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Towards a Net-Zero Built Environment: A Review of Challenges, Opportunities, and Strategies for Achieving the SDGs in the Global South

Grace Oloukoi; & Adepeju Babalola
Department of Urban and Regional Planning, Lead City University, Ibadan, Nigeria.
Corresponding Author: oreofeadeniji@yahoo.com
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Abstract

Achieving a Net-Zero Built Environment (NZBE) is central to climate action, yet its alignment with the Sustainable Development Goals (SDGs) in developing contexts such as Nigeria remains underexamined. This review synthesizes over 50 global and regional studies to identify critical gaps, emerging innovations, and policy-practice mismatches in the Global South with special reference to Nigeria's path to net-zero. Key themes include passive and climate-responsive design, digital technologies, off-grid renewables, low-carbon materials, and inclusive policy frameworks. The study maps these themes to SDG 7 (Clean Energy), SDG 9 (Infrastructure), SDG 11 (Sustainable Cities), and SDG 13 (Climate Action), offering a context-specific roadmap grounded in local realities. The review also proposes a model and a circular roadmap for Nigeria's NZBE strategy, integrating design standards, financing, capacity-building, and community inclusion. By connecting built environment action to SDG sub-targets, the review offers practical insights for architects, planners, and policymakers seeking to localize net-zero ambitions in Nigeria and other Global South spaces.

Keywords: Net-Zero Built Environment, Sustainable Development Goals, Climate Action, Urban Infrastructure, Nigeria.

Introduction

The urgency of net-zero stems from the scientific consensus that global greenhouse gas (GHG) emissions must reach net-zero by mid-century to limit global warming to 1.5°C, as outlined in the Paris Agreement (UNFCCC, 2015). The Intergovernmental

Panel on Climate Change (IPCC) warns that exceeding this threshold could trigger irreversible tipping points, ranging from rising sea levels to extreme weather events and biodiversity loss (IPCC, 2023). At COP28 and COP29, global leaders reiterated that current efforts remain insufficient, with the Global Stocktake revealing that emissions must decline by 43% by 2030 and reach net-zero by 2050 to remain within the 1.5°C pathway (World Economic Forum, 2025). In 2025, COP30 further emphasized the need for a just, orderly, and equitable energy transition, recognizing that global efforts to halt temperature rise remain off track. By the end of COP30, 119 countries representing more than 70% of global emissions had revised their Nationally Determined Contributions (NDCs), yet these commitments were collectively projected to deliver less than 15% of the emission reductions required by 2035 (World Resources Institute, 2025). This demonstrates that current climate trajectories remain far below what is required to achieve global climate targets.

Among all sectors, the built environment stands out, accounting for nearly 40% of global energy-related emissions (UNEP, 2022). These emissions comprise both operational emissions generated from heating, cooling, lighting, and building operations, and embodied emissions associated with material extraction, construction, maintenance, and demolition (McKinsey & Company, 2023). As global floorspace is projected to double by 2060, the urgency of decarbonizing both new and existing buildings cannot be overstated (GlobalABC, 2022). Beyond emissions, the built environment directly influences energy consumption, urban mobility, infrastructure development, and quality of life, making it central to the achievement of SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action). Despite growing international attention to net-zero transitions, efforts to align built environment practices with climate targets remain underdeveloped in many developing countries, including Nigeria. Although Nigeria has formally committed to achieving net-zero emissions by 2060 through instruments such as the Climate Change Act (2021) and the Energy Transition Plan (2022), major implementation gaps persist. There is currently no dedicated national Net-Zero Building Strategy, while existing instruments such as the Building Energy Efficiency Code (BEEC) suffer from weak enforcement. Furthermore, policy attention remains concentrated on operational emissions, with limited consideration of embodied carbon despite its growing significance in lifecycle building emissions.

Additional challenges include weak institutional coordination, inadequate climate literacy across technical and vocational sectors, limited access to climate finance, and the predominance of informal urban development. More than 60% of Nigeria's urban population resides in informal settlements, yet sustainability policies largely target formal development systems. At the same time, Nigeria receives only a fraction of the climate finance required to support adaptation and mitigation efforts (Connected Development et al., 2025). While a growing body of literature examines net-zero technologies, sustainable buildings, climate policy, and SDG implementation, these themes are often addressed in isolation. Consequently, there remains limited synthesis of how Net-Zero Built Environment (NZBE) strategies can be

integrated with SDG implementation pathways within the institutional, socio-economic, and urban realities of Nigeria and the wider Global South.

