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ENVIRONMENTAL IMPACT EVALUATION ON INTERLOCKING COMPRESSED EARTH BRICK USING LIFE CYCLE ASSESSMENT

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ABSTRACT: Interlocking Compressed Earth Bricks (ICEB) is one of the alternative low carbon building materials replacing conventional brick. This study evaluates the embodied environmental impact of ICEB production in terms of embodied environmental implications for global warming potential (GWP). The life cycle assessment (LCA) analysis methodology was performed to identify and quantify the environmental performance of brick production from cradle-to-gate. Additionally, the emission in terms of GWP is analyzed using GaBi software. The system investigated includes raw materials and machinery used for brick production and transportation. Energy use and emissions are quantified, and the potential environmental effects are assessed. Sensitivity analyses were calculated on the percentage of cement content of 15% and 10% of the soil weight. The results show that the embodied carbon for 1 kg clay bricks in Sabah is 0.202 kgCO_2-eq. Cement usage in brick production contributes the most significant environmental impact with carbon emissions of 0.172 kgCO_2. The carbon emission of ICEB found a slight improvement compared to the conventional fired clay bricks (FCB). The result on sensitivity analyses found that the GWP reduced to 27-51% as the percentage of cement content was reduced at 10 and 15%. The findings proved that carbon emissions could be reduced with a lower cement usage in the mix design of ICEB.

Keywords: Interlocking Compressed Earth Brick, Environmental Impact, Carbon Emission, Global Warming Potential, Life Cycle Assessment

1. INTRODUCTION

The conventional fired clay bricks (FCB) were widely used in construction industries as a significant building material worldwide. However, the FCB's manufacturing process, which involves the fuel burning for the firing process, causes pollutants and ash emissions into the air. Study by Darain, Jumaat, Islam, Obaydullah, Iqbal, Adham and Rahman [1] has found that conventional brick kilns are energy inefficient and environmentally harmful. This is not in line with environmental issues regarding air pollution and global warming due to the increased production of carbon dioxide gas in the conventional combustion bricks process [2]. Therefore, environmental issues have reached worldwide attention.

Following the trends of developing more sustainable building materials, a set of alternative bricks were created by adding industrial wastes. Ramos Huarachi, Gonçalves, Francisco, Canteri, and Piekarski [3] also mentioned that it is essential to analyze the environmental impact of various types of bricks to determine whether alternative bricks are indeed more environmentally friendly than conventional bricks. Thus, Interlocking Compressed Earth Brick (ICEB) becomes an alternative to conventional production and system where the brick is fabricated by compressed method (not fired). ICEB is a dry-stacked masonry brick with a similar production process to the Compressed Earth Brick (CEB) [4]. In accordance with Malaysian Standard (MS) 76:1972, as cited by Tonduba, Mirasa and Asrah [5] the minimum compressive strength requirement for a load-bearing masonry brick is 5.0MPa

The ICEB can reduce the carbon emissions during the production process, and the construction method can reduce cost, environmental-friendly, and energy-efficient [6], [7]. According to Han, Mirasa, Saad, Bolong, Asman, Asrah and Abdullah [8], in terms of environment, ICEB has lower embodied energy (EE) and CO_2 emission (CE) than most construction materials. Moreover, it has higher thermal conductivity than fired bricks, making it suitable for use in tropical or hot climates but less so in cooler regions. In addition, implementing ICEB in building construction contributes to a carbon footprint reduction of 35% from conventional construction and is suitable to be used as a low carbon footprint building material [9].

In this regard, life cycle assessment (LCA) is a strong technique for evaluating all the product's potential environmental impacts using life cycle assessment. Besides, LCA is a comprehensive method that allows assessments in several areas and industrial sectors, such as the construction industry, and is beneficial when comparing traditional and innovative technologies [3], [10]. As cited by Rodrigues, Konig and Freire [11], the LCA method also has been widely used to assess wall systems and particularly comparing conventional systems with waste-based novel systems.

This study aimed to evaluate the embodied environmental impact of ICEB manufactured in Sabah, Malaysia. Life cycle assessment (LCA) is required to assess the environmental performance of ICEB. This work consists of the following steps based on goal and scope definition; life cycle inventory analysis (LCI); life cycle impact assessment (LCIA); and interpretation [12]. In the goal and scope definition, the ICEB production located at the Faculty of Engineering, Universiti Malaysia Sabah (UMS) in Malaysia case study, and the system boundaries were set for the embodied environmental impact assessment (cradle-to-gate) with a functional unit of one kilogram (1 kg) of brick production. In the LCIA, GaBi software was used to analyze the emission in terms of GWP.

