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A hybrid life cycle assessment of embodied energy and carbon emissions from conventional and industrialised building systems in Malaysia

Wan Mohd Sabki Wan Omar

School of Environmental Engineering, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia

A R T I C L E I N F O

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A B S T R A C T

Life cycle assessment (LCA) is considered to be the most systematic methodology that is widely used in the area of energy analysis. However, embodied energy (EE) and carbon (EC) analysis requires significant time and effort to ensure the reliability of the LCA results. Therefore, a more comprehensive model of conducting the energy analysis is required to provide more realistic EE and EC analysis in turn. Hybrid LCA has been identified as the best model in improving the completeness of EE and EC inventory data. However, such a benefit was not empirically verified extensively, especially in the Malaysian construction industry. This paper demonstrates an extended application of hybrid LCA to Malaysian building design systems, and further investigates the completeness of the model. Finally, the potential for EE and EC reduction through the allocation of low EE and EC intensities of alternative materials, products or components has been evaluated. The results revealed that the hybrid LCA improved the completeness of the EE and EC inventory data compared with other models. By using low EE and EC intensity materials, products or components, a total EE and EC reduction of 43% and 41%, respectively was achieved. The results showed that the proposed methodology can assist designers practically during the early stage of the design process in the Malaysian construction industry.

1. Introduction

The United Nations Environment Programme currently reports that building construction in developed and developing countries consumed more than one third of total energy use and greenhouse gas (GHG) emissions [1]. Thus, this sector has significant opportunities to reduce the GHG emissions that cause global warming. Malaysia is among the fastest developing countries in the Asian region. Rapid urbanisation and capital development is the main target for the Malaysian government in order to achieve developed country status in 2020. Therefore, the requirements for the energy sectors (e.g. natural gas, coal, petroleum products, and electricity supply) are compulsory not only for Malaysia, but for additional developing countries. In Malaysia, energy consumption is increasing rapidly because of economic growth and development between 2000 and 2010. The energy consumed by commercial and residential buildings accounted for about 13% and 48% of the total energy and electricity consumption [2]. Energy-intensive industries such as cement, ceramic, iron and steel were predicted to be major consumers for the future [3].

For building energy and emissions in Malaysia, previous studies mainly focused on operational energy. Due to the comprehensive analysis of operational energy, EE and EC analysis became a significant component of the energy rating systems for operational energy use [4]. LCA has been adopted in EE and EC analysis, as there is an important opportunity to reduce environmental impacts at various stages in the life cycle of a building. The current recommendation for the standard methodology for EE and EC analysis of a building construction such as TC350 (which is developed in Europe and the UK) includes the whole life impact of the products, including building using the LCA approach [5]. While this method has frequently been applied to the post-construction of buildings, its application at the feasibility phase is less clear due to the complexity of LCA and the unreliability of data sources. However, the greatest opportunities to control carbon emissions are found in the decisions made during the early design phase, which is similar to the value curve framework to look to the upstream stages for greater EE and EC reduction opportunities [6,7]. The option for EE and EC reduction across construction phases is graphically depicted in Fig. 1. Although the options for choosing different solutions are many, and the data for the products required in a life cycle inventory (LCI) analysis are scarce, some decisions require an engineer

