QUANTIFICATION OF CARBON FOOTPRINT FROM MAJOR CONSTRUCTION MATERIALS FOR OFFICE PROJECTS IN MALAYSIA

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ABSTRACT: *Global warming occurs due to the concentration of greenhouse gases (GHGs) in the atmosphere which can occur due to energy consumption from several industries. Although, the building and construction industry are the key sector for sustainable development, but it considered as one of the biggest threat to the environment by producing harmful emissions. In addition, construction sector is responsible for significant amount of energy consumption through the life cycle of the building which leads to enormous carbon emissions. Office building's construction is one of the fastest growing sectors in the construction industry and the energy consumption from these buildings are approximately about 70-300 kWh/m^2 which is 10-20 times bigger than the residential sector. Manufacturing and transporting of building materials consume great quantities of energy and emit large amount of GHGs. The unparalleled carbon emission growth, coupled with business-as-usual practices will possibly lock Malaysia in, for an unsustainable development. Therefore, this paper aim to investigate the embodied energy consumption from manufacturing of building materials and transportation in order to quantify the carbon emission from pre-construction phase with "cradle to gate" boundary. Malaysia should be strategic in implementing policies that support the mainstream implementation of green practice to reduce its carbon emissions levels.*

Keywords: Carbon footprint, LCA, Office Building, Energy consumption, Construction materials

1. INTRODUCTION

The concentration of greenhouse gasses (GHGs) in the atmosphere had led to what is called the "Global warming" phenomena. The emissions of these gasses from any activities have threats the human being and ecological environment and caused other serious environmental issues such as increasing earth temperature, rising of sea levels, melting of north and south poles, failure of agriculture and many other effects. In additions, it is widely known that the carbon dioxide emission is considered one of the main causes of global warming.

As stated by U.S Energy Administration (EIA), there is a significant rise of carbon emissions concentration from energy consumption in the world, and 32,310 million tons was estimated in 2012, however, 199 million tons is emitted from Malaysia [1]. Moreover, Malaysia is exposed to the risks of current climate change and global warming issues.

One of the strategic sectors in Malaysia is the construction industry sector, which contributed about 11.6% to the country's GDP with RM33 billion in 2014 compared to RM 29.5 billion in 2013, giving it a share of 3.8% of the country's total GDP [2]. Although construction industry plays an important role in the national economy but it has a significant impact on the environment. In addition, the growth rate of energy consumption in the building construction industry is accelerating and the fossil fuels consumption used to generate electricity or directly during different stages of building lifecycle produces about 40% of global wastes, and consumes approximately 16% of water sources [3]. The stage of construction, operation, and demolition of a building in the European Union contribute approximately about half of the total final energy consumption and half of the carbon emissions [4]. Therefore the main objective of this paper is to quantify and determine the carbon footprint of construction materials from the Malaysian office building for future research in order to identify the relationship between construction materials and its associated carbon emission to aid in developing carbon emission optimization model.

2. LITERATURE REVIEW

Levels of Carbon Emissions:

According to data from World Bank, the approximate average carbon emissions per capita is about 4.6 metric tons in comparison to the Malaysia's carbon emission in the year of 2010 which it was approximately 40% of the world average carbon emissions with an average carbon emission of 7.7 metric tons per capita [5]. In addition, the Malaysian construction industry is accounted for 40% of the total energy consumptions. Moreover, the carbon emission from buildings construction is around 4% of all emissions that were related to energy consumptions [6]. It has been reported that the average energy consumption and carbon emissions from building sector in Malaysia is expected to rise for approximately of 6% annually [7].

Additionally, the building and construction industry in Europe are responsible for 50% of total carbon emissions into the atmosphere and it accounts for more than 40% of total energy consumption. The energy demand from the Australian buildings sector is approximately 23% of total carbon emissions [8]. The Construction activities are considered as a major contributor to environmental pollution [9-10]. The amount of carbon emission from construction activities in the United States are accounted for about 40% which comes mainly from transportation activities and construction equipment with more than 50% of all emissions [11].

In addition, the estimated energy consumption form construction sector is about 2.6-3% of the total energy consumption in the US [12]. In the United Kingdom, the construction activities from construction sector are responsible for 47% of total carbon emission in the country and in 2011 about 42.6 mega tons has been released to the environment, with approximately 10 Mega tons is associated with the operational stage of the buildings and 22 Mega tons contributed from the production of building materials [13]. The building sector in Korea comprises for about 23% of the country's total carbon emissions [14].

