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An assessment of the effects of manual energy and material haulage on the initial embodied environmental impact of residential buildings

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ABSTRACT

The energy inputs associated with all the stages of production of a building are known as initial embodied energy. These stages range from the mining of natural materials to manufacturing, transportation, and construction. . Inadequate local data in the formulation of climate change mitigation strategies have made studies on the effects of construction and transportation energy/emissions very significant. The study aims to appraise the impact of material haulage and site construction processes on the initial embodied energy and emission in the Nigerian context with the view of identifying the effects of manual labour and material haulage. The objectives are: to estimate the transportation energy, and site construction, and identify the percentage of energy from manual work. The study adopted a case study methodology using multiple case studies and integrated the international energy/emission protocol. Construction energy and carbon emissions accounted for 3.9% and 1.52% respectively. Manual energy was found to be significant with an average manual energy intensity for the study area at 9.5MJ/m2. Also, transportation energy accounted for 11.65% of the initial embodied energy and 6.95% of emissions. Thus, recommended sustainable haulage approaches such as the reduction and enforcement of age restrictions on imported used trucks from <15 years to <5 years.

1. Introduction

The imperatives embodied energy and embodied carbon emissions have remained on the increase and gaining attention from key players in the building and construction industry. Despite their significance, they are still substantially unexploited [1]. Building construction involves the extraction and transportation of natural and material resources. Building material extraction and haulage consume a lot of energy with substantial carbon emissions. About 33% of the world's energy consumption and approximately 40% of direct and indirect carbon emissions are traceable to buildings and the construction sectors [2]. Also, 40% of the world's annual energy use in their life cycle phases of construction, use, maintenance, and demolition is linked to the building [3]. Haddad, et al.[4], added that construction is accountable for about 40% of total energy consumption in Europe. Energy use and carbon emission intensity are key parameters for assessing the environmental sustainability of a building. This is because these parameters are the major causes of global warming and thus, climate change.

Conceptually, the whole life of a building, from its conception and construction to its usage, upkeep, remodelling, and eventual demolition or adaptive reuse, is referred to as the "building life cycle."[5]. To be more precise, the building life cycle can be divided into a number of different phases. These phases are; the embodied phase, operation phase, and demolition/reuse phase. Occupancy is the operation phase, during which the building's compliance with all applicable codes and laws is ensured for the residents' safety and comfort. When the building reaches the end of its useful life, it will either need to be demolished or put to new use through adaptive reuse programs. The main focus of this study is on the embodied phase.

The embodied phase describes the various stages of material extraction and production of building materials. The initial embodied phase denotes the emission/energy expended during the extraction of raw materials, transportation to the factory, manufacturing, haulage to the site, and construction [5, 6]. Different means can be used or employed to transport building materials to the construction site or their point of use. These could be surface (road and rail), water (boats and ships), or air transportation subject to their endpoint [7-9]. However, there are two dominant modes of building material haulage in Nigeria that is; by road and Sea (For imported building materials). Roads in the country account for approximately 70% of goods haulage [10]. Sadly, in developing countries, the knowledge of handling construction material logistics is inadequate [11]. IEA/UNEP [2] and Lucuik et al. [12], posited that material haulage consumes a wide range of energy sources and associated carbon emissions: Petrol (PMS), Diesel, Gasoline, etc.

On the other hand, construction processes in the sub-Sahara and Nigeria, in particular, are both manual and mechanical. According to Udomiaye et al.,[13], the building process in the Nigerian housing sector is manual labour intensive. Thus, it is imperative to ascertain to what extent manual labour energy influences the Initial Embodied Energy Assessment (LCEA) of buildings. Moreover, Ezema et al.,[14] and Udomiaye et al. [13] stated that the embodied energy/carbon emission intensity in the Nigerian housing sector is high when matched with other countries. However, energy and emission intensity values vary depending on the country and region. As posited by Seo, et al. [1], the reduction of embodied energy/ emissions may have a great outcome on the lessening of global carbon emissions and energy intensity. The on-site energy consumption is a key contributor to carbon emissions (direct and indirect) with about 4% of total energy use through the entire phase of the construction projects [15]. However, Hong, et al., [16] observed that less attention is often given to the detailed construction stage in the life cycle of a building. Recent studies on Life Cycle Assessment (LCA) suggest that the operational energy of buildings has significantly reduced as a result of the stringent energy performance requirements by national agencies. Thus, Delphine et al., [17] added that embodied impacts of buildings are imperative, and require more attention being a panacea for decreasing the environmental impact of buildings. This underscores the need for more studies and active strategies for embodied emission/energy reduction in the housing sector. Transportation and construction activities are significant aspects of embodied environmental impact assessment. The existing assessment protocols pay less attention to the peculiarities of these key elements. Hence, this study is significant because, for the first time, it identifies and highlights the need to integrate manual energy and building material haulage peculiarities in the environmental sustainability assessment of buildings. In developing countries, material haulage peculiarities include bad roads and the adoption of fairly-used trucks as a mode of transportation of building materials from the cradle -to the gate.