Against this backdrop, this paper critically explores the challenges, opportunities, and strategic pathways for achieving a Net-Zero Built Environment (NZBE) in Nigeria, while examining how these efforts can accelerate progress toward the Sustainable Development Goals. Through an extensive review of literature, case studies, and contextual realities, the study contributes to the evolving discourse on net-zero transitions within developing economies.

The review makes three key contributions. First, it synthesizes a broad but fragmented body of knowledge spanning design, policy, infrastructure, technology, and governance while explicitly linking these themes to SDG targets. Second, it places Nigeria and comparable Global South contexts at the centre of the net-zero discourse, addressing a gap in literature that often overlooks local institutional constraints and socio-political realities. Third, it proposes a context-sensitive roadmap informed by global experience, regional evidence, and Nigeria's specific development challenges, thereby providing actionable guidance for planners, policymakers, and built-environment professionals.

The following research questions guide this review:

1. What are the key challenges facing Nigeria in achieving a Net-Zero Built Environment, and how do these intersect with SDG targets such as affordable energy, sustainable cities, and climate action?
2. What technological, policy-related, and socio-cultural opportunities can be leveraged to accelerate the transition to NZBE?
3. How can lessons from global case studies inform a locally relevant roadmap for Nigeria's urban and construction sectors?
4. What design principles and planning tools are most effective for aligning built environment practices with SDGs 7, 11, and 13?

These questions are addressed throughout the review. Research Question 1 is examined primarily in Sections 6, 8, and 9; Research Question 2 in Sections 4 and 5; Research Question 3 in Section 10; and Research Question 4 in Sections 4 and 7.

The remainder of the paper is organized as follows. Following the methodology section, the paper introduces the concept, historical evolution, and policy background of Net-Zero within the built environment and its connection to the SDGs. Subsequent sections discuss net-zero building design principles, supporting technologies and innovations, the African and Nigerian context, urban planning and infrastructure considerations, policy frameworks, implementation challenges, global case studies, and finally a proposed roadmap for Nigeria's transition toward a Net-Zero Built Environment.

Methodology

Data Sources and Strategies

To ensure a comprehensive, transparent, and reproducible review of the literature intersecting the Net-Zero Built Environment (NZBE) and the Sustainable Development Goals (SDGs), a systematic search strategy was deployed. Primary literature searches were conducted across

three major international, multi-disciplinary databases: Scopus, Web of Science (WoS), and Google Scholar. These platforms were selected due to their robust coverage of peer-reviewed literature spanning urban planning, environmental management, engineering, and climate policy.

The search was bounded chronologically between 2015 and 2025, anchoring the timeline to the global adoption of the United Nations SDGs. To capture the full breadth of relevant scholarship, a Boolean search string was constructed combining terms related to carbon neutrality, urban infrastructure, and sustainability frameworks. The exact search string executed was as follows:

("Net-Zero" OR "Carbon Neutral" OR "Zero-Carbon") AND ("Built Environment" OR "Urban Infrastructure" OR "Sustainable Buildings" OR "City Planning") AND ("Sustainable Development Goals" OR "SDGs" OR "Climate Adaptation")

Inclusion Criteria

The initial search yielded a total of 1,221 records. These studies were screened based on relevance using predefined inclusion and exclusion criteria. Inclusion criteria include: *Thematic Relevance***:** The literature had to focus directly on net-zero initiatives within either the macro urban planning scale (e.g., regional infrastructure, green spaces, spatial planning) or the micro building scale (e.g., sustainable building materials, retrofitting, energy efficiency). Crucially, the study had to explicitly link these interventions to broader sustainability frameworks or the UN SDGs. *Document Type:* Only peer-reviewed journal articles, indexed book chapters, and authoritative international reports (such as the IPCC, World Urban Forum, or UN-Habitat) were included. *Language and Timeline:* The search was strictly restricted to documents published in English between 2015 and 2025. This was to capture the post Paris Agreement and the last Convention of Parties (COP 30).