2. RESEARCH SIGNIFICANCE

Fired clay brick (FCB), a major building material in the construction industry, has been extensively produced and utilized worldwide. Since the firing process for manufacturing FCB consumes a certain level of natural resources, the vast applications of FCB bring negative impacts to the environment. While the concern of awareness on the sustainability of building material and environmental pollution issues arises, the interlocking compressed earth brick (ICEB) has been innovated to replace FCB. Nevertheless, the investigation of the behaviour and green properties of the ICEB is still limited. Thus, this research mainly aims to study the environmental impact of the ICEB through life cycle assessment (LCA).

The findings should make an important contribution in evaluating the impact assessment of ICEB production. Hence this will aid in reducing the environmental harm brought on by greenhouse gas emissions. The ICEB carbon footprint findings can also be used as embodied carbon coefficient for building material ($kgCO_2/kg$). The embodied carbon coefficient is important to calculate the total carbon emission of all building materials in the building life cycle. In addition, it is hoped that this study will be the beginning of an ongoing body of research indicating the significant potential of using Interlocking brick with local raw material in producing sustainable ICEB by replacing the conventional FCB.

3. METHODOLOGY

This study evaluates the embodied environmental impact in terms of carbon emission of ICEB for cradle-to-gate life cycle boundaries, which are manufactured in Sabah, Malaysia. The International Organization for Standardization life cycle environmental impact assessment approach was used with ISO standards [12], [13]. The LCA framework comprises four main stages, including defining the goal and scope, LCI, LCIA, and life cycle interpretation, as summarized in Fig.1.

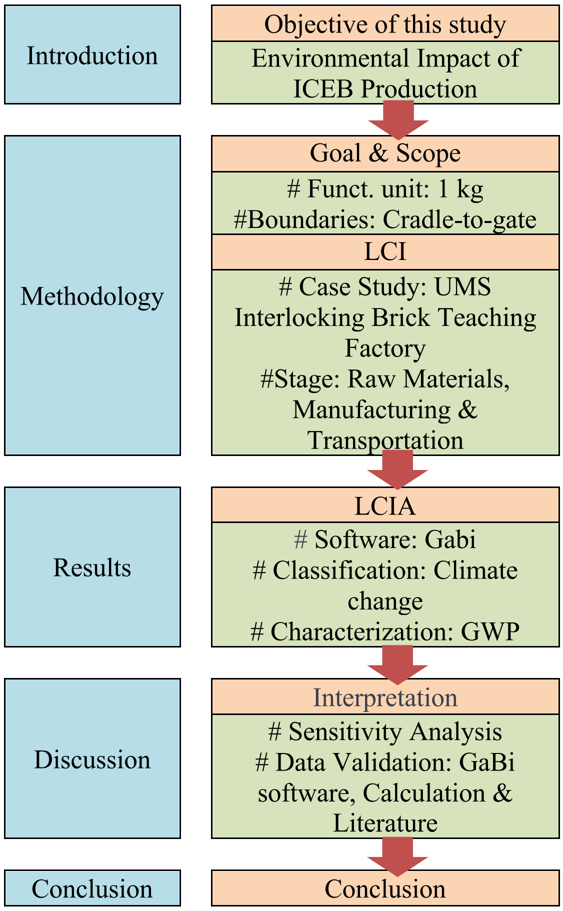

Fig. 1 LCA framework of this study

3.1 ICEB Production Goal and Scope Definition

According to ISO 14040 [12], the definition of goal and scope is typically used to determine the LCA and the probable outcomes of the research [14]. This study assessed the environmental impact of the ICEB produced at UMS Interlocking Brick Teaching factory. The ICEB factory from which the necessary data are taken is located at the Faculty of Engineering, Universiti Malaysia Sabah (UMS), with 6° 2.1196' N latitude and 116° 7.349' E longitude. Besides, it is necessary to state the scope of this study, which includes functional unit, system boundary and transportation energy requirements.

3.1.1 Functional Unit

The functional unit plays a significant role in the product or process in LCA studies. The main goal of developing a functional unit is to ensure that the product's input and output are linked to a specific function. As Youssef, Rabenantoandro, Dakhli, Chehade, and Lafhaj [15] mentioned, the functional unit is selected wisely to enable apple-to-apple assessment when comparing two or more product assessments. The functional unit is 1 kg of brick production. Fig.2 shows the dimensions of the ICEB, which is 250 mm x 100 mm x 125 mm (length × height × thickness).