These were few examples of industrialized countries in the world, however, Malaysia is considered one of the developing countries in Southeast Asia and its development could be possibly accomplished through implementation of sustainability measures by reducing the level of carbon emissions and save energy in the construction and built environment.

Embodied Energy and Carbon Emissions:

There are two types of carbon emissions associated with the construction which is embodied or operational carbon emissions. Embodied carbon emissions are associated with the initial production of materials. This includes emissions from; raw material extraction, transport, processing and manufacturing, distribution of materials to the site; and energy used on site in assembly. The manufacturing process and transportation of the materials to the site consumes an enormous amount of energy, even when they represent a small portion of the total cost of the building as compared to the total cost during its lifetime including operational energy [15]. Furthermore, extracting primary raw materials and other minerals from Earth reduces our planet's natural stock. In addition, building materials have a significant and harmful impact on the environment [16]. Moreover, as stated by [17] the carbon footprint of a building is the total amount of carbon emission over the life cycle of building [18]. This includes the extraction of building materials, manufacturing processes, construction, operation and maintenance stage up to demolition stages. It is also involves recycling and reuse of building materials. Embodied carbon emission which includes all GHGs from the construction of a building, transportation of building materials to the site, the operation of the building is calculated throughout the life cycle of the building which is expressed as kilograms of carbon dioxide equivalent. There are four sources of GHGs emission in the construction of buildings, which are; the manufacture and transportation of building materials, energy consumption of construction equipment, energy consumption of processing resources and disposal of construction's waste [19]. It has been determined that the embodied emissions of a typical building account for 60% of the overall life cycle energy consumption. Furthermore, the selection of alternative material could reduce the amount of embodied energy saved over a 50-year lifecycle by up to 20% [20].

Life Cycle Assessment:

Life Cycle Assessment (LCA) is used for the evaluation of the environmental effect of process, product or activity [21]. LCA consists of four components which are goal definition, inventory analysis or life cycle inventory (LCI), impact assessment, and interpretation. The goal and scope definition determine the condition boundary and the assumption of the study. While the LCI quantifies resources and energy uses with its associated emissions releases to the environment. In this stage, the results are converted to environmental impact measures. After the accomplishment of resources quantification, the impact assessment allows for the interpretation of results. In additions, LCA procedures are standardized through International Standards Organization (ISO) 14040 and 14044 series [22-23]. Moreover, Input-Output (IO) and process-based uses the inputs (material) and outputs (carbon emission) based on industry sectors. IO approach is itemized and track single processes used in the manufacturing and transportation of the product. Additionally, IO approaches are a cumulative effect of all products of the sector rather than specific to one type of manufacture process involved for one product. For instance, the manufacturing of cement will report all data used from energy and carbon emissions of that sector. However, process-based approaches involve the usage of all materials and energy in order to calculate its associated emissions impact. The evaluation of carbon footprint can be performed through LCA in order to access the sustainability of the construction works through consideration of all environmental implications of development, from a primary input to disposal of final output and by product, including wastes.

Construction Materials Selections:

The selection of environment friendly building materials has gained impetus in the construction industry. This is mainly due to the onset of building rating systems that have been widely implemented by both private and public entities for their buildings. According to [24], materials used along with their energy data are fundamental to the LCA of any manufactured product. In a global context, the material selection impacts the amount of carbon emissions released into the environment. A study of these effects is necessary as they can be used to support environmental decisions, particularly to identify alternative materials to reduce the level of carbon emissions to the atmosphere.

3. RESEARCHM ETHODOLOGY

The selected case study for this research is an office building (Research and Development) constructed in three blocks. The total gross floor area (GFA) for is 24,291 m2 and consist of 4 floors which is located in Universiti Teknologi PETRONAS campus, Perak, Malaysia. The building is designed to meet the required environmental and sustainability performance criteria with GBI "Certified" status.

A life cycle inventory was conducted with consideration of the amount of each input and output for processes which occur during the life cycle of a product. Undertaking a life cycle inventory is a necessary initial step in carrying out an LCA analysis. The building materials inventory was conducted in accordance with given schematic design drawings. After extracting all the building components, carbon emission was calculated through the utilization of Inventory of carbon emission (ICE) database. The study boundary is shown in Figure (1) below.