Exclusion Criteria

Papers addressing carbon mitigation or net-zero strategies in unrelated sectors, such as heavy manufacturing, aviation, or maritime logistics, with no direct structural application to the green design and management of the built environment. Highly localized or isolated materials-science studies (e.g., the microscopic chemical properties of a specific concrete polymer) that lacked any systemic, or policy-level integration into the management of built environment. Non-peer-reviewed source material, from students' thesis, opinion posts and blogs.

Data Extraction and Thematic Synthesis

A qualitative thematic synthesis approach was adopted to analyze the final corpus of 53 global and regional studies. Data extraction was systematically guided by the core dimensions of the study's objective: identifying challenges, emerging innovations, gaps, opportunities, and strategies within the NZBE landscape in the Global South with special reference to Nigeria's path to net-zero. To evaluate the systemic impact of NZBE interventions, individual strategies

were cross-referenced against the UN Sustainable Development Goals. Particular analytical emphasis was placed on mapping direct contributions to **SDG 11** (Sustainable Cities and Communities), **SDG 13** (Climate Action), and **SDG 7** (Affordable and Clean Energy).

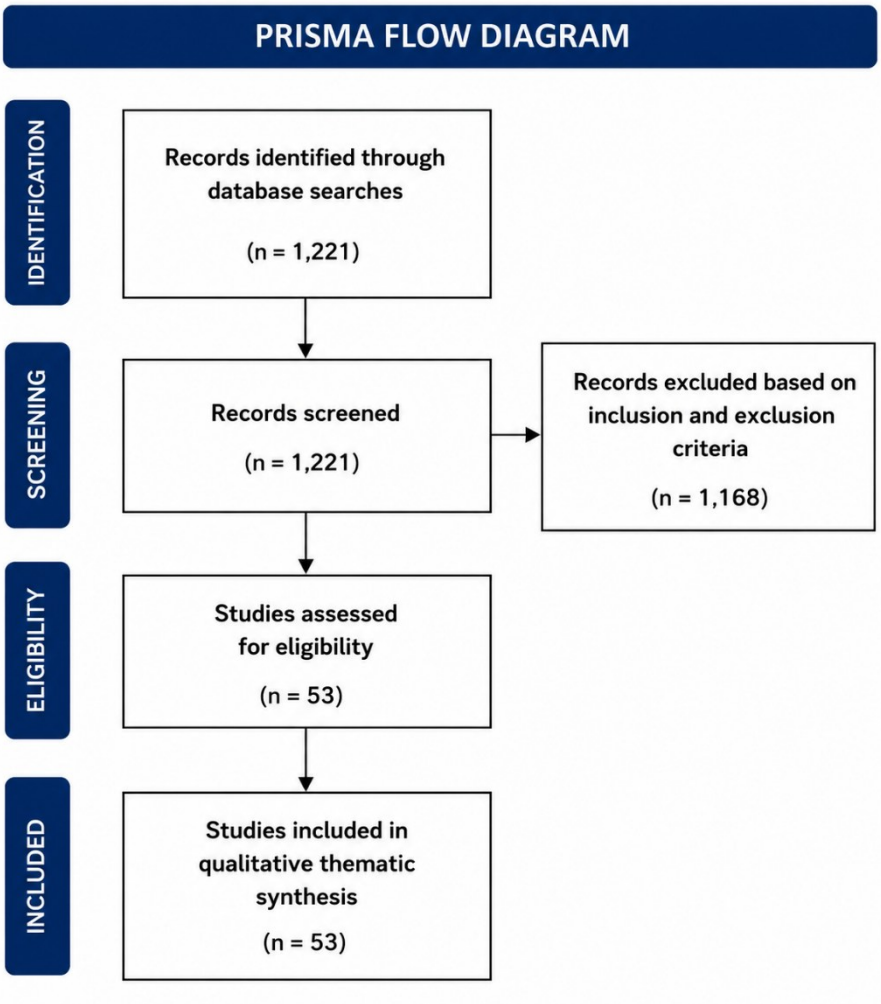


Figure 1: PRISMA Flow Diagram of the Literature Selection Process
Source: Author's Conceptualization, 2026

Understanding the Concepts of and Background to Net-Zero in the Built Environment Discourse

To implement effective strategies for achieving a Net-Zero Built Environment (NZBE), it is important to first clarify what the term "Net-Zero" means and how it differs from similar sustainability concepts. This section outlines the definitions, core principles, and global development agendas that shape Net-Zero thinking, with a particular emphasis on its relevance to the Sustainable Development Goals (SDGs).