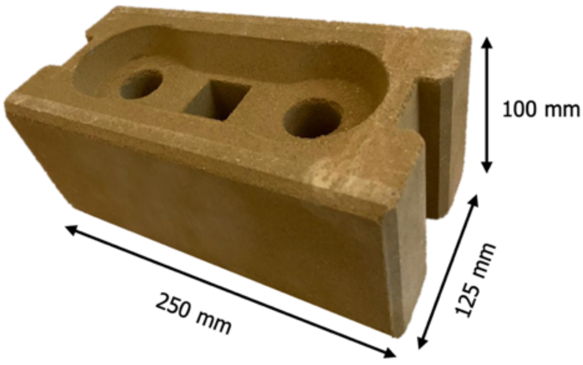

Fig.2 Dimension of ICEB

3.1.2 System Boundary

A review of studies on LCA of brick by Ramos Huarachi, Gonçalves, Francisco, Canteri, and Piekarski Ramos Huarachi et al. [3] mentioned that system boundary from cradle-to-gate is the most popular alternative brick. On the other hand, for conventional brick, the system boundary from cradle-to-grave is the most approached boundary used. However, even in conventional brick, considering all life cycle stages is difficult due to the complexity of obtaining data for the use and end-of-life stages [16]. Furthermore, the data for cradle-to-gate assessment has the best quality and reliability for the construction sector, and thus, it is easier to compare with other studies [17], [18].

This LCA study's system boundary covers the product's cradle-to-gate which only involves a partial life cycle of ICEB from the extraction of raw material and transportation of raw materials to the production plant until the manufacturing of products. Therefore, the use and end-of-life phase of ICEB are not included in this study.

3.1.3 Transportation Distance

The raw materials used to produce the ICEB were locally available, including clay soil, cement, and sand. The clay was excavated from the site at Numbak village. The sand used was river sand from Tuaran, Sabah, which was obtained from the river bed or river bank. Next, the cement used is Ordinary Portland Cement (OPC) type CEM I 42.5 N of the company Cement Industries (Sabah) Sdn. Bhd. Raw materials for clay soil, sand and cement were transported by lorry to the manufacturing factory at a distance of 8.7 km, 26 km and 6.1 km, respectively, measured using Google Maps. Table 1 summarizes the distance between the raw material extraction site and the manufacturing plant.

Table 1 Transportation Distance from Site to ICEB Factory

Material	The site to ICEB Factory	Distance (km)
Clay Soil	Kg. Numbak, Kota Kinabalu	8.7
Cement	Kingfisher, Kota Kinabalu	6.1
Sand	Tuaran	26.0

3.2 LCI for ICEB Production

Life Cycle Inventory (LCI) is the second stage of LCA that is concerned with gathering the necessary information to achieve the study's objectives. The data that are used in this LCA study include the raw data collected during the brick production in UMS. Data regarding the actual amount of input used (raw materials, transportation, water, and electricity) and output of ICEB in the process were collected from primary sources (Interlocking Brick Teaching Factory) and were calculated. The data collection for ICEB production per one tonne (1,000 kg) of brick were collected. Then, it will be converted to the functional unit of 1 kg to be analyzed and calculated.

The impact calculations of ICEB were performed with the LCA software Gabi Edu and the finding results will be presented in the next section: results and discussions.

4. RESULT AND DISCUSSION

This section describes the evaluation of ICEB's environmental impact by analyzing the LCI and LCIA and performing a life cycle interpretation. Interpretation on sensitivity analysis and data validations are done by comparing with previous LCIA works [16], [19] - [24].

4.1 Life Cycle Inventory (LCI) Analysis of ICEB

The system investigates the raw material, transportation, and machineries of ICEB production at UMS Interlocking Brick Teaching's factory. The main primary inputs for the ICEB production are clay, sand, cement, water, transportation, and electricity. According to Koroneos and Dompros [24], raw material acquisition is a significant energy-consuming life cycle process. The LCI process includes the inputs and transfer of mass and energy. The data for LCI in this study for the ICEB operation per kg of brick production is presented in Table 2.

