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A Review of Embodied Energy (EM) Analysis of Industrialised Building System (IBS)

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Abstract
Sustainable design and construction have become global issues. Therefore, the reduction of carbon emission has become a main focus of environmental strategies around the world. In construction industries, the extraction of materials and the erection of buildings consume embodied energy and emit carbon dioxide (CO_2) that caused negative impacts on the environment. Therefore, it is necessary to consider embodied energy and CO_2 amongst other factors in selecting building materials used in building projects. The paper presents the on-going research which aims to developed life cycle assessment (LCA) methodology for estimation of embodied energy and carbon emission in a building that used Industrialised Building System (IBS) as an innovation construction process for the Malaysian construction industry. The methodology includes calculating environmental impacts of life cycle of building production in terms of embodied energy and carbon emission. For this study, the boundary of the studies and tools had been explained to assess embodied energy and carbon emission.

Keywords: Embodied Energy, Carbon Dioxide (CO_2) Emission, Environmental Impacts, Industrialised Building System (IBS), Malaysian Construction Industry

1. Introduction
Nowadays, strategies in achieving sustainable building have become a global focus in the world. Government of many countries has attracted to take great efforts to prevent or eliminate activities that contribute to climate change due to global warming and unpredictable impacts towards the environment. Therefore, the reduction of carbon emissions has become a primary focus of environmental strategies around the world. In the UK, legislation requires all new residential buildings to be 'zero carbon' by 2016 and non-domestic by 2019. While in Malaysia, carbon emission has to be reduced by up to 40% by the year 2020. Currently, Malaysia is ranked 30th in the world for countries that have the highest amount of carbon emission. According to Nation Master Statistic [1], construction industry contributes 24% of total carbon emission. There are various ways of reducing the amount of carbon emission in the construction industry. In the context of sustainable development, building should be constructed with adequate occupant comfort, limited natural resource use and low environmental impact, seen over the entire of building life cycle [2]. The life cycle of the building includes the production of building material, construction, operation, maintenance, disassembly and waste management. All these stages have to be considered in order to minimize the life cycle primary energy usage and CO_2 emissions. In Malaysia, Industrialised Building System (IBS) is one of alternative to achieve sustainability in the country. In addition, review shows that IBS not only result in energy efficiency, but also can prevent maintenance as well as low in total cost of building construction [3].

Embodied energy and carbon emission mainly due to the extraction, processing, manufacture and transportation of the materials to construction site [2]. However, considerable efforts have concentrated largely on reducing energy used during building operation. Some of the efforts are improved with insulation, reduced air leakage through the house envelope and by heat recovery from ventilation air. These efforts result in minimizing operation energy, but increased in construction materials use and hence increased in energy demands for production [3][4][5]. According to Dixit [6], the focus of current research is on minimizing the energy use of the operation phase, while the amount of energy use of the other phases is often neglected. These imply an increase in materials use and hence increased energy demands for production [7]

Therefore, this study will be conducted to develop a LCA methodology for systematic estimation of embodied energy and carbon emission in building and Malaysian construction industry. LCA has been used to evaluate environmental impact, energy use and costs and as one of the strategies to achieve sustainability in the construction industry. The process-based analysis is employed to evaluate the amount of embodied energy and carbon emission of building and construction related to the different type of construction methods and building components.

2. Malaysian Construction Industry and Embodied Energy

In meeting national target to reduce the carbon emission up to 40%, embodied energy and carbon emission during production phase have to take into consideration. The choice of construction material affects the energy use in the production phase. The importance of embodied energy in total life cycle of the building shows the importance in selecting construction materials to be used in building. However, this matter is often neglected when the stakeholders only focusing on the operational energy used for building operation in order to achieve sustainable building [5]. Previous studies have concentrated largely on energy efficiency during operation of a building which result in decreasing the space heating demand and thermal comfort of buildings [8]. However, these measures result in the increment of construction materials usage [5][6][9]. As the energy for building operation decreases, the relative importance of the energy used in the production phase has increased [6]. Therefore, there is a genuine demand to calibrate the performance of buildings in terms of both embodied and operation energy in order to reduce energy consumption.