According to the World Green Building Council (2023), a Net-Zero Carbon Building is "highly energy efficient and powered from on-site and/or off-site renewable energy sources,

with any remaining carbon offset." Net-Zero emphasizes deep reductions in emissions across direct, indirect, and supply chain scopes, allowing offsets only for residuals. This makes it a key metric for aligning with the Paris Agreement (Net Zero Now, 2024).

Other related terms are often used interchangeably but carry distinct implications. Carbon-neutrality, for instance, can be achieved solely through offsetting and is often criticized for enabling business-as-usual practices (National Grid, 2022). Zero-carbon refers to buildings that produce no emissions at all, which are typically powered fully by renewable energy (Plana Earth, 2023). Meanwhile, Net-positive or climate-positive buildings go beyond emissions reduction, actively restoring ecosystems and removing more carbon than they emit (Unity Environmental University, 2025).

Global Sustainability Frameworks and the SDGs

The 2030 Agenda for Sustainable Development outlines 17 interlinked goals designed to balance economic, social, and environmental progress. Within this framework, four goals (SDG 7, 9, 11, and 13) are particularly relevant to shaping a Net-Zero built environment. Each includes specific targets that support cleaner, more inclusive, and more climate-resilient systems (see Figure 1).

SDG 7: Affordable and Clean Energy

Targets 7.2 and 7.3 focus on increasing the share of renewables in the global energy mix and improving energy efficiency. NZBE strategies support this through the integration of solar, wind, and biomass systems, passive building design, and smart energy management.

SDG 9: Industry, Innovation, and Infrastructure

Targets 9.4 and 9.5 promote clean technologies and sustainable infrastructure. Circular construction methods, low-carbon materials, and WLCA (Whole Life-Cycle Assessment) tools all respond directly to these objectives.

SDG 11: Sustainable Cities and Communities

Targets 11.1, 11.3, 11.6, and 11.b emphasize affordable housing, participatory urban planning, and urban resilience. NZBE strategies promote passive cooling, slum upgrading, and green infrastructure, which are especially vital in low-income and informal settlements.

SDG 13: Climate Action

Targets 13.1 to 13.3 call for strengthened resilience to climate risks, policy integration, and climate awareness. NZBE contributes through disaster-resilient design, integrating climate goals into urban strategies, and building technical capacity at the local level.

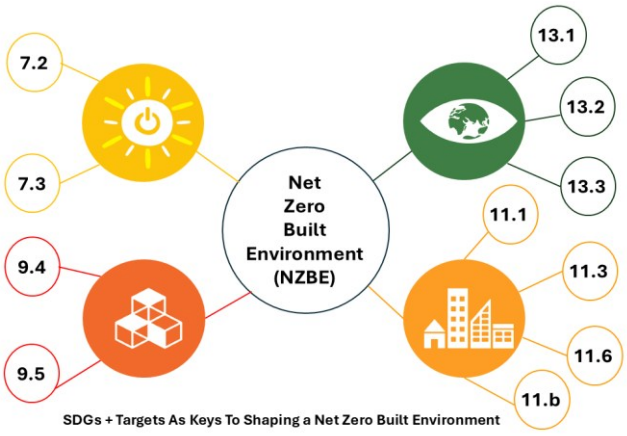


Figure 1 shows how these SDG targets align directly with Net-Zero strategies in the built environment.
Source: Author's Conceptualization, 2026

Several studies have explored how Net-Zero strategies advance broader sustainability goals:
Govindan (2023) examined how circular economy (CE) practices influence SDG outcomes and Net-Zero goals using a textile-sector case study. Through multi-criteria tools (BWM, grey DEMATEL), the study identified critical CE success factors tied to digitalization and sustainability.
Ahmed et al. (2024) noted that the built environment accounts for up to 40% of global emissions and emphasized Net-Zero Energy Buildings (NZEBs) as practical solutions for reducing carbon footprints and achieving SDGs 7 and 13.
Razzaq et al. (2023) converted an academic building into an NZEB using solar energy and retrofits, reducing emissions by 32.8 metric tons annually. The project achieved LEED Silver status and demonstrated that climate goals can align with economic returns.
Scherz et al. (2020) argued that achieving Net-Zero requires a "strong sustainability" approach that prioritizes environmental systems over economic or social trade-offs. They proposed a systemic design model to guide early-stage Net-Zero planning decisions in alignment with SDGs.
Aboulnaga & Elsharkawy (2023) emphasized the urgency of Net-Zero adoption in fast-urbanizing regions. Drawing from policy reviews in Egypt and beyond, they linked clean mobility, low-carbon buildings, and citywide energy transitions to achieving COP26 and Paris Agreement targets.