Table 2 Data Inventory to produce 1 kg of ICEB

Data Inventories	Quantities
Raw Materials	
Clay Soil (kg)	0.543
Sand (kg)	0.368
Cement (kg)	0.185
Water (kg)	0.050
Energy	
Electricity – Crusher (kWh)	2.2E-3
Electricity – Conveyor (kWh)	3.53E-3
Electricity – Mixer (kWh)	9.67E-3
Electricity – Compactor (kWh)	19.39E-3
Transportation	
Soil extraction (tkm)	0.005
Sand transportation (tkm)	0.011
Cement transportation (tkm)	0.001

The output of the ICEB production is the environmental impact on carbon dioxide emissions for the GWP. The data collection and inventory analysis were calculated to be modelled and analyzed using the GaBi software. 1 kg of ICEB production requires 0.185 kg of cement, 0.368 kg of sand and 0.543 kg of clay soil (design mix of 1:2:3 for cement: sand: clay soil).

4.2 Environmental Impact Performance of ICEB

The impact category of GWP refers to a shift in global temperature induced by human activities that contribute to the emission of greenhouse gases. Özkan, Günkaya, Tok, Karacasulu, Metesoy, Banar and Kara [25] mentioned the boundary from cradle-to-gate, the production stage had the highest potential impact in all the categories. Thus, this study evaluates the environmental impact for the specific life cycle boundaries focussing on brick production. The global warming potential is typically measured in kgCO_2 equivalent.

Fig.3 represents the environmental impacts category on global warming potential for 1 kg of ICEB Production using the ReCiPe Midpoint Method from GaBi analysis. Portland cement shows the highest environmental impact and is the major contributor to the GWP.

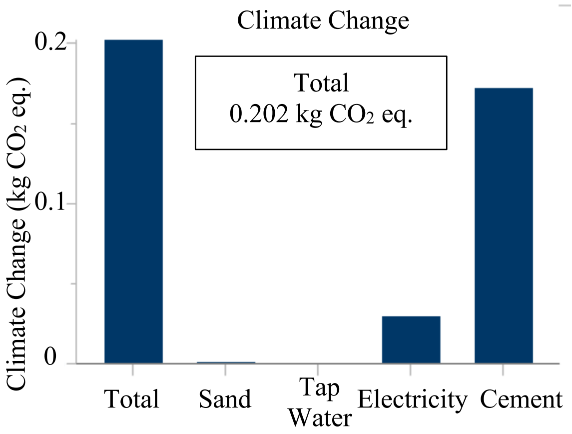

Fig.3 GaBi analysis - GWP of ICEB Production (ReCiPe)

The findings indicate that the cement used in brick production contributes the most significant environmental impact with carbon emissions of 0.172 kgCO_2. The high emission of cement is mainly because a substantial amount of cement is being used in brick manufacturing where the cement is heated to a relatively high temperature to form a clinker [26]. Thus, a massive amount of carbon dioxide is released through the calcination process of cement production. Furthermore, the high concentration of CO_2 and greenhouse gases released by the brick industry is to blame for the unusually rapid acceleration of global climate change [27].

A low environmental impact denotes a low carbon footprint released by brick production. water has the lowest impact value with 4.39E-06 kgCO_2-eq/kg of carbon emission. The result reveals that the impact of water is negligible in this study as they constitute the same amount of contribution to climate change.

There are similarities in the impact of climate change expressed in this study and those reported by Hui [27]. Studies by Hui [27] on a compressed brick in Malaysia show similar trends with these studies, where the findings using the ReCiPe method also indicate the cement (1.72E-01 kgCO_2-eq/kg) as the foremost contributor, whereas water (4.49E-06 kgCO_2-eq/kg) is the lowest environmental impact. Hui [27] mentioned that it remains chemically inert despite the water required in brick production. However, it will be evaporated in water vapor to the atmosphere, which may slightly increase the earth's temperature. Therefore, some brick industries tend to reuse the recirculated water for brick production so that the amount of water usage in the brick manufacturing process can be decreased [28].

4.3 Interpretation - Sensitivity Analysis and Data Validation

The final step in LCA is to interpret results where the inventory analysis (LCI) and impact assessment (LCIA) were summarized. The outcome was a set of conclusions and recommendations in the study. It is identified the significant issues based on the results of the LCI and LCIA phases of an LCA. Data validation will also be conducted by comparing to other published research and performing sensitivity analysis to evaluate the reliability of non-local databases [29].

Sensitivity analysis on GWP has been carried out on the identified major GWP contributor which is cement. The sensitivity analysis was analyzed at 15% and 10% of the soil weight. The results of the sensitivity analysis are shown in Fig.4.

