Assessment of Carbon Emissions for the Construction of Buildings Using Life Cycle Analysis: Case Study of Lagos State

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ABSTRACT
Environmental impacts associated with construction, use, and end-of-life of buildings have become a great concern to all and sundry especially as it concerns the health of people. This study aims to evaluate and ascertain the level of carbon emissions for the construction of a case residential building using life cycle analysis. In an attempt to determine carbon emissions at different stages, the following areas were considered: materials consumed during formwork construction, materials for structure, transportation of materials from factory to site, energy consumed by tenants, carbon emission removals and disposal of debris. Emission factors were obtained from local sources to have cognitive and representative results. The results therefore established that the total carbon emission throughout the life cycle of the case building is 1,212 ton of CO$_2$e which was found to pose minor threat to the environment according to standard. It was also deduced that carbon emission due to energy consumed by tenants emerged the most significant with 47% followed by materials for structure (36%), materials consumed during formwork construction (8%), materials based on demolition (7%) while transportation of materials from factory to site and debris to disposal site emerged as the least significant with just 1% each. Overall, findings suggest that sufficient reduction of carbon emissions in building construction starts from the extraction, processing and manufacturing of building materials. Hence, law makers and professionals in the built industry should enforce implementable policies that will encourage designs of low carbon and sustainable residential edifice.

Keywords: Carbon emission, Residential building, Life cycle analysis.

1.0 INTRODUCTION
Of late, climate alterations around the globe have shown extraordinary challenge for mankind. A recent statistics show that on average, over 1.5 Pico ton of carbon emissions (PtCO$_2$) was experienced from 2010 to 2019 [1-3]. This occurrence is predominant because of the kind of activities people engage in. Such activities include cement production [4], deforestation [5], burning of fossil fuel and the likes. The urgent need to ascertain the level of emission in our environment cannot be overemphasized. Global warming [6] effects would eventually become calamitous, except adequate reduction strategies of greenhouse gases are put in place. These gases trap the heat from the sun and cause a gradual rise in temperature of the earth’s atmosphere [7]. At present, the built environment shows the highest emitter of greenhouse gases [8-10]. As a result, the built environment has an undeniable part to play as buildings are responsible for more than two-thirds of the carbon emissions across the globe [11-12]. Residential buildings have also been found to take up a major portion of energy consumption [13] with carbon emissions resulting from energy used for construction and demolition of buildings [14]. The increase in residential buildings and continuous growth in...
population [15], are expected to make energy consumption and carbon emission increase exponentially with time except reduction schemes are in place.

An essential decision by relevant authorities is to establish a practical and implementable policy that will assist the built environment to reduce greenhouse gas emissions as much as possible. These emissions are common in densely populated urban cities because renewable energy like solar or wind energy are somewhat limited. Many countries including China have begun campaign on how to reduce energy level by half by year 2030 [16-18], especially in both residential and public buildings as records show in 2009 that 0.7 million kWh of energy or 6 million tons of CO$_2$ was consumed [19-21]. Many research works have been carried out to measure the impacts of carbon emissions on buildings. For instance, [22-24] recommended in their study that greenhouse gas emissions should be considered as a major factor when evaluating environmental performance of buildings. A study on carbon emissions [25-27], for two hundred and fifty completed buildings due to the number of structural materials applied without putting the entire life cycle into consideration. They succeeded in developing a model that assesses the environmental impacts [28] of the building construction [29]. A study was conducted by [30] on environmental performance of three different kinds of buildings in Germany based on types of construction material, heating energy and transport adopted. His results show that heat energy is responsible for majority of carbon emission generated in buildings. The aim of this research therefore, is to evaluate and ascertain the level of carbon emissions for the construction of a residential building using life cycle analysis while the specific objectives are: to estimate carbon emissions of the building from cradle to grave based on these six areas namely: 1) materials consumed during formwork construction 2) materials for structure 3) transportation of materials from factory to site 4) energy consumed by tenants 5) carbon emission removals 6) disposal

| Carbon emission ($C_{em}$), tons of CO$_2$ | Consequence          |
|-----------------------------|-------------------|
| $C_{em} \leq 1000$        | no threat        |
| $1000 \leq C_{em} \leq 4000$ | minor threat  |
| $4001 \leq C_{em} \leq 8000$ | severe threat |
| $C_{em} \geq 8001$        | extreme threat   |