Why Net-Zero Built Environment Matters
The importance of achieving a Net-Zero built environment cannot be overstated. Globally, the built environment accounts for nearly 40% of energy-related carbon emissions, 40% of material use, and a significant share of water consumption (Ahmed et al., 2024). It also shapes public health, housing access, mobility, and economic resilience. In sub-Saharan Africa, where rapid urban growth meets limited infrastructure, the stakes are even higher. If current

development patterns continue, emissions will rise steeply. However, integrating Net-Zero strategies early on, through energy-efficient design, renewable integration, inclusive urban planning, and low-carbon construction, can help cities become enablers of both mitigation and adaptation. The built environment thus stands as a strategic entry point for realizing the SDGs, particularly in regions where climate resilience is a developmental issue.

With this section, we clarified the core concepts underpinning Net-Zero in the built environment and linked them to the global sustainability agenda. By mapping these strategies to relevant SDG targets and reviewing emerging research, it establishes the knowledge foundation for the rest of the papermoving from conceptual clarity to real-world application in planning and governance.

Background of the Net-Zero Principle

The Net-Zero principle refers to achieving a balance between greenhouse gas (GHG) emissions produced and those removed from the atmosphere. It is grounded in climate science, which shows that global warming only stops when net emissions reach, particularly for carbon dioxide (CO_2), the most persistent greenhouse gas (Net Zero Climate, n.d.). This does not require eliminating all emissions immediately, but calls for deep reductions across all sectors, with removals or offsets reserved only for emissions that are technically difficult to eliminate. The principle emerged from carbon budget modeling in the early 2000s, where scientists demonstrated that cumulative CO_2 emissions directly determine global temperature rise. The IPCC's Special Report on 1.5°C (2018) affirmed this connection, concluding that limiting warming to 1.5°C would require global CO_2 emissions to reach Net-Zero by 2050.

Codified in the Paris Agreement (2015), the Net-Zero principle now serves as a key benchmark for global climate ambition. It not only offers a measurable standard for accountability but also supports principles of climate justicerecognizing the responsibility of developed countries to lead emissions reductions while supporting developing nations with finance and technology (Morgan, 2024). The principle aligns with the broader concept of planetary boundaries, ensuring human activity stays within safe ecological limits. In the built environment, it informs strategies such as whole-life carbon assessments, energy efficiency, and renewable integration.

Global Environmental Change and the Built Environment

Global environmental change (GEC) refers to the large-scale shifts occurring in Earth's biophysical systems due to human activities, including climate change, biodiversity loss, and resource depletion. The built environment, which encompasses buildings, infrastructure, and construction, has long been a key contributor. According to UNEP (2023), the buildings and construction sector accounts for nearly 40% of global energy-related CO_2 emissions.

Traditional construction practices rely heavily on carbon-intensive materials like concrete and steel, and poor zoning or urban sprawl leads to deforestation, biodiversity loss, and waste generation. Cities also suffer from the urban heat island effect, driving up cooling demand and energy use.

In response, the Net-Zero Built Environment (NZBE) concept has emerged. NZBE refers to infrastructure and buildings designed or retrofitted to achieve lifecycle Net-Zero GHG emissions. This includes embodied carbon (materials and construction) and operational carbon (use and maintenance). Whole-life carbon assessments, renewable energy integration, and passive design strategies are central to this approach. Circular construction, which emphasizes reuse, modularity, and material efficiency, also supports this transition.

Global frameworks now clearly link the built environment to climate goals. The Paris Agreement (2015) emphasizes infrastructure decarbonization. COP28 introduced the Buildings Breakthrough Initiative, calling for near-zero emission buildings to become standard by 2030. Bodies like the GlobalABC and the IEