

CARBON FOOTPRINT AND ECONOMIC IMPLICATIONS OF CONSTRUCTION MATERIALS FOR GREEN BUILDING DEVELOPMENT: A SUSTAINABILITY ASSESSMENT

Abdulkadir Shehu Rasheed, Taibat Ranti Adebisi, Kafayat Kofoworola Abdulkadir

Department of Quantity Surveying, University of Ilorin, Ilorin, Nigeria
Corresponding Author: rasheed.as@unilorin.edu.ng

Abstract

The contribution of construction materials to greenhouse gas emissions is relatively high and the economic implications are vital to green building development in Nigeria. Data on the carbon footprint of key construction materials is yet fully available in Nigeria. This study assessed the carbon footprint of reinforcing steel, sandcrete block, cement, sand, granite and concrete with a view to highlighting their environmental impact and economic implications. The study used a narrative literature review to synthesis themes for a sustainability analysis to draw conclusion. Results show that cement and concrete are the dominant sources of carbon emissions in the construction sector with 8–10% of global greenhouse gas emissions, thereby contributing 40% of global carbon dioxide discharge, with 60% from cement alone. Other materials have significantly less emissions but equally contribute to global greenhouse gas emission. Findings also reveals that there is modest cost savings on construction materials resulting in reduce carbon emissions in cement, concrete, and sandcrete block when alternative materials are employed in the production process. This process can result in a reduction of 7% of the total cost while reducing indicators of global warming and promoting green building development.

KEYWORDS: Carbon Footprint, Construction Materials, Cost, Green Building, Sustainability,

Introduction:

The Nigerian Construction Industry (NCI) significantly contributes to the country's environmental degradation while also producing significant greenhouse gas emissions (Labaran *et al.*, 2022). As a result, the industry experiences substantial sustainability challenges (Tunji-Olayeni *et al.*, 2018). The reason for this being the industry's dependence on conventional construction materials and their production processes which significantly produces greenhouse gas emissions (Ajayi *et al.*, 2024). Dependence on high-energy materials and processes, together with the extraction and processing of locally sourced raw materials for construction, impacts climate change and depletes natural resources respectively (Zhao *et al.*, 2025). Similarly, construction industry worldwide contributes significant waste to the environment and the improper management of these waste has negative impact on the environment (Wang *et al.*, 2024). Nigeria, being a developing nation, construction and demolition waste management has been identified as a critical issue, with evident potential for waste reuse through circular economy strategies (Abubakar *et al.*, 2024).

To address these challenges, sustainable construction practices and models have been proposed and implemented in the NCI (Unegbu *et al.*, 2025). Life cycle assessments reveal that sustainable construction materials with lower embodied carbon and reduced waste generation such as bamboo, recycled concrete, low-carbon concrete, recycled steel and earth-based materials, are better alternatives to the existing conventional materials in the NCI (Ajayi *et al.*, 2024; Unegbu *et al.*, 2024). This is because of their reduced carbon emission and impact on the environment. Similarly, low-carbon materials, particularly stabilized earth blocks, offer promising solutions for sustainable construction in Nigeria (Adedeji *et al.*, 2013). Also, sustainability models such as the green building concept and implementation of various sustainability rating systems such as EDGE, DGNB and LEED certifications have contributed to reducing the overall greenhouse gas emissions within the industry (Labaran *et al.*, 2022).

Despite the existence of sustainability strategies for implementation in Nigeria (Labaran *et al.*, 2022; Ajayi *et al.*, 2024), sustainable construction practices are still very low (Unegbu *et al.*, 2025). This has been attributed to low awareness of sustainability issues among construction organisations, and has resulted into a critical impediment to the implementation of effective sustainability strategies (Tunji-Olayeni *et al.*, 2018; Labaran *et al.*, 2022; Ajayi *et al.*, 2024). The carbon footprint and economic implications of construction materials that are more prevalent in the NCI are not properly articulated for construction organisations to understand their environmental and economic impact (Ajayi *et al.*, 2024). To improve the implementation of sustainability strategies in the NCI, awareness of the carbon footprint and economic implication of key construction materials is paramount. Therefore, aside from strengthening regulatory frameworks, offering financial incentives, and boosting local production of sustainable materials, increasing awareness of the carbon footprint and economic viability of key materials through education is the most vital challenge to sustainability strategy implementation (Unegbu *et al.*, 2025; Abubakar *et al.*, 2024).