Green Building Index (GBI) has been developed by the Association of Consulting Engineers Malaysia (ACEM) and Pertubuhan Arkitek Malaysia (PAM) to promote sustainability in the Built Environment. GBI has highlighted that the stakeholder has to integrate building design and its buildability, with careful selection of building materials in relation with the embodied energy and durability of the materials to lower carbon content and better building life cycle. One of way to deals with sustainable issue in Malaysia is by using low embodied energy materials. Omar & Doh [10] has conducted preliminary works on methodology in assessment of embodied energy and CO_2 emission of building and construction processes in Malaysia. They mentioned that embodied energy and carbon emission important to achieve sustainability and demonstrate different methods of tracing energy path. However, more process data are still needed in the literature to enhance the data inputs required for analysis methods, especially on transportation of materials to the construction site. Yeen [11] has analyzed carbon footprint on IBS to calculate carbon footprint, but, there is no comparison conducted towards conventional building system.

Studies on building embodied energy and CO_2 assessment in Malaysia are scarce [12]. This outcome has been led to this study, which to assess embodied energy and CO_2 for both construction methods in Malaysia.

3. Method of Embodied Energy Analysis

Three (3) common methods of assessment are the input-output analysis, the process-based analysis and the hybrid analysis [13] . Input-output (I-O) analysis was developed by Leonteif [14] to model national economic production flow and further incorporated in energy analysis, which includes embodied energy and carbon analysis [15][16][7]. An input/output-based analysis could account for most direct and indirect energy inputs in the process of production of building materials and thus is considered relatively complete. Using matrix operations, a change in economic demand from a sector can be measured in environmental effects or resource utilization. Henry et al. [13] indicate a few examples; the purchase of a construction crane would directly impacts steel, aluminium, and plastic. Other examples are the indirect impacts from the production of steel as well as the entire supply chain of the plant through the economy.

Process-based analysis is one of the most widely used methods of embodied energy and CO_2 emission analysis on products and it is usually undertaken at an industrial level through the measurements of energy and material flows during production processes [10]. This methodology delivers more accurate and dependable solutions. The procedure begins with the building material as a final product and goes backward in the upstream of main process, taking into account all possible direct energy inputs or sequestered energy of each contributing material.

Hybrid analysis is a method to compute embodied impacts by combination of I-O analysis and process-based analysis. Nevertheless, this method also suffers the same completeness and limitations of the other two methods. It can be seen that using a hybrid method can lead to greater accuracy; however, it involves a longer calculation process to obtain the final figure. Calculating the effect of changes in design would be a time consuming, and therefore costly, process. Many of the shortcomings noted for Input-output analysis can also impact hybrid analysis, such as the age and availability of data. In order to justify the choice of the methods used in this study, a summary of the advantages and disadvantages of the preferred choice illustrated in Table 1.

Table 1: Advantages and Disadvantages Method of Embodied Energy Analysis

Method of Assessment	Advantages	Disadvantages
Input-Output Analysis	• Representative of the national average. [17]	• Lack of representation being used due to over-aggregation of data • National sector by sector economic interpendently data or sectoral matrix is often too old and outdated in developed countries and worse in developing countries • Lack of comprehensive and reliable database of energy use from industry [15] • Requires a significant number of assumptions on the energy tariffs and material prices in the conversion to energy data [17]
Process-based Analysis	• Allows for a detailed analysis of a specific process based on time and space	• Complex based on different types of building materials [9]. • At each stage of construction, there are many large or small inputs of good & services which cannot all be covered in detail [15]
Hybrid Analysis	• Combine strengths of process analysis with I-O analysis • Being accurate, like a full process analysis, at the same time as being economical with resources especially time	• Weakness in completeness and errors • Lack a comprehensive and reliable database of energy use data from industry [15] • The unreliable I-O data have to be relied upon for many processes which include the main process and processes.

4. Life Cycle Analysis (LCA)

LCA is the most widely used technique which consider environmental impacts of a building's life cycle [18]. LCA is a modelling tool to assess and manage the environmental impacts of product, process, or activity by evaluating its entire life. It is a tool for assessing environmental burdens and environmental impact quantitatively at all the life cycle stages of the target product, ranging from the collection of raw materials to the acquisition of materials, the manufacture, consumption stage, disposal and recycling of the product. The description of the LCA methodology is based on the International Standards of Series ISO14040 (Figure 1).