Deploying ‘fairly-used’ trucks for building material haulage coupled with bad roads [18,10], the imperative of reducing the embodied environmental burden in the housing sector as seen in the Nigeria scenario, and the paucity of local data to formulate climate change mitigation strategies have made studies on the effects of site construction processes, and building material transportation very significant. Therefore, the study aims to appraise the environmental impact of material transportation and the construction processes (Manual labour and machine) in the Nigerian context with the view of identifying ways of reducing the environmental burden, especially in the embodied phase. The objectives include; 1) to assess the environmental impact of building materials, and material haulage and 2) to determine the percentage contribution of construction processes (Manual and Mechanical. The study adopted a case study methodology using multiple case studies and the International Energy/Emission Protocol. It is quantitative (fuel-based energy inventory), and considers the material haulage, energy flows, and associated emissions from cradle to gate. The study area is Abakaliki, Nigeria. Abakaliki is the capital of Ebonyi State, Southeastern Nigeria, located at 6.32° North latitude, and 8.12° East longitude.

2. Material and Methods

There are several international literature and a few local literature on life cycle energy/CO_2 analysis. Energy consumption in buildings at the operational stage within the life cycle dominated the documented or published life cycle energy reports with the assumption that the embodied energy/emission is inconsequential [19-21].

A Sri Lankan study reported the dominance of cradle-to-gate material embodied energy and CO2 emission with 61.12 % and 70.74 %, respectively [22], however, the study was silent on transportation energy and emission. While, a study in Hong Kong by Chen et al., [9] reported a higher value of transportation energy at 7% of the life cycle embodied energy, and pointed out that the value was owing to the addition of surface and water transportation of building materials that are imported from other countries. They, however, concluded that energy from surface transportation (Road and Rail) was insignificant. A study in Lagos, Nigeria by Ezema et al., [23] reported 3.0% for transportation energy, the result is low compared to Chen et al., [9] and Kim[24]. It was observed that only surface (Road) transportation mode was considered in the Nigerian study resulting in a lower value. Utama and Gheewala[25] and Ramesh et al.[26] reported transportation energy intensity of 1.13% and 3.8% respectively.

Although labour is a major component in developing construction management procedures [27], manual labour energy is often not considered and the portion of energy linked to material haulage is generally argued [28]. According to Hes [29], human labour is mostly not seen as an environmental impact in its own right, except for the substantial effect on costs. Dixit[28] added that it is still contentious whether to take into account the subsidiary element of energy connected with the haulage of building materials and manual labour during energy/emission assessment. Understandably, the exclusion of manual energy from site construction energy assessment in most research conducted in developed countries is because of the dominance of mechanical construction techniques in their mode of construction. However, Rocco [30] posited that the non-inclusion of human labour effects might create an unfortunate partiality in environmental impact assessment. Akinshipe, et al.,[31] identified the paucity of knowledge of labour energy outlook as an impediment to the effective adoption of ecologically friendly construction methods within the Nigerian construction sector. This underscores the need for more studies to identify the contributions of local peculiarities (such as manual labour) to the environmental burden, especially in developing countries with high manual energy intensity.

Life cycle assessment consists of two principal elements: operational and embodied energy/emission [32,33]. However, the study focuses on the initial embodied components as presented in the research design. The impact categories adopted for the assessment are energy use and carbon emission.

As presented in Fig. 1, the study is directed at the construction processes and material transportation as components of embodied phase in buildings and the study area is Abakaliki-Nigeria. It is the capital of Ebonyi State, Nigeria. Abakaliki is located in the southeastern part of Nigeria and within longitude 08º 65' - latitude 06º4' of the Southeast of Nigeria [34].