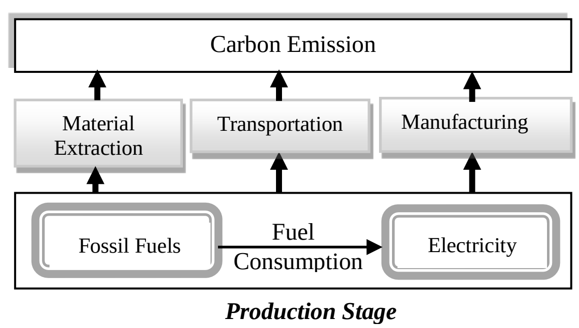

Fig (1) Research boundary

In addition, the conversions to tonnes are the density value, where it can relate the volume and weight of each material. Along with greenhouse gas emissions from processes associated with the production of construction materials (e.g., concrete, steel, and glass), combustion of fuel during the transportation were also calculated.

4. RESULTS AND DISCUSSIONS

The building materials used for construction were extracted from the bill of quantity. This calculation was carried out in order to identify the major construction material that contributes the most carbon emission compared to other materials. From the results obtained in Figure (2) and Figure (3), the carbon emission was classified into seven major construction elements. The result shows that the concrete contributed to the highest level of carbon emission with the amount of 2.68 million $kgCO_2$ which represents 30.69%, followed by steel (1.77 million $kgCO_2$) with 20.43%, mortar (1.52 million $kgCO_2$) with 17.61%.

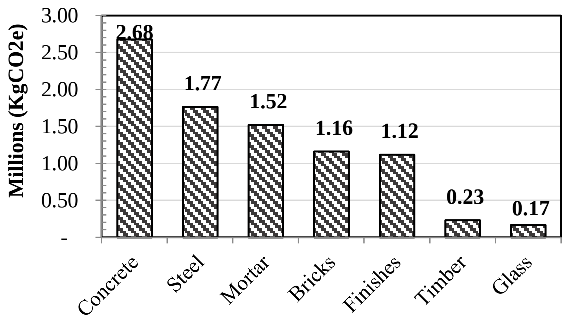

Fig (2) CO_2-equivalent emission from building components

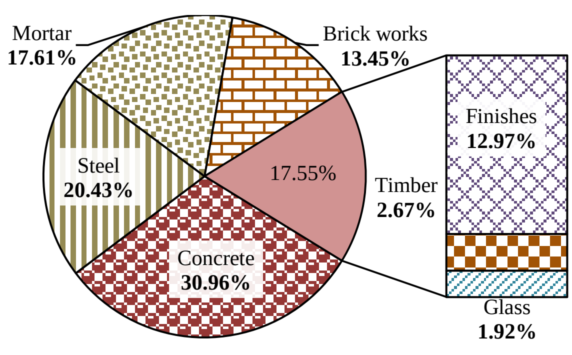

Fig (3): Contribution of building component in office buildings

While brick and block works (1.16 million kg CO_2) for internal and external walls, external accounted for 13.45%. Finishes for internal and external wall, floor and ceiling (1.12 million kg CO_2), which is about 12.97%, followed by timber (0.23 million kgCO2) for formwork and doors which is about 2.67% and glass (0.17 million kg CO_2) for windows, doors, wall partitions and cladding is 1.9% which is considered the lowest emission. In addition, Figure (4), breakdown the contribution of materials to carbon emission in details.

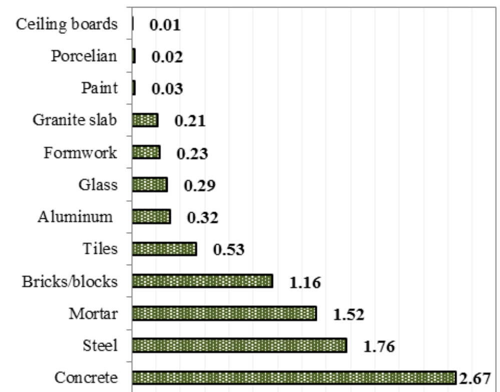

Fig (4) Total carbon emission form building components

It can be seen that from Figure (5), the highest quantity of carbon emission was observed from homogenous and ceramic tiles which have embodied emission of 47.36% adding of porcelain tiles (2.72%) would have a total of 50.08%. This is because most of the floors and walls were mostly covered with tiles. In addition, aluminum works such as in cladding, ceilings have 28.34%, and Granite slabs have a great contribution of carbon emission since it presents 18.93%. While paint works contributed for about 2.34 %. The lowest carbon emission was observed from gypsum and calcium silicate boards which are 3.41%.