This study aims to articulate information on the carbon footprint of some key construction materials used in the NCI with a view to bringing awareness to construction organisations on their environmental impact and reason to promote change. Similarly, awareness on the short and long-term economic implications of these materials will help construction organisations understand the importance of embracing sustainability strategies in the NCI.

Literature Review

The NCI is making strides towards sustainable development but with apparent existence of both challenges and opportunities. Recent studies highlight the growing adoption of sustainable construction practices in Nigeria, despite significant challenges (Unegbu *et al.*, 2024; Okeke *et al.*, 2023). The NCI is gradually embracing sustainability models, with a focus on environmental responsibility and social inclusiveness (Unegbu *et al.*, 2024). However, the actual implementation of these practices remains limited, emphasizing the need for context-specific sustainability models within the industry (Unegbu *et al.*, 2024; Okeke *et al.*, 2023). Key challenges include inadequate funding, weak institutional capacity, and corruption, highlighting the need for stronger policy frameworks and educational initiatives (Unegbu *et al.*, 2024; Okeke *et al.*, 2023). Despite the growing global awareness of sustainability, the adoption and use of sustainable construction materials remains limited in Nigeria (Adedeji *et al.*, 2013).

Material Adaptation for Green Building Development in the NCI

Material adaptation for green building development in Nigeria has significant opportunities for utilizing local sustainable materials across different climatic regions (Tunji-Olayeni & David, 2024; Isang, 2023). For instance, In North-Western Nigeria's hot-dry climate, expert consensus identified 19 suitable materials including straw bales, adobe bricks, ash waste bricks, and various agricultural waste products for construction applications (Yakub *et al.*, 2024). However, implementation faces challenges due to misalignment between international certification systems such as EDGE or LEEDS and local realities, including lack of local Life Cycle Analysis (LCA) databases and high certification costs (Adekunle *et al.*, 2025). Cost-effectiveness studies demonstrate that green materials like adobe bricks and bamboo can reduce construction material costs by 16.67% to 67.99%, making them viable solutions for addressing Nigeria's 17-20 million housing deficit while promoting environmental sustainability (Adams & Turner, 2024; Adeniyi & Mohamed, 2019).

Awareness of Sustainable Construction Materials In the NCI

Findings on sustainable construction materials in Nigeria reveals low awareness and adoption among industry practitioners (Labaran *et al.*, 2021). Construction organizations often lack sustainability strategies due to limited knowledge about alternative construction material that fits (Tunji-Olayeni *et al.*, 2018; Labaran *et al.*, 2022). Awareness levels vary across sectors, with client organizations and academia showing higher awareness compared to consulting and contracting

firms (Amuda-yusuf *et al.*, 2020). Insufficient research and development and skills gaps also impede progress in the adoption of sustainable construction material (Abisuga & Oyekanmi, 2014). To promote the use of sustainable construction materials, increased awareness is recommended (Amuda-yusuf *et al.*, 2020; Tunji-Olayeni *et al.*, 2018).

Key Construction Materials in the NCI

The NCI is known to be slow in embracing innovations because of the traditional sense of many stakeholders in the industry. Key construction materials which have been prevalent in the industry include reinforcing steel, cement, sand, granite, sandcrete blocks, and concrete (Bamigboye *et al.*, 2019). These materials are posited to contribute significantly to greenhouse gas emissions from their production processes to use (Labaran *et al.*, 2021). Material planning and handling are critical factors in construction project delivery (Okorochoa, 2013), hence, effective material control strategies are essential. Over 60% of sites in the industry uses materials scheduling which are primarily managed by quantity surveyors (Albert *et al.*, 2018).