### 2.0 METHODOLOGY

This study employed life cycle analysis for assessing the carbon emissions of the residential building under consideration. This technique allows assessment of environmental impacts of buildings. Carbon emissions from extraction of raw materials to disposal after demolition of building was considered in this study. The carbon emission calculations was done by assessing the greenhouse gases metrics as defined by [31] for Standard organization of Nigeria (SON) and international standard organization (ISO). These carbon emissions are converted into kgCO$_2$ emissions using the Inter-governmental Panel report on Climate Change 80-year global warming coefficients [32]. It must be stated that conducting an environmental assessment of the entire building is complex due to the differences in materials [33], associated transportation, and various considerations at the use stage, end-of-life of the building and lifespan of the building. Although this study has attempted to include all these in the assessment, several limitations cannot be avoided. This study did not consider the contributions of non-structural materials. Waste material generated during the construction and end-of-life stages were not considered in this assessment. During the use stage of building, actual energy consumed by tenants was not accessible. Thus, average energy consumption data was collected from the nearest electricity distribution company. This study only focused on carbon emission assessment and excluded other impact categories. A four bedroom, two-storey modern building as shown in Figure 1 was considered for this study. This building is located at 2, Adebimpe crescent Isolo, Lagos. This design has a total floor area of 176m$^2$ which can be built with a minimum lot frontage of 11.3 meters and minimum lot size of 156 m$^2$. The carbon emissions over this building’s life cycle were estimated based on their sources and components. The estimation of carbon emissions of the building from cradle to grave were based on six areas namely: 1) materials consumed during formwork construction 2) materials for structure 3) transportation of materials from factory to site 4) energy consumed by tenants 5) carbon
emission removals 6) disposal as shown in Table 2. The guidelines provided by ISO standards [33], [34] were employed to derive Equations (1) to (6) in this study.

![Design of the considered residential building](image)

**Figure 1: Design of the considered residential building**

**Table 2: Study scope for carbon emission evaluation**

| Aspects                              | Sources of carbon Emissions                                      |
|--------------------------------------|------------------------------------------------------------------|
| Materials used up during construction| Steel formwork for superstructure,                              |
|                                      | Timber formwork for superstructure,                             |
|                                      | Steel formwork for substructure,                                |
|                                      | Timber formwork for substructure.                               |
| Materials for structure              | Steel for superstructure,                                       |
|                                      | Timber for superstructure,                                      |
|                                      | Steel for substructure,                                          |
|                                      | Timber for substructure.                                         |
| Transportation of materials from factory to site | -                                                          |
| Energy expended by tenants           | Lighting, Television, air-condition, ironing,                  |
|                                      | cooking, refrigeration, washing machine,                        |
|                                      | pumping machine, electrical distribution,                       |
|                                      | electric fan., computer.                                         |
| Carbon emissions removal             | Tree planting                                                   |
| Demolition and disposal              | Dismantling of building, transportation of building debris from site to disposal site. |
2.1 Carbon emission due to formwork and structure construction

This involves key building materials expended during formwork and structure construction including concrete, steel, timber and formwork. For the sake of calculating carbon emissions, the quantities of concrete, steel and timber were actually obtained from the tender documents as well as the drawings. Table 3 gives the greenhouse gas emission factors as retrieved from local sources. The carbon emission for steel production was taken out from inventory of carbon and energy gathered by [34] Concrete production was according to [34]. Timber production was according to [34]. The local emission factors employed was necessary to produce representative results. Equation (1) gives the carbon emissions from formwork and structure constructions, where \( C_{em_{CSF}} \) is the total carbon emissions of concrete, steel and formwork, \( m_i \) is the amount of building material \( i \) (m\(^3\)) and \( f_i \) is the carbon emission factor for building material \( i \) (kg\(CO_2e/m^3\))

\[
C_{em_{CSF}} = \sum_{i=0}^{n} m_i * f_i
\]  