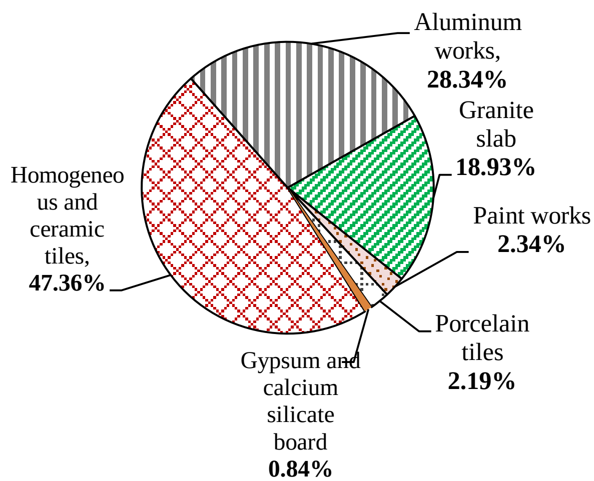

Fig (5) Major embodied carbon emission of finishes components

Materials production consume a massive amount of energy during the manufacturing processes. This energy consumption results in producing a high amount of carbon emission. It can be seen that from Figure (6) the embodied energy of steel is the highest among other building elements. Although steel manufacturing has higher amount of embodied energy compared to embodied energy from concrete but the embodied carbon emission equivalent of concrete is higher than steel. In addition, the amount of concrete used in Malaysia for the building is higher compared to other countries since the structural system is reinforced concrete than steel system.

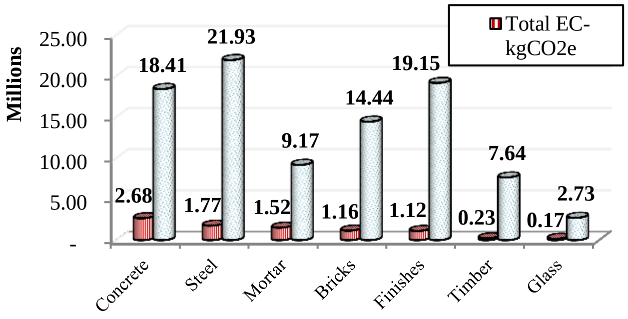

Fig (6) Comparison of embodied energy and embodied carbon

Since the boundary of this study is limited to cradle to the site, after manufacturing stage, transportation will take place. This includes the transporting the materials from manufacturer to the construction site. According to Figure (7), brick has the highest carbon emission equivalents among others, followed by concrete, steel, and framework, mortar building finishes, glass, and timber respectively. In another word, the contribution of transportation to the total carbon emission is less than 2% of overall emissions.

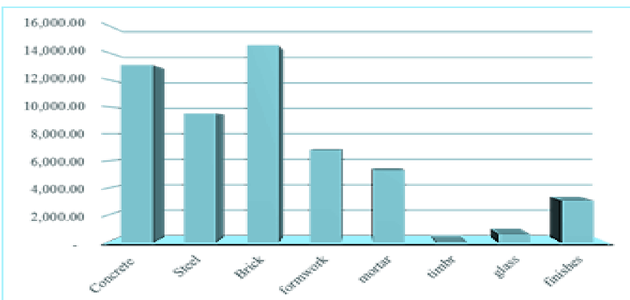

Fig (7) Carbon emission from materials transportation

The building elements were further analyzed in details in order to understand the nature of its carbon emission and associated building's GFA.

As it can be seen in Figure (8), It was observed that, concrete has the highest carbon emission per square meter among other elements with (110.24) $kgCO_{2e}/m^2$, while steel ranked the second for carbon emission per square meter, which have (72.75) $kgCO_{2e}/m^2$, mortar has carbon emission per meter square of (62.71) $kgCO_{2e}/m^2$. While brick and block works have embodied emission of (47.91) $kgCO_{2e}/m^2$, finishes have (46.19) $kgCO_{2e}/m^2$, timber (9.50) $kgCO_{2e}/m^2$ and glass (6.82) $kgCO_{2e}/m^2$ were the lowest in carbon emission per square meter.