In general, the study adopted the process-based energy and CO_2 assessment framework to analyze three selected apartment buildings coded as T1, T2, and T3. The process-based analysis is a common procedure of embodied energy (EE) and CO_2 analysis because it provides a more precise outcome [35]. Data from the field survey, inventory, and appropriate international energy protocols, were employed to evaluate energy consumption and carbon emission at the embodied stage of the designated residential buildings. Documentation, identification, and computation of materials and energy flows (outputs and inputs) of the case study residential buildings were deduced primarily from the floor plans and specifications sheet provided by the government development agencies. The referenced buildings are coded T1, T2, and T3. The reference buildings -T1, T2, and T3 have a gross floor area of 355.68m2, 208.32m2, and 181.80m2, respectively

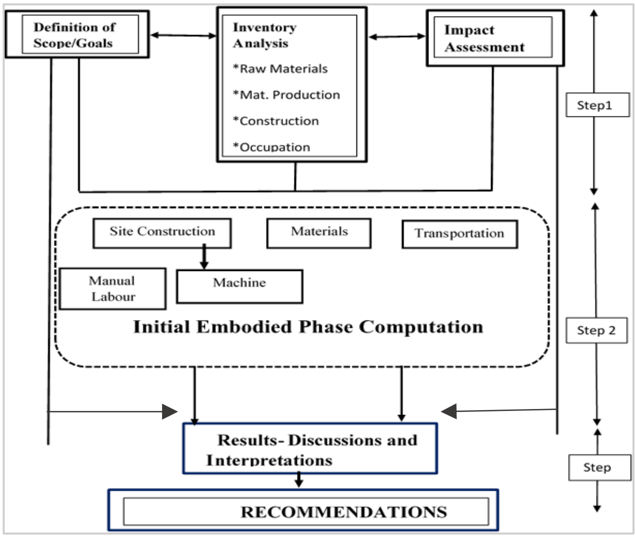

Fig. 1. Research Design Framework

2.1 Process-Based Embodied Carbon And Energy Assessment

In addition to the material inventory provided, a life cycle database and appropriate embodied energy and emission factors were integrated into the material inventory to determine the cradle-to-gate outcome. Similar to studies by Ezema et al.,[23]; Hugo et al.,[36], and Stephan[37], the Inventory of Carbon and Energy (ICE) database[38] was chosen as the ideal database for building material embodied emission and energy estimation being the data source closer to the Nigeria scenario.

To estimate the initial embodied energy/emission (cradle-to-gate), transportation, and construction for case studies T1, T2, and T3; the formula below were used:

$$EE_I = EE_M + EE_T + EE_C \quad \text{---- (Eq. 1.0)}$$

$$EE_M = Q_M (EE_{CF}) \quad \text{---- (Eq. 2.0)}$$

$$EE_T = Q_F (LHV) \quad \text{---- (Eq. 3.0)}$$

$$CEF = A \times EC \quad \text{---- (Eq. 4.0)}$$

Regarding Manual Energy - For labour-intensive input, the study relied on the manual energy estimation in an agricultural sector effectively enhanced contextually by Ohunakin et al.,[39] and Oyedepo and Aremu[40] by utilizing a labour-intensive energy factor of 0.75 MJ/hour. Accordingly, labour energy for the study was estimated using the Eq.:

$$ME = 0.75(LT) \quad \text{.......... (Eq. 5.0)}$$

$$PFC = Q_F \times C_f \quad \text{............... (Eq. 6.0)}$$

The terms "embodied carbon" and "global warming potential" (GWP) refer to the weight of carbon dioxide equivalents (CO2eq), which is the equivalent in carbon dioxide of all lifecycle greenhouse gas emissions. Hausfather [41] opined that employing a unit of CO2eq over a specific period is preferred and that carbon dioxide equivalency(CO2eq) offers the chance to account for additional greenhouse gases and climate variables in standard units. Therefore, the more reason this study focuses on GHG (CO2eq) emissions.

2.2 Description of Case Studies

The case studies consisted of three residential buildings. These are; a block of one-bedroom apartments (Five Units) selected from Udensi estate (coded as T1) see Appendix 1, a block of two-bedroom apartments (2units) selected from Sakamori estate (coded as T2) see Appendix 2, and a block of two-bedrooms apartment(2units) selected from Democracy estate (coded as T3) see appendix 3. Designed by EDT/GEMEX architects and engineers in 1997 and constructed by Ebonyi State Housing Development Corporation (EBSHDC), Abakaliki, Nigeria.