Contribution of Key Construction Materials to Greenhouse Gas Emissions

The construction industry significantly contributes to global greenhouse gas emissions, accounting for 39% of total emissions (Crawford, 2022). Concrete and steel production are identified as the most significant contributors to emissions in construction supply chains (Crawford, 2022; Kerr *et al.*, 2022). Concrete production alone represents approximately 8.6% of all anthropogenic CO₂ emissions globally (Miller *et al.*, 2016; Kerr *et al.*, 2022). Cement production is particularly problematic, being the primary contributor to CO₂ emissions in reinforced concrete (Santoro & Kripka, 2017). However, mitigation opportunities exist through readily implementable techniques. Miller *et al.* (2016) demonstrate that increased use of supplementary cementitious materials, appropriate cement replacement proportions, and extended concrete design age could reduce global concrete production emissions by 24%, equivalent to 650 million tonnes CO₂ equivalent annually. Material choice also matters significantly, with reinforced concrete sleepers producing up to six times fewer lifecycle emissions than timber alternatives (Chamasemani *et al.*, 2023).

Methodology

The study deployed qualitative research design through a Narrative Literature Review (NLR) to draw conclusions. The NLR provides a comprehensive analysis of existing literature on a specific topic (Juntunen & Lehenkari, 2021). This type of review synthesizes key findings, identifies gaps,

and informs further study, thereby, offering a flexible and qualitative approach to comparing knowledge across diverse fields (Theile & Beall, 2024). According to Ebador & Ikhede (2024), NLR are useful for understanding a broad subject or topic within a shortened timeframe. Unlike systematic reviews, NLR provide broader context and enable deeper understanding of complex issues by integrating insights from multiple disciplines (Ahmad, 2025). The NLR process is characterized as iterative, non-structured, and multi-layered, embedded within social contexts where various actors guide researchers (Juntunen & Lehenkari, 2021). The key elements of NLR include clear rationale, defined boundaries, justified inclusion criteria, reflexivity, and transparent analysis (Sukhera, 2022).

However, NLR face limitations including potential bias due to their subjective nature and lack of standardized methodology (Ahmad, 2025; Sukhera, 2022). Despite these challenges, they remain significant tools for knowledge dissemination and theoretical exploration when conducted with rigor and transparency (Ebador & Ikhede, 2024). Therefore, for this study, bearing in mind that the national data on greenhouse gas emissions or LCA from different construction materials are still being developed (Adekunle *et al.*, 2025), the NLR will aid in articulating the diversity in literature in order to identify trends, and emerging themes while facilitating theoretical explorations. The study investigated open access journals using the google scholar search engine, with key construction materials such as reinforcing steel, cement, sand, granite, sandcrete blocks, and concrete as key words. Inclusion criteria of literature reviewed are those with their study focus predominantly on carbon emission of key construction materials and their economic implications. In addition, studies carried out in Nigeria was prioritized. One hundred and thirty-four (134) studies were assessed but only 43 meet the inclusion criteria. Ten (10) of the studies focused on carbon foot print and eight (8) focused on economic implications. Other studies did not have adequate information for a thematic analysis with regards to the research questions. Subsequently, a synthesis and analysis of the themes was carried out to extract findings.

Results and Discussions

Carbon Footprint and Environmental Impact of Conventional Construction Materials

The study extracted all quantitative and qualitative findings to carbon footprint and environmental impacts including; specific CO₂ emission values or ranges, global warming potential data, comparative environmental performance between materials, percentage reduction achieved with alternatives and other sustainability metrics including water, resource depletion and energy use.