(1)

| References                      | Timber | Steel | Concrete |
|---------------------------------|--------|-------|----------|
| Adetona and Richard, [34]      | 468    | 15210 | 317      |
|                                 | -      | -     | 426      |
|                                 | 962    | -     | -        |

Table 2: Carbon emission factors/standards for building materials (kg\(CO_2e/m^3\))

2.2 Carbon emission due to transportation from factory to site

This emission was generated from the transportation of building materials from factory to site. The distance between the factory and site was obtained as 15km. Equation (2) gives the carbon emission generated from transportation of building materials to site where \( C_{em_{Tr}} \) is the total carbon emission due to fuel consumption of transportation of building materials in kg\(CO_2e\), \( m_i \) is the amount of building material \( i \) transported in m\(^3\) (5m\(^3\) of loading limit per truck was assumed), \( d_i \) is the diesel consumption in liter/km/truck (0.325L/km), \( x_i \) is the distance covered by transporting building materials \( i \) (15km assumed) and \( f_i \) is the emission factor for transporting by diesel truck (2.62kg\(CO_2e/liter\)) (Michael, 2011)

\[
C_{em_{Tr}} = \sum_{i=0}^{n} \frac{m_i \ast d_i \ast x_i \ast f_i}{5}
\]  

(2)

2.3 Carbon emission due to energy expended by tenants

This stage involves carbon emissions due to electricity and heat consumed by tenants during the period. Equation (3) gives the total carbon emissions due to the energy expended over the 40-year building life cycle in kg\(CO_2e\), where \( e_i \) and \( g_i \) are the yearly electricity and gas consumed for building services system \( i \) in kWh and gas unit (1unit =48MJ) respectively. Also, \( f_{ei} \) and \( f_{gi} \) are the emission factors of the energy consumed by electricity and gas respectively and given as 0.7 kg\(CO_2e/kWh\) and 0.59 kg\(CO_2e/unit\) of gas procured [34].

\[
C_{em_{Tenant}} = \sum_{i=0}^{n} (e_i \ast f_{ei} + g_i \ast f_{gi} \ast 40)
\]  

(3)
The electricity end-use data for the period was obtained from Ikeja electricity Distribution Company while the gas use data was obtained from the landlord of the building.

2.4 Carbon emission removals

This helps to determine the amount of carbon emission removed during the period as a result of tree planting. A recent study by [34] shows that 23 kgCO$_2$ can be removed by each tree based on the height. Equation (4) gives the total carbon absorption over the 40-year building life cycle by tree planting in kgCO$_2$e, where $t$ is the number of newly planted trees within the premises while $f_a$ is the carbon emission removal factor and taken as 23 kgCO$_2$/tree/annum.

$$C_{absorption} = (t * f_a) * 40$$

(4)

2.5 Carbon emission due to pulling down of building

This stage is categorized into two stages namely: emission due to energy expended on demolition and emission due to transportation of building debris to disposal sites. Equation (5) represents carbon emission due to demolition and transportation, where $m_{dem}$ is the amount of building materials dismantled or building debris, 5m$^3$ load per truck is assumed, $f_{dem}$ is the emission factor for dismantling a building, which is 17 kgCO$_2$e according to [34], $d_e$ is the diesel consumption, which is 0.325 L/km $x_i$ is the total distance for transporting materials $i$, which is 15km according to and $f_t$ is the emission factor for transporting by diesel truck.

$$C_{em_{demkipan}} = m_{dem} * f_{dem} + (m_{dem} * d_e * x_i * f_t) / 5$$

(5)

2.6 Total carbon emissions over the buildings life cycle

$$C_{em_{TOTAL}} = C_{em_{CSF}} + C_{em_{Transp}} + C_{em_{Tenant}} + C_{em_{absorption}} + C_{em_{demkipan}}.$$  

(6)