Sensitivity analysis was conducted to determine the influence of variations in the assumptions, and data of the results. For this study, the sensitivity analysis for the cement content having 15% and 10% of the soil weight; was carried out using GaBi software for GWP in the ReCiPe method. The result shows that percentage of cement content of the total soil has an effect towards GWP. The GWP reduced as the percentage of cement content was reduced. The total GWP ($kgCO_2$-eq) for control (20%), cement 15% and cement 10% are 0.202, 0.157 and 0.114, respectively. The findings proved that carbon emission released could be reduced with lower cement usage in the mix design of ICEB.

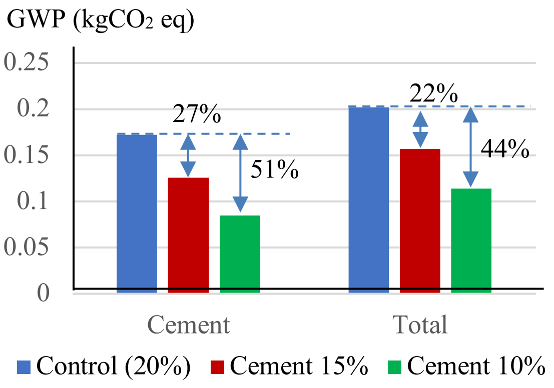

Fig.4 Results of Sensitivity Analysis for Global Warming Potential

Table 6 summarizes the comparison of environmental impact from previous studies with findings from these studies that highlight on carbon emission of brick production.

The results showed that the carbon emission of ICEB is comparable with the other studies wherein this study, the environmental impact on carbon emission using GaBi is 0.202 $kgCO_2$-eq. Findings on the environmental impact of GWP (carbon emission) for the ICEB support the hypothesis set earlier that the ICEB production could improve the carbon footprint of the brick product compared to the conventional FCB. The interlocking bricks have been found environmentally friendlier than conventional bricks [29].

Table 6 Carbon emission (CE) of brick production

Brick	CE ($kgCO_2$-eq)	Ref.
CSEB	0.022	
Concrete Blocks	0.143	
Fired Clay Bricks	0.200	
Aerated Concrete Blocks	0.280 – 0.375	[15]
CEB	0.07	
Ceramic Brick	0.25	[16]
Sandcrete Blocks	0.136	
CEB	0.082	[17]
Adobe Brick	0.0128	[18]
Solid clay bricks	0.195	[9]
Common brick	0.24	[20]
ICEB	0.202	This study

The findings of this study on the carbon emission were slightly reduced with the ICEB (GaBi: 0.202 $kgCO_2$-eq) compared to FCB (ICE database: 0.24 $kgCO_2$-eq) by 16-18% reduction. Cement was the major contributor to carbon emission impact in this study. This is because, although no firing process is involved during the ICEB production, cement usage is the main contributor to the high carbon emission. The proportions of cement is 20% of the soil weight design mix for the ICEB production which is considered high. According to Riza, Mujahid and Zaidi [31], cement binder is added between 4% and 10% of the soil dry weight. He also mentioned that if the cement content is greater than 10% then it becomes uneconomical to produce the brick.

5. CONCLUSION

The main primary inputs for the Interlocking Compressed Earth Brick (ICEB) production are clay, sand, cement, water, transportation, and electricity. the evaluated cradle-to-gate embodied carbon for 1 kg clay bricks in Sabah is about 0.202 $kgCO_2$-eq.

Tap water has the lowest impact value and the result reveals that the impact of tap water is negligible in this study. The cement used in brick production contributes the most significant environmental impact with carbon emissions of 0.172 $kgCO_2$. The cement content in the ICEB mix design contributes to high carbon emissions. The results on the carbon emission of ICEB for the production process found a slight improvement compared to the FCB.

Sensitivity analyses were done on percentage of cement content of 15% and 10% of the soil weight and result found that the GWP reduced as the percentage of cement content was reduced. GWP percentage reduction of cement are 27% and 51% on 15% and 10% of cement content, respectively. The findings proved that carbon emission released could be reduced with an optimal cement in the mix design of ICEB.

The ICEB produced from this research was used for community/residential housing construction with the overall target of improving the sustainability. The result on ICEB embodied carbon can be used as a carbon factor to calculate the carbon emission of buildings.

To improve the materials, this study recommends to reducing the percentage of cement in the brick. Researchers also can improve the product by using waste material for cement replacement.

6. ACKNOWLEDGEMENTS

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