The chosen case studies foundation is a concrete strip foundation made of grade 25 concrete that is 450 mm wide and 150 mm thick. The 150 mm thick bottom floor slab is supported by sand-cement blocks that will hold lateritic, which is compacted into 300 mm layers, and 150 mm thick hard-core made of lumps, or natural stone. The floor is composed of a 150mm concrete slab with a 25mm cement screed. Sand-cement blocks of 450 x 150 x 225 mm were used to construct the walls. Y12 reinforcement bars were used to brace the lintel and columns. The major building materials include cement, rods, coarse aggregates, roofing sheets, wood, and tiles.

3. Results

3.1 Cradle-To-Gate Material Embodied Energy (MJ)

Using equations 1 and 2, the material embodied energy (cradle-to-gate) of the referenced buildings- T1, T2, and T3 were estimated at 1,095,475.8MJ, 479,782.61MJ, and 430,439.98MJ, respectively. As shown in Fig. 2, the substructure contributed an average of 31% of the total material embodied energy and was tailed by internal and external walls which contributed 22%. While the Roof structure/covering contributed 17 %. Moreover, for the group of building finishes, painting/decorations accounted for the highest average value of 8%. Further examination of the result shows that ceiling finishes, Walls, contributed an average of 3 % and 6%, while, plumbing, electrical, and floor contributed 4%, 3%, and 4, respectively. Doors and windows accounted for 3%.

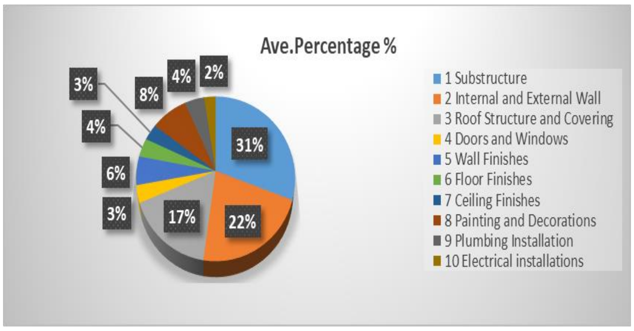

Fig. 2. Average Embodied Energy (Cradle-To- Gate) Percentage Contributions For The Building Components Of The Referenced Case Studies (T1, T2, And T3)

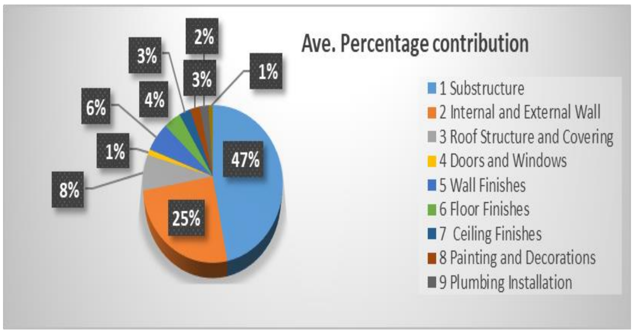

Fig. 3. Average Embodied Carbon Emission (Cradle-To-Gate) Percentage Contributions For The Building Components Of The Referenced Case Studies (T1, T2, And T3)

3.2 Cradle–To–Gate Material Embodied Emission (KgCO2eq)

The material embodied emission (cradle-to-gate) of the referenced buildings- T1, T2, and T3 were estimated at 142,748.49 KgCO2eq, 63,343.96KgCO2eq,and 3,230.56KgCO2eq, respectively. From Fig. 3, the substructure contributed 47% on average and was tailed by internal and external walls which contributed an average of 25 % followed by the roof and wall finishes with an average of 8% and 6% respectively. Further examination of the result shows that ceiling finishes contributed an average of 3% of the material embodied energy while plumbing and electrical fittings contributed 2% and 1%, respectively.

3.3 Site Construction Energy/Emission - Machine and Manual

Machine / Equipment Energy - Most of the construction activities were carried out manually and only a small number of contractors had machines/equipment. Earth-moving equipment such as bulldozers was leased from equipment leasing companies by EBSHDC for site preparation. Thus, more manual labour than the use of construction equipment thereby making the project labour-intensive. This implies the use of shovels to mix concrete and hoes for digging and excavation.