3.0 RESULTS AND DISCUSSION

Table 4: Materials consumed due to formwork construction

| Materials consumed during construction | Type                           | Quantity (m$^3$) | Emission factor (kgCO$_2$e / m$^3$) | Total emission (kgCO$_2$e) |
|--------------------------------------|--------------------------------|------------------|-------------------------------------|---------------------------|
| Steel formwork for superstructure    | 4.5                            | 15210            |                                     | 68445                     |
| Timber formwork for superstructure   | 28.92                          | 962              |                                     | 27821.04                  |
| Steel formwork for substructure      | 0                              | 15210            |                                     | 0                         |
| Timber formwork for substructure     | 0.68                           | 962              |                                     | 654.16                    |
| Sub Total                            |                                |                  |                                     | **96920.2**               |

Table 4 shows materials consumed due to formwork construction using Equation (1). Steel formwork for superstructure produced the highest carbon emission (68445 kgCO$_2$e) while steel formwork for substructure emerges the least (0). During this phase, steel remains the dominant building material not only in terms of quantities but also
the embodied carbon as seen above. The total carbon emission due to materials consumed during construction gives 96920.2 kgCO₂e.

Table 5: Materials consumed due to structure

| Materials for structure | Type                  | Quantity (m³) | Emission factor (kgCO₂e / m³) | Total emission (kgCO₂e) |
|-------------------------|-----------------------|---------------|-------------------------------|-------------------------|
|                         | Steel for superstructure | 8.6           | 15210                         | 130806                  |
|                         | Concrete for superstructure | 409           | 426                           | 174234                  |
|                         | Steel for substructure  | 5             | 15210                         | 76050                   |
|                         | Concrete for substructure | 164           | 426                           | 69864                   |
|                         | **Sub Total**           |               |                               | **450954**              |

Table 5 reveals the materials consumed due to structure using Equation (1). Concrete for superstructure recorded the highest carbon emission (174234 kgCO₂e) while concrete for substructure records the least (69864 kgCO₂e). The total carbon emission due to materials for structure gives 450954 kgCO₂e.

Table 6: Transportation of materials

| Transportation of materials | Type  | Quantity (m³) | Distance from site (km) | Total emission (kgCO₂e) |
|-----------------------------|-------|---------------|-------------------------|-------------------------|
|                             | Steel | 123.5         | 15                      | 316.1                   |
|                             | Timber| 25.5          | 15                      | 65.3                    |
|                             | Concrete | 4771.8   | 15                      | 12203.6                 |
|                             | **Sub Total** |          |                        | **12585.0**            |

Table 6 represents carbon emission due to transportation of materials using Equation (2). Transportation of concrete records the highest carbon emission (12203.6 kgCO₂e) while timber records the least (65.3 kgCO₂e). The total carbon emission due to transportation of materials gives 12585.0 kgCO₂e. This is an indication that concrete remains the most significant material during construction of structure hence the highest carbon emitter.

Table 7: Energy consumed by tenants

| Energy consumed by tenants | Annual energy consumption (kWh) | Annual emission (kgCO₂e) | Total emission in 40 years (kgCO₂e) |
|----------------------------|---------------------------------|--------------------------|------------------------------------|
| Lighting                  | 39.6                            | 332.64                   | 13305.6                            |
| Television                | 47.8                            | 401.52                   | 16060.8                            |
| Air condition             | 56.4                            | 473.76                   | 18950.4                            |
| Ironing                   | 132                             | 1108.8                   | 44352                              |
| Refrigeration             | 45.2                            | 379.68                   | 15187.2                            |
| Washing machine           | 55.7                            | 467.88                   | 18715.2                            |
| Standing fan              | 79.5                            | 667.8                    | 26712                              |
Table 7 shows the energy consumed by tenants using Equation (3). This was generated due to several utilities used by tenants. From the entire utilities, electrical distribution shows the most significant in terms of carbon emission (255293 kgCO$_2$e) as well as ironing, electric cooker, electric fan and pumping machine. This reflects that carbon emitted are strongly dependent not only on the building and occupancy factors, but also on the source of energy.

| Utilities               | Quantity (MW) | Annual Emission (GWh) | Total Emission (GWh) |
|-------------------------|---------------|-----------------------|----------------------|
| Home theatre            | 38.5          | 323.4                 | 12936               |
| Electrical distribution | 759.8         | 6382.32               | 255293              |
| Others                  | 359.5         | 3019.8                | 120792              |
| Electric cooker         | 28.4          | 238.56                | 9542.4              |
| Pumping Machine         | 78.5          | 659.4                 | 26376               |
| **Sub Total**           |               |                      | **578222**          |