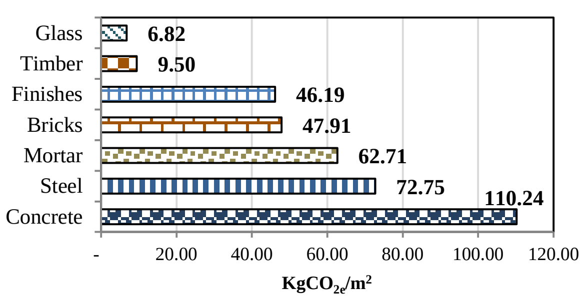

Fig (8) Contribution of carbon emission per (GFA) m^2

One approach to validate the study results is through testing the correlation co-efficient between embodied energy and embodied carbon emission. It can be seen from Figure (9), the correlation coefficient is R2 = 0.77. This result suggests a strong positive association between the two variables. The case study is derived using materials emissions coefficients derived using a hybrid input-output methodology it is proposed that the results of the study are valid.

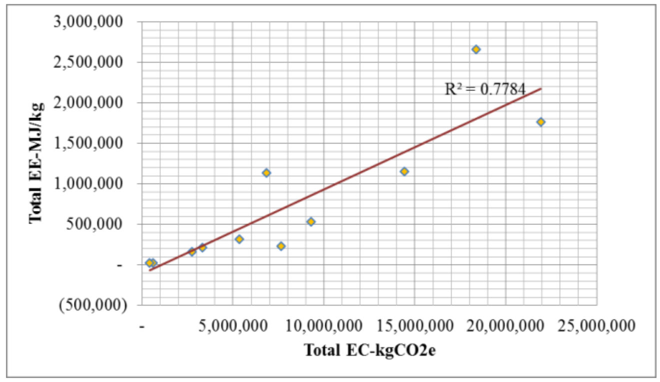

Fig (9) Correlation co-efficient between embodied carbon and embodied Energy

It was observed that concrete was the main contributor of carbon emission in this study. In addition, the primary goal of this study is to determine and quantify the embodied carbon emission from a commercial office building. However, it also investigates the cement replacement materials in order to reduce the carbon emission to the environment. Fly Ash and Blast Furnace Slag (BFS) were selected as cement replacement materials since they were used in many studies. Figure (10) shows the comparison between these replacement materials. It was observed that fly ash produce a higher level embodied carbon emission compared to the normal concrete which is used in the structural system; in fact this is due to the energy required in manufacturing and transportation of fly ash. Adding of more than 30% might reduce emission in the concrete mixture. While the emissions from Blast Furnace Slag is lower compared to fly ash. It can be seen, the additions of BFS even with 15% would reduce embodied carbon emission in concrete. This is concluded that cement replacement materials would have significant advantages in reducing the level of carbon emission from buildings.

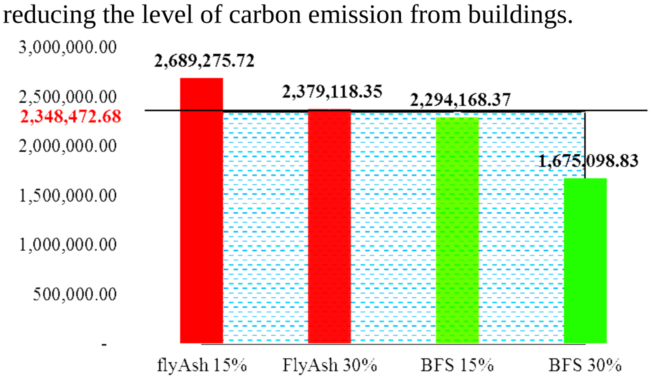

Fig (10) Comparison between levels of carbon emission in Flyash & BFS

5. CONCLUSION

The results of this study concluded that concrete gives the highest embodied carbon emission among all other main building materials followed by steel/reinforcement, mortar, brick/block, finishes…etc. implementing sustainable practices in the design and construction of buildings through the selection of building materials can be a solution in order to reduce the carbon emission.

By choosing the right environmental friendly materials, this would absolutely help in minimizing the depletion of natural resources including raw materials such as water, gravel, and sand as well as energy (electricity) and water used annually in the manufacturing & construction process. Due to this reason, this study selected two alternative materials as a replacement for the building structure. Although Fly Ash considered to be as environmental friendly material but based on the results, carbon emission increased as compared to the original building materials. It was occurred due to the higher embodied energy level of consumption during the manufacturing process.

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