Synthesis of Literature for Carbon Footprint of Key Construction Materials

Most included studies, especially reviews, consistently report that cement and concrete are the dominant sources of carbon emissions in the construction sector, both globally and in Nigeria. Sandcrete blocks, widely used in Nigeria, are also identified as significant contributors due to their reliance on Ordinary Portland Cement. There is limited discussion of the carbon footprint of reinforcing steel, sand, and granite in the Nigerian context. Details of the synthesised reviews are as below:

Cement and Concrete: Several included studies, primarily reviews, report that cement production is a major contributor to global and Nigerian carbon dioxide emissions, accounting for 8–10% of global greenhouse gas emissions. In Nigeria, one review estimates cement production contributes 40% of global carbon dioxide discharge, with 60% from Ordinary Portland Cement alone. Concrete production is also described as highly carbon-intensive operation, with approximately 1 ton of cement producing 1 ton of carbon dioxide. The concrete industry is reported to be responsible for 8–10% of global carbon dioxide emissions.

Sandcrete Blocks: Sandcrete blocks made with Ordinary Portland Cement are highlighted as significant contributors to greenhouse gas emissions, with Ordinary Portland Cement production responsible for over 1.35 billion tons of carbon dioxide per year globally (about 7% of total greenhouse gas emissions).

Reinforcing Steel: One study noted that recycled steel, while supporting circular economy goals, is associated with higher energy demands and emissions due to the recycling process.

Other Materials (Sand, Granite): The evidence base for sand, and granite is limited, with only brief discussion of their carbon footprint in the Nigerian context.

The carbon footprint and environmental impact of key construction materials synthesised is presented in table 1 below.

Table 1. – Carbon Footprint and Environmental Impact of Key Construction Materials

Material Type	Carbon Footprint (kilograms of CO ₂ equivalent)	Global Warming Potential	Resource Depletion Impact
Cement Ordinary Portland Cement. (Etim <i>et al.</i> , 2021)	~1,000 kg carbon dioxide/ton cement	8–10% of global greenhouse gas emissions	High (limestone depletion)
Concrete (conventional) (Ogunjiofor <i>et al.</i> , 2025)	No mention found	8–10% of global greenhouse gas emissions	High (aggregate, water use)
Sandcrete blocks (Ordinary Portland Cement-based) (Unegbu <i>et al.</i> , 2025)	No mention found	Significant, due to Ordinary Portland Cement content	High (sand, cement use)
Bamboo (Daramola <i>et al.</i> , 2025)	No mention found	Lowest among assessed materials	Lowest among assessed materials
Low-carbon concrete (Fapohunda <i>et al.</i> , 2021)	No mention found	Lower than conventional concrete	Lower
Recycled steel (Olatoyan <i>et al.</i> , 2023)	No mention found	Higher than bamboo/low-carbon concrete	High (energy for recycling)
Geopolymer cement (Sbahieh <i>et al.</i> , 2023)	No mention found	10–70% lower than Ordinary Portland Cement	Lower
Fibre-reinforced polymer (vs. steel) (Patil & Sathe, 2020)	No mention found	4–75% lower than steel	No mention found
Agricultural waste Supplementary cementitious material (Goyal & Kumar, 2018)	No mention found	Up to 30% cement replacement can reverse carbon dioxide rise	Lower (waste utilization)
Biomass (Nukah <i>et al.</i> , 2023)	No mention found	Lower than fly ash / conventional cement	Lower

Synthesis of Literature for Environmental Impact for Key Construction Materials

A quantitative carbon footprint value was found for only cement (Ordinary Portland Cement), at approximately 1,000 kilograms carbon dioxide per ton of cement. For the other nine materials, no quantitative carbon footprint values were found in the included studies.

Cement (Ordinary Portland Cement) and conventional concrete are associated with high global warming potential and resource depletion. On the other hand, bamboo displays low-carbon potential while concrete, geopolymer cement, agricultural waste supplementary cementitious materials, and biomass ash are reported to have lower global warming potential and resource depletion impacts. Recycled steel is reported to have higher global warming potential and resource depletion impacts compared to bamboo and low-carbon concrete.

Economic Implications of Carbon Footprint for Key Construction Materials

The study extracted all quantitative and qualitative economic implication of carbon footprint for key construction materials. The economic metrics used for analysis are mainly quantitative cost analysis and qualitative cost analysis (general statements about cost reduction or affordability, without figures).

The economic effects of carbon reduction are presented in table 2 below.