On the basis of ISO 14040 (Figure 1), the LCA study encompasses four (4) phases: (i) Defining the Goal as well as the Scope, (ii) Life Cycle Inventory Analysis (LCI), (iii) Life Cycle Impact Assessment (LCIA) and (iv) Interpretation. The definition of both the goal and the scope include the goals intended to be achieved through execution of the analysis, the intended utilization, and the purported audience [19]. The boundaries in the system of conceived analyses were described and the parameters of the functions were defined. The functional parameters are the quantitative measures of those functions which are provided by the goods (or service). Each of these products will then be subject to its own life cycle assessment as 'downstream' to the building. If the process is a building, then each of the products and processes which form the building must be assessed. In this study the assessment methodology adopted follows ISO14040 which has been adopted as part of the British Standard for evaluation of environmental impact**.**

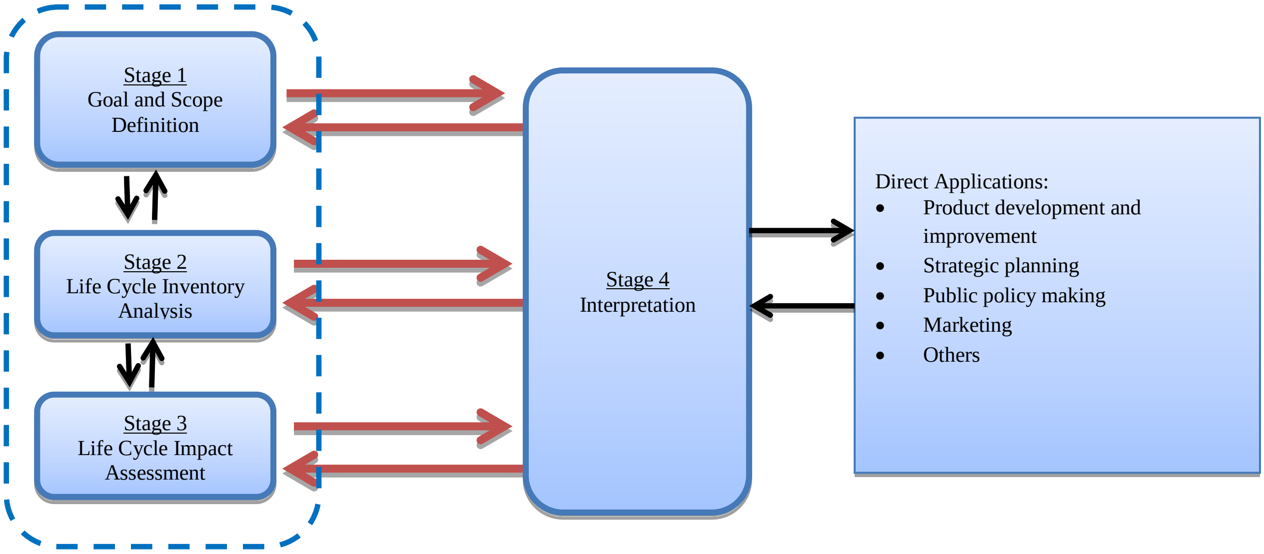

Figure 1: Life Cycle Assessment framework defined by ISO 14040 [18]

5. Life Cycle Analysis (LCA) Methodologies

5.1. Introduction

The development of LCA methodologies is based on the LCA framework developed in ISO14040 (Figure 1). The purposed methodologies outlines four (4) stages to be performed which encompass:

1. Stage 1 – Goal and scope definition
2. Stage 2 – Life cycle inventory analysis
3. Stage 3 – Life cycle impact assessment
4. Stage 4 – interpretation

Detailed discussion of each task is given in the following section.

5.2. Stage 1- Goal and Scope Definition

The research use process-based analysis to expand the boundary complete from cradle to site to the upstream process of the material production of Industrialised Building System (IBS). The research goal is to quantify embodied energy and carbon emission in building and construction process using IBS and conduct comparison study with conventional method. There are two (2) steps to clearly define the system boundary of this study. The first step is defining the boundary of construction materials or components by considering material production which consists of extraction of raw materials, transportation and manufacturing of building components. However, in this study, the extraction of raw material from its original sources and transportation to the manufacturing plant is not included due to many assumptions have to be made during the extraction of raw materials process. This study mainly focuses on the manufacturing process of IBS components.

