($SO_2$), particulate matter (PM), hydro carbons (HC) and non-methane volatile organic compounds (NMVOC) due to partial combustion of fuel. Emission inventories from inventory of carbon and energy (ICE), Australian greenhouse gas accounts (AGGA), United States Environmental Protection Agency (US EPA) and Australian National Inventory Report are used to estimate the relevant emissions. Table 1 summarizes pollutants and the corresponding inventories used to estimate emissions from each emission source at the construction stage.

### 3.2. Models for emissions estimation

#### 3.2.1. Embodied emission calculations for materials ($E_M$)

Embodied emissions of materials are measured using the following equation

$$E_M = \sum Q_i * e_{im} \tag{1}$$