The direct fuel consumption by the machine was calculated using equations 4 and 6 in line with the IPCC[7] for translating 'delivered energy' to primary energy [42]. As presented in Table 1, 999.80 litres of diesel, 446.40 litres of PMS (Petrol), and 16 litres of grease/lubricants were expended for case study T1 and a total of 417 litres of diesel, 108 litres of PMS (Petrol) and 3.9 litres of grease/lubricants for T2. While, a total of 295.60 litres of diesel, 97.04 litres of PMS (Petrol) and 3.5 litres of grease/lubricants for T3 in eight months of construction works. Diesel consumption for concrete mixers and bulldozers constituted more than half of the site construction energy. For the reference buildings (T1, T2, and T3), the Primary energy equivalent was estimated at 57, 226.41MJ, 20,125.37MJ, and 15,253.83MJ, respectively. From Table 2; emission from the referenced buildings T1, T2 and, T3 amounted to 2,731.57 KgCO2eq, 1,133.73 KgCO2eq and, 805.13 KgCO2eq, respectively. Diesel dominated the site construction emissions with an average of 99% for the study area.

Table1

Site Construction Energy (Machine) for the Referenced buildings T1, T2 and T3

	T1			T2			T3		
Type of energy or Fuel	Quantity (Litres)	*Lower Heating Value (LHV)	Primary Energy Equivalent (MJ)	Quantity (Litres)	*Lower Heating Value (LHV)	Primary Energy Equivalent (MJ)	Quantity (Litres)	*Lower Heating Value (LHV)	Primary Energy Equivalent (MJ)
Diesel	999.80	35.94	35,932.81	417	35.94	14,988.06	295.6	35.94	10,624.22
Petrol	446.40	46.5	20,757.60	108	46.5	5,006.66	97.04	46.5	4,512.36
Lubricants	16	33.5	536.00	3.9	33.5	130.65	3.5	33.5	117.25
Total			57,226.41			20,125.37			15,253.83

IIPCC 2006

Table 2

Site Construction Emission for referenced buildings T1, T2, and T3

		Reference Buildings											
		T1				T2				T3			
No	Type of emission or Fuel	Quantity (Litres)	Emission Factor	Emission (Kg)	%	Quantity (Litres)	Emission factor	Emission (Kg)	%	Quantity (Litres)	Emission Factor	Emission (Kg)	%
1	Diesel	999.8	2.7	2,699.46	98.82	417.03	2.7	1,125.98	99.3	295.61	2.7	798.15	99
2	Petrol	446.4	0.0693	30.94	1.1	107.67	0.0693	7.46	0.66	97.04	0.0693	6.72	0.8
3	Lubricants	16	0.0733	1.17	0.043	3.9	0.0733	0.29	0.03	3.5	0.0733	0.25655	0.2
	Total (KgCO2eq)			2,731.57	100			1,133.73	100			805.13	100

Manual Work (Human Labour) - According to Held[43], the incorporation of energy from labour during energy estimation of productive actions could be a remedy for sustainable development. However, energy demands of human labour exhibit a level of inconsistency with features such as lifestyle, sex, age, weight, and socioeconomic settings [44]. Determining labour components in a bill of quantity is mostly dependent on the type of contract/construction, skills involved in carrying out the work, and location. This study, therefore, adopted 25%, as the labour factor of construction cost (Nigerian Institute of Quantity Surveyors' recommendation) earlier adopted by Udomiaye et al [13]. The referenced case study T1 contract sum was put at ₦4,250,000.00. Labour cost was computed as ₦1,062,500 (25% of ₦4,250,000.00). The average labour cost per person is ₦2,000 at the time of construction. Thus, in the study, a daily labour wage of ₦2,000.00 was adopted. The total labour deployed was 531 (total labour cost of ₦1,062,500.00 divided by the daily labour cost of ₦2,000.00). Using Eq. 5, the human energy factor of 0.75 MJ/hour for the Nigerian agricultural sector's settings (Eq. 4) and successfully adopted in engineering settings or circumstances by Odigboh [45]and Ohunakin et al.,[38]. With a working period of 8 hours/day, the human energy input to the construction was calculated using Eq. 5 as 3,187.50MJ. The manual energy intensity for the case study T1 was 8.95 MJ/m^2. The same method was applied for referenced buildings T2 and T3 with manual energy of 1,950 MJ and 1,837.50 MJ respectively, as presented in Table 3.