The second step is to identify boundary of building and construction system by using simplified LCA to reduce uncertainty and assumptions that may affect the final results of this research. The detailed of system boundaries are given in Figure 2. However, energy from the operation phase, maintenance phases and demolition phase are beyond the scope of this research and will not be considered in the analysis. Operation phase of the building consists of natural gas consumption and electrical consumption due to cooking, appliances, cooling and lighting. Operation of a building consists of the operational energy use, the maintenance of degraded or defective parts, and the replacement of the defected and degraded parts. The end of life phase which consist of maintenance, dismantling and the demolishing the building's components, their transport to the landfill site and to recycling sorting plant. Energy consumes during end of life phase is not considered due to limited data and information about building demolition in Malaysia.

The system boundary of this research includes manufacturing of IBS components includes manufacturing of IBS components, plant and machineries, transportation used to deliver product to construction site and construction process of installation IBS components to building structure. For the purpose of this study, two (2) categories method of construction commonly used in the Malaysian construction industry will be investigated in relation of their embodied energy and CO_2 emission. The two categories of construction method represent Industrialised Building System (IBS) and conventional building system. Comparison study will be conducted for both of these methods. Table 2 shows that the conventional building system assessment included brickwall with burn clay bricks and reinforced concrete slab. Conventional building system is considered as a base case in the study. For IBS, assessment of embodied energy and CO_2 emission generally refers to IBS components manufactured at the same manufacturing plant but different construction site, i.e., interlocking bricks, precast concrete half slab, and precast concrete wall panel.

Table 2: Building Materials and Components Classification

Method of Construction	Classification of Building Materials and Components	Type of Building Materials and Components
1. Conventional Building System	Conventional Materials (Base Case)	• Brick wall with burn clay bricks • Reinforced concrete slab
2. Industrialised Building System (IBS)	Alternative 1 (Interlocking blocks)	• Interlocking bricks
	Alternative 2 (Prefabricated System)	• Precast concrete half slab • Precast concrete wall panel

5.2. Stage Two – Life Cycle Inventory Analysis

The computation of environmental emissions depends largely on the accuracy, relevance and completeness of inventory data. However, in most cases, complete data are often impossible to obtain and the computation of emissions is often found on the "best evidence" as a compromise. As individual data inventories do not contain all the emission factors for the estimation of embodied CO_2 for all building processes, a combination of various inventories are often used to carry out the estimation. The common embodied energy and CO_2 emission inventories used include:

- The Bath Inventory of Carbon and Energy (ICE) which contains emission factors for construction materials. This is the most popular and most widely used emission factors datasets developed by the Sustainable Energy Research Team at the University of Bath [20]. The current version ICE V2.0 was developed in 2011.
- Eco-inventory database developed by the Swiss Centre for Life Cycle Inventories
- Bilan Carbon 6 developed by the French Environment and Energy Management Agency
- Emission factors for road vehicles by UK Department of Transport.
- Emission factors for off-road equipment by DEFRA.
- Intergovernmental Panel on Climate Change (IPCC) Emission Factor Database (EFDB): This is a web-based tool developed by IPCC that contains greenhouse emission factors for use by the community.

Based on the inventories mentioned before, the Bath ICE is more specific to buildings than others. Furthermore, it is widely used in Europe and is already being used in developing countries [13]. Therefore, Bath ICE will be used in this study. To maintain the applied objectivity of this study, the embodied energy and CO_2 results obtained from using the Bath ICE should be used in a comparative sense.

5.3. Stage Three – Life Cycle Impact Assessment

There are available general- purpose LCA software tools in the market for computation of embodied energy and CO_2 emissions as shown in Table 2. However, their data and calculation often do not cover the whole life cycle of buildings thus, only partial estimation is possible [13]. For example, the Greenhouse Gas Protocol Initiative toolset based on Excel Spreadsheet can be used to calculate various greenhouse gases of different products. Among building-specific LCA software in Table 2, the Carbon Calculator by the UK Environment Agency includes the construction site energy use and waste management in the calculation. There is also some commercial software that includes these elements in calculating the embodied energy and carbon of buildings. However, the scope of data considered over the life-cycle of buildings varies.