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**Table 8: Carbon emission removals**

| Carbon emission removals | Type | Quantity | Annual emission absorption (kgCO$_2$e) | Total absorption in 40 years (kgCO$_2$e) |
|--------------------------|------|----------|----------------------------------------|-----------------------------------------|
|                          | Tree | 22       | 506                                    | 20240                                   |
|                          | Sub Total |        |                                        | -20240                                  |

Table 8 shows carbon emission removals due to tree planting using Equation (4). For the 22 trees planted for the 40 years life cycle, the total carbon removals recorded is 20240 kgCO$_2$e. This shows that when more trees are planted then more carbons emission are removed.

**Table 9: Carbon emission due to demolition and transportation of debris**

| Demolition                      | Dismantling of building | Quantity (m$^3$) | Emission factor (kgCO$_2$e / m$^3$) | Total emission (kgCO$_2$e) |
|---------------------------------|-------------------------|------------------|-------------------------------------|---------------------------|
| Transportation of debris        | Transportation of building debris to disposal site | Quantity | Distance to disposal site (km) | Total emission (kgCO$_2$e) |
|                                 | 4792                    | 17               | 81464                               |
| Sub Total                       |                         |                  |                                     |
| **TOTAL**                       |                         |                  | 93705.2                             |
|                                 |                         |                  | **1,212,146**                       |
|                                 |                         |                  | *(1,212 tons CO$_2$e)*              |

Table 9 shows carbon emission due to demolition of building and transportation of debris to disposal site using Equation (5). The total emission due to these two aspects is 93705.2 kgCO$_2$e. Considering all the six aspects, the total carbon emission throughout the life cycle using Equation (6) and the assumptions is 1212 tons of CO$_2$e. This result shows that there is minor threat in this condition according to recommendations of International standard organization shown in Table 1.
Figure 2: Contributions to carbon emission of the sampled building

The pie chart in Figure 2 shows the contributions of carbon emissions in various life cycle phases of the building. Carbon emission due to energy consumed by tenants emerged the highest with 47% while transportation of materials and debris to disposal site emerged as the least with just 1% each. This shows that majority of carbon emission in residential building come from the use of electricity and gas. It also means that the operating energy consumption by tenants is clearly impacting the environment the most. This corroborate a study by [34] where the use of heat and electricity produced the highest contribution to carbon emission in residential buildings.

4.0 CONCLUSION

In this study, we have discussed how to determine carbon emissions for construction of residential building. Different stages of construction considered are: materials consumed during formwork construction, materials for structure, transportation of materials from factory to site, energy consumed by tenants, carbon emission removals and disposal of debris. Emission factors were obtained from local sources based on the region and standards. This specific assessment was carried out not just to ascertain the level of emissions in building constructions but to also suggest ways of mitigating the impacts from buildings. Results show that the total carbon emission throughout the stages considered gives 1212 tons of $CO_2e$. Also, based on all the stages studied, carbon emission due to energy consumed by tenants emerged the most significant with 47% while transportation of materials and debris to disposal site emerged as the least with just 1% each. This shows that majority of carbon emission in residential building come from the use of electricity and gas.

5.0 RECOMMENDATIONS

Relevant authorities such as government, professionals in the built industry should as a matter of urgency enforce the following recommendations:

- Reducing the carbon content of concrete through the manufacturing process.
- Adopting recycled materials or materials with lower environmental impact such as pulverized fuel ash, granulated blast furnace slag, and silica fume in the concrete mixes can save significant amount of cement and the associated $CO_2$ emissions.
- Carbon emissions can be minimized by using environmentally-friendly materials or energy efficient appliances, lighting, heating, and cooling equipment
- Switching to low carbon fuels and utilizing renewable energy are considered effective in tackling the climate change problem.
- Reducing carbon emissions by sourcing sustainable materials and using low carbon materials.
- Planting sufficient trees for carbon emission removals

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