The site construction energy for the referenced buildings -T1, T2, and T3 was computed as 60,413.91MJ, 22,075.36MJ, and 17,091.33 respectively. The energy from the machine was 93%, while, manual labour was 7% of the site construction energy as presented in Fig. 4.

Table 3

Manual Energy computation for the reference buildings - T1, T2, and T3

Reference Buildings	Contract sum(N)	Labour Sum (25%)	Ave. labour cost per person(N)	No of Labourers	HE Coefficient MJ/h	Manual Energy (MJ/h)	Total Manual energy per day(8hrs) for the period (MJ)	Intensity (MJ/m2)
T1	4,250,000.00	1,062,500.00	2,000.00	531	0.75	398.44	3,187.50	8.95
T2	2,600,000.00	650,000.00	2,000.00	325	0.75	243.75	1,950.00	9.38
T3	2,450,000.00	612,500.00	2,000.00	306	0.75	229.6875	1,837.50	10.10

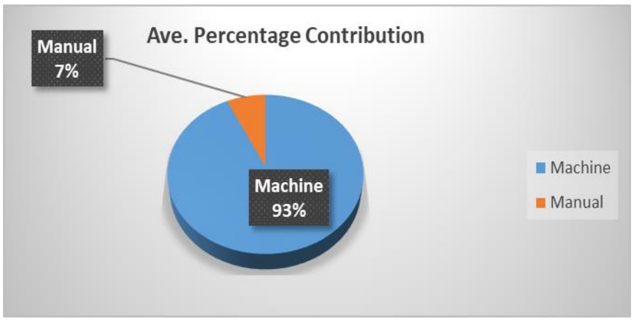

Fig. 4. Average Percentage Contributions Of Machine And Manual Energy Of The Referenced Buildings (T1, T2, And T3)

3.4 Transportation Energy/Emission

There are two main modes of carriage of construction materials used in the referenced building cases. Firstly, the non-surface, that is by Sea, especially for imported building materials mainly from China and Ukraine [46]. Secondly, the surface mode uses heavy/light-duty trucks (Tippers and Lorries) powered with diesel. Notably, the non-surface (by Sea) is not within the scope of the study. Thus, in corroboration with Harrington and Krupnick [47], fuel consumption was valued using 35 litres/100km as the fuel intensity for heavy trucks and 20 litres/100km for light vehicles as provided by the US Department of Transportation- USDT [47,48].

Using Eq. 6, the computed quantity of diesel used was 3,408.72 litres and multiplied by the default heating value of 35.94, the total energy from materials haulage amounted to 122,509.36 MJ for case study T1. The quantity of diesel consumption was multiplied by the emission factor giving 9,203.54 kg of carbon emission. The same method was applied to referenced buildings T2 and T3 giving 67,712.89MJ (5,086.95 $KgCO_2$) and 69,696.47MJ (5,235.89$KgCO_2$) respectively.

4. Discussion

The initial embodied energy of case study buildings was estimated using Eq. 3. The initial embodied energy of T1, T2 and T3 were computed as 1,278,399.07 MJ, 569,570.86MJ, and 517,226.78MJ with an initial embodied energy intensity of 3,594.24MJ/m^2 , 2,734.12MJ/m^2 and, 2,845.03MJ/m^2 respectively.

The initial material embodied energy accounted for 84%, while transportation was 12% and Site construction accounted for 4 % of the initial embodied energy for the study area. The initial carbon emission for the referenced buildings T1, T2 and T3 were 154,683.60 $KgCO_2eq$, 69,564.64 $KgCO_2eq$ and, 69,271.58 $KgCO_2eq$ respectively. The initial embodied emission intensity was calculated as 434.9$KgCO_2eq$/m2, 333.93$KgCO_2eq/m^2$ and, 381.03 $KgCO_2eq/m^2$. The cradle-to-gate material embodied emission dominated with an average of 92%.

The building material cradle-to-gate embodied energy and GHG emission of the case study buildings accounted for 83.2% and 91.5% of the initial embodied environmental impact and with an average intensity of 2,583.57 MJ/m^2 and 351.02 $KgCO_2eq/m^2$, respectively. The dominance of cradle-to-gate material embodied energy and emission in the study agrees with the existing study from tropical and developing countries [22].