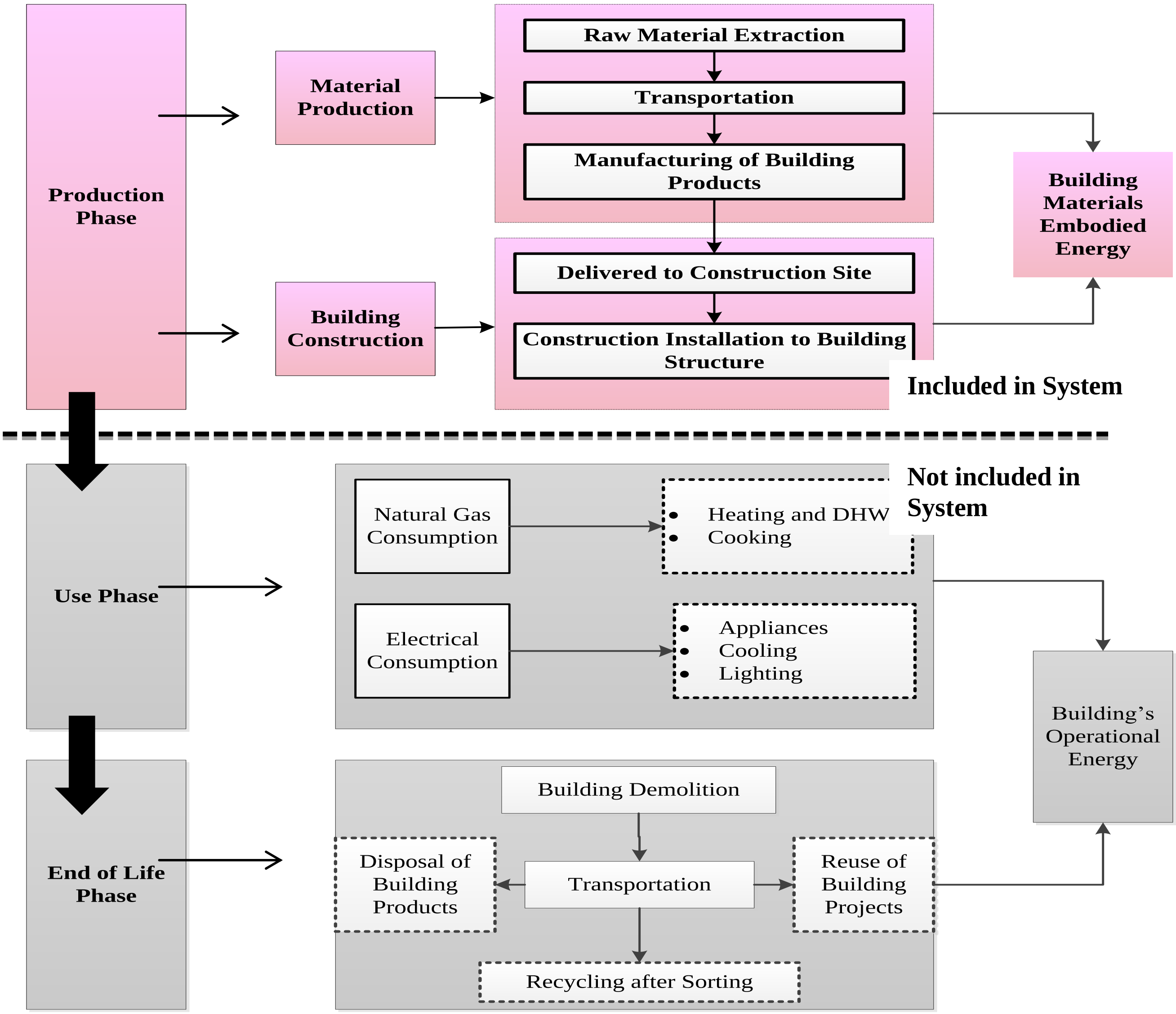

Figure 2: System Boundaries of building production [6]

Athena Eco Calculator is software that has been developed specifically for evaluating whole buildings. On the other hand this software does not include database for all types of material, which is limiting to the assessment process provides environment impacts estimate of the building based on minimal inputs. However, this tool provides no sensitivity analysis showing how buildings component's environmental impacts vary over a range of design alternatives [20].

In this study, a manual computation process was adopted and data analyzed using Carbon Calculator developed by Environmental Agency, an Executive Non-departmental, in United Kingdom. The tool is designed to increase resource efficiency and reduce the carbon emission associated with construction projects. It also helps to access and compare the sustainability of different design options and highlight the carbon savings for specific construction projects [22,27,28].