E-mail addresses: sabki.wanomar@griffithuni.edu.au, wansabki@unimap.edu.my

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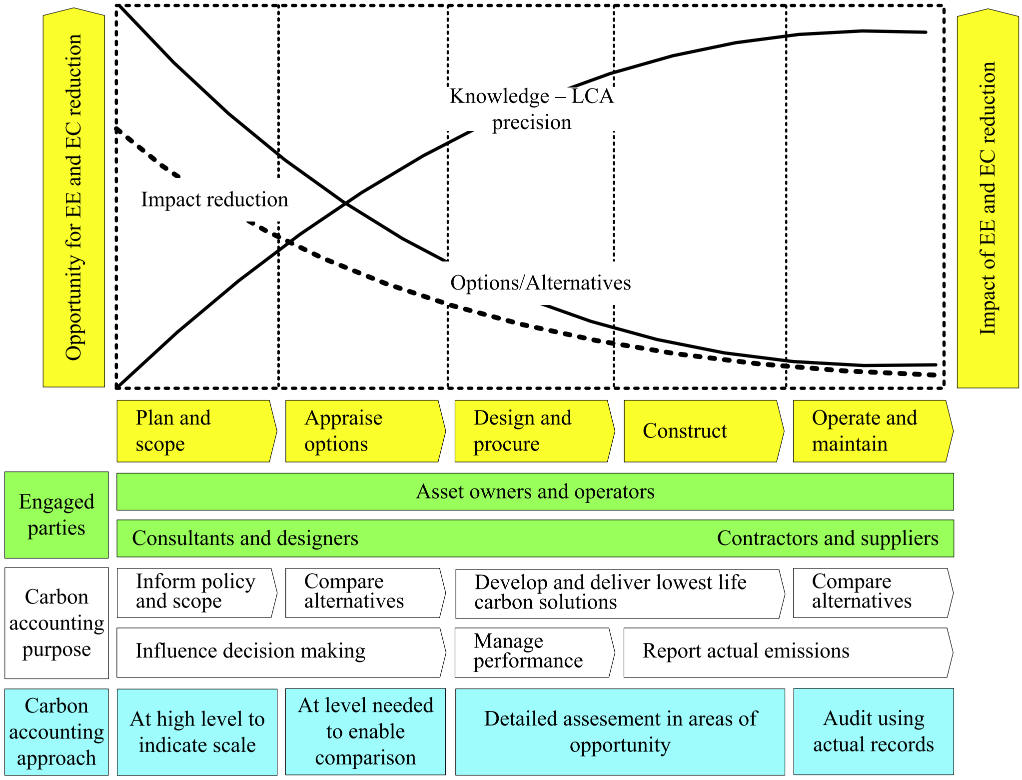

Fig. 1. The greatest potential for EE and EC reduction during the earliest phases of the building life cycle (adopted from [7]).

to decide, based on unreliable results and a lack of detailed analysis.

The hybrid LCA model has been developed as a comprehensive LCA methodology to provide a more complete and reliable LCI in EE and EC analysis. However, these advantages were not extensively verified, particularly in the Malaysian building industry. Therefore, this paper aims to demonstrate and extend the application of hybrid LCA to Malaysian building construction at the early design stage. The objectives of this study are to quantify the EE and EC intensities of the key building elements that significantly contribute to EE and EC content; to analyse low EE and EC intensities of alternative materials and products using the hybrid LCA; to extend the application of the hybrid LCA model to the different building design systems in Malaysia, and to evaluate the potential for EE and EC reduction. To achieve these objectives, a number of different case studies comprising of various building design systems in Malaysia were selected. These systems have been classified into conventional and IBS.

2. Building design systems in the Malaysian construction industry

There are two types of building design system in Malaysia: conventional, and IBS, as shown in Fig. 2. The conventional building system is categorised into two major components. The first component is referred to as the structural system, which consists of a column-beam-slab frame. This frame is constructed throughout four phases: fabrication of formwork and scaffolding, erection of reinforcement bar, placement of concrete, and dismantling of formwork and scaffolding [8]. The second component is known as a wall system which consists of non-load bearing brick acting as infill materials. Meanwhile, cast-in-situ formworks, prefabricated, and composite systems were classified as IBS. This system includes the manufacturing processes of building components in which they are conceived, designed, fabricated, transported, and finally erected on-site [9]. The cast-in-situ system uses a lightweight prefabricated formwork produced from steel, fibreglass or aluminium, to replace the conventional timber formwork. The prefabricated system, on the other hand, involves casting a structural element on-site or off-site before erecting it at the actual location, whereas the composite construction method involves casting some elements off-site in the factory, while others are cast on-site.

3. Methodology

3.1. Overview of case studies

In order to extend the application of hybrid LCA, 10 different building design systems in Malaysia were selected as case studies. Detailed descriptions of each case study have been given in Table 1. These case studies comprise of conventional, fabricated and composite systems (i.e. a combination of the three other building design systems such as cast in-situ wall with prefabricated slab). These case studies include two office buildings utilising the conventional system, and eight residential buildings constructed using IBS. Different types of building design systems were selected so that a wider application of hybrid LCA can be conducted to identify the potential for EE and EC reduction.

The selection of the case studies was based on the most common applications of building design systems in Malaysia. Based on the previous research studies [10,11], the conventional building system was used in all types of building construction, because of the flexibility of the system to suit all types of construction works. Meanwhile, the cast-in-situ table and tunnel form was only utilised in apartments and condominiums, as the steel mould used in this system is expensive and can only be used in large numbers of buildings (i.e. repeated construction) to take advantage of the economics of scale. Thus, this type of system was excluded from