Transportation energy and emission accounted for an average of 11.65% and 6.95%, respectively. This situation is similar to a recent study in Ecuador presented by Vázquez- Calle et al., [49] in which it was identified that cement and transportation contributed significantly to the total embodied impact.

Nevertheless, the values are significantly high compared to other existing local and international studies. For instance, Utama and Gheewala [25] and Ramesh et al.[26] reported 1.13% and 3.8% respectively, while Ezema et al [23] reported 3.5%. The average transportation energy intensity of 0.35GJ/m^2 in the study is also significantly higher than 0.19GJ/m^2 and 0.06GJ/m^2 earlier reported by Vukotic et al.,[50] and Leckner and Zmeureanu [51], respectively. The reasons for the high transportation energy intensity in the Nigerian context as observed in the study were traced to the application of ‘fairly-used diesel-powered trucks, haulage distance, and bad roads. It was also observed that the majority of the functional Ports in Nigeria are located in Lagos and thus, most of the building material factories are located in southwestern Nigeria. Hence, the haulage distance for the study area (South-Eastern Nigeria) contributed significantly. Consequently, haulage distance and mode of transportation are key to the reduction of embodied carbon emissions and energy intensity in the housing sector.

Concerning the research question, construction energy and carbon emissions contributed 3.9% and 1.52% respectively. Notably, manual labour accounted for 7% of the total site construction energy, while, the average manual labour energy intensity for the study area was 9.5MJ/m^2. Therefore, in the assessment of embodied environmental sustainability of residential buildings manual labour energy is significant. In addition, the values underscore the imperatives of integrating manual labour energy in the environmental profiling of residential buildings in developing countries. The result shows that the environmental burdens resulting from construction activities could vary significantly if the human labour component is integrated. Hence, the study suggests that the national environmental sustainability assessment protocol should have a manual energy assessment component. Moreover, the assessment tools currently being used are based on the peculiarities of their country of origin, and hence, need to be reviewed based on these findings.

5. Conclusion

The study examined embodied energy use with a specific focus on manual labour and material transportation energy also known as material haulage energy in residential buildings (Apartment Buildings) in Abakaliki, South Eastern Nigeria. The values obtained for embodied energy intensity and transportation energy intensity in the study area were found to be similar to other studies in different environments. The comparatively high haulage energy intensity observed in the study area which is characterized by high surface (Road only) transportation mode and the usage of old diesel-powered trucks is indicative of the effects of building material haulage on the embodied energy of residential buildings. An efficient building material transportation mode could also be a solution for the reduction of the embodied impact in the housing sector and the construction industry.

In addition to recommending the inclusion of human labour energy in the environmental profiling of residential buildings, the study suggests the following sustainable measures to reduce initial embodied energy and emission in developing countries and Nigeria in particular:

- Reduce haulage distance: To reduce haulage distance, the two Seaports in south-eastern Nigeria (Port Harcourt and Calabar) need to be overhauled to function to full capacity. Dredging the River Niger and Onitsha Port-Dredging Niger/Benue to carry larger vessels should be completed with a Seaport at Lokoja in addition to Onitsha Port to abridge the road distance between Lagos and the Northern states as well as Enugu. The Onitsha River Port if put to use will reduce haulage distance by over 60% for the study areas and neighbouring cities.

- Improve rail network: Revamp and modernize the rail system. Rail links to connect Lagos (South Western Nigeria and Enugu (South-Eastern Nigeria) warehouses. The Aba Dry Port (Isiala Ngwa LGA, Abia State) should be completed and linked by rail directly from Onitsha River Port. This will significantly reduce the haulage burden on the Lagos-Enugu highway.
- Age restrictions for imported trucks: Presently, Nigeria has a 1:131 ratio of new trucks to 'used- trucks' and an import age restriction of < 15 years. The paper suggests an age restriction of < 5 years for imported trucks and the introduction of trucks with hybrid engines. And not an outright ban of 'used trucks', but shifting to cleaner and safer imported 'used trucks.

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8. Author Contributions

Udomaiye and Ukpong designed the research and data computations. While Ikpa produced the as-built drawings.

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10. Conflict of Interest

The author declares no conflict of interest.

11. Research transparency and reproducibility

There are no data files, sensitive information, or statistical analyses associated with this paper. There are no scientific photographs.

12. References

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