As stated in Table 2, Carbon Calculator can be used to calculate embodied carbon of materials used in civil construction works and transportation involve parallel with the aimed of this study. In the Carbon Calculator, carbon footprint of "embodied energy" and "transportation" refers to the tonnes of CO_2E produced by the energy required to manufacture IBS components.

Table 2: Construction-specific LCA Software [7]

Researcher	Software	Developer	Default data used in software	Calculations	Copyright
Lee et al.[21] Thiel et al.[22] Moncaster et al.[23] Sing et al.[24]	Athena EcoCalculator	Athena Institute, Canada	Athena's in-house datasets, US Life Cycle Inventory	LCA for common building assemblies (Limited to North American cases)	Free of charge with registration
Hossaini et al.[25] Khasreen et al.[26] Keoleian[27]	BEES (Building for Environmental and Economic Sustainability)	National Institute of Standards and Technology (NIST), US	In-house database	LCA and LCC for building products	Free access (online version)
Moncaster et al.[23]	DEMScot model	Cambridge Archi- tectural Research (CAR), UK	Bath ICE v. 1.6a for the embodied energy and carbon calculation	Both operational and embodied greenhouse gas emissions in Scottish housing	Free access
	Life Cycle Inventory	Franklin & Andrews, UK	In-house database	Products LCA, corporate Eco performance, LCI modelling	Commercial
	Knowledgebase	Faithful & Gould (Atkins), UK	In-house database	Energy usage and carbon footprint of products and processes	Commercial
	Ramboll Carbon calculator	Ramboll, UK	Bath ICE v.1.6a, In-house engineering judgement	Embodied energy and carbon of building assemblies	Commercial
Moncaster et al.[23] Hammomd & Jones[28] Hamilton et al.[29]	Carbon Calculator	Environment Agency, UK	Bath ICE v.1.6a, Jakobs UK in- house calculation, Defra (2009)'s greenhouse conversion factors	Embodied carbon of materials used in civil construction works, transportation, site energy use and waste management	Free access

Tonnage of CO_2E is measured in this study to represent all GHG. CO_2 is categorized as the main GHG contributor and it contributes significantly to global warming. Tonnage of CO_2E is calculated through the multiplication of the tonnage of materials by the emission factor associated with that material. Estimates of mobile plant fuel mass consumption are derived by multiplying the hours of operation by the kilowatt (kW) rating of the engine and by the appropriate fuel mass consumption rates. The equations are as summarized as in equation (1) and (2) [30].

GHG = Wm x Fe Equation (1)

Where,
GHG –Amount of greenhouse gases in CO_2E (tonne)
Wm – Quantity of materials (tonne)
Fe – Emission factor of material

Fc = t x Re x Rc Equation (2)

Where,
Fc –Mobile plant fuel mass consumption (litre)
T –Hours of operation (hour)
Re –kW rating of the engine (kW)
Rc – Fuel Mass Consumption Rates

5.4. Stage Four – Intepretation

The final step in LCA is the interpretation of results where values from the impact assessment will be analysed for robustness and sensitivity to inputs and conclusions are drawn with reference to the goals and objectives of the LCA. Data validation also will be conducted by comparing to other published research. Blengini et al. [31]suggested that in order to minimise uncertainty in input data, a 10,000 cycles of Monte Carlo simulation to get deterministic value.

Conclusions

The reduction of carbon emission is gaining importance among researchers, professionals, builders and material manufacturing. In this study, life cycle assessment (LCA) methodology was used to assess embodied energy and carbon emission for IBS construction method. This paper sets out to determine and identifies the system boundary of the studies and tools to assess embodied energy and carbon emission. Carbon Calculator was used to compute embodied energy and carbon emission. Carbon Calculator designed to increase resource efficiency and reduce the carbon emission associated with construction projects. In addition, it also helps to assess and compare the sustainability of different design options and highlight the carbon savings for specific construction projects. The finding of this study suggests that IBS method have lower in embodied energy compared to conventional method. Therefore, implementation of LCA and assessment of embodied energy and carbon emission can determine and mitigate the environmental impacts in the development stage thus promoting sustainability in the construction industry. More research is required on the empirical findings of embodied energy and carbon emission assessment.

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