Table 2 – Features of Included Studies for Economic Implications of Material Carbon Footprint

Material/Technology	Cost Impact	Emission Reduction	Economic Benefit
Retrofit technologies in cement (Akinyemi <i>et al.</i> , 2021)	US\$520,836 savings over 10 years (1.41% total cost reduction)	6% CO ₂ reduction	Economic viability at 6% reduction; higher targets not cost-effective
Rice husk ash (RHA) substitution in concrete (Adisa, 2013)	>Nigerian Naira 90,000 savings (~7% of building cost)	Qualitative reduction in global warming	Reported as cost-effective for low-cost housing; study also reports reduction in resource depletion
Coal ash in sandcrete Blocks (Ogunjiofor <i>et al.</i> , 2025)	Qualitative cost reduction, improved affordability	Qualitative reduction in CO ₂	Potential for affordable, eco-friendly construction. (As reported by the study)
Lean production in sandcrete blocks (Aka <i>et al.</i> , 2019)	Qualitative cost savings via waste reduction	Qualitative CO ₂ reduction	Process efficiency, lower energy/material use (as reported by the study)
Timber as alternative to concrete (Ede <i>et al.</i> , 2015).	Promising cost comparison (no figures)	Qualitative environmental benefit	Study reports timber may rival concrete in cost and sustainability, based on qualitative assessment
Carbon capture / alternative fuels (Etim <i>et al.</i> , 2021)	No mention found	30–60% CO ₂ reduction recommended	Study implies potential health and environmental cost savings
Decarbonization pathways (Roche, 2022)	No mention found	21%–tripling of emissions by 2050 depending on scenario	Policy-driven efficiency and material substitution needed (as reported by the study)
Cement industry growth (Muhammad <i>et al.</i> , 2018)	No mention found	25 million tons CO ₂ /year	Highlights scale of emissions, not mitigation (as reported by the study)

Synthesis of Literature for Economic Implications of Carbon Footprint on Key Construction Materials

Both quantified cost savings and qualitative descriptions of cost savings was evident in the studies presented, Nigerian Naira 90,000 savings, ~7% of cost is posited in a study. Emission reduction is recorded in quantified CO₂ emissions (30–60%). Also, qualitative descriptions of emission

reduction were prevalent in the studies selected. Similarly, both quantified or qualified economic benefit also were reported.

Conclusion

Cement and concrete emerge as the most carbon-intensive materials in the Nigerian construction context. Reviews report that Ordinary Portland Cement production generates about 1,000 kilograms of CO₂ per ton and accounts for 8–10% of global greenhouse gas emissions. Also, in Nigeria, cement production may contribute as much as 40% of the nation's carbon emissions, with 60% of that coming from Ordinary Portland Cement. Sandcrete blocks, due to their reliance on cement, are similarly implicated.

Alternative materials offer potential for emission reduction in green building development. Coal ash used in sandcrete blocks, bamboo, low-carbon concrete, geopolymers, and agricultural waste supplementary cementitious materials are associated with reductions of 10–70% in carbon intensity compared to traditional formulations. Recycled steel appears to demand higher energy inputs, while limited evidence exists on the carbon impacts of reinforcing steel, sand, and granite.

In Nigeria, modest cost savings on construction materials may accompany efforts to reduce carbon emissions in cement, concrete, and sandcrete block production. Similarly, retrofitting cement plants creates a 6% CO₂ reduction which results in a reduction of total costs by 1.41%. Equally, substituting 15% rice husk ash for cement in concrete cuts building costs by over 7% of the total cost while reducing indicators of global warming. Sandcrete block production also describes qualitative reductions in costs and emissions when coal ash is used as a cement substitute or when processes are streamlined to reduce waste.

The finding from this review states the carbon footprint of key construction materials and their economic implications for green building development in Nigeria. However, most studies do not perform full life cycle assessments, and the evidence spans both Nigeria-focused and global analyses. Therefore, studies that will perform Life cycle assessments is very sacrosanct to the acquisition of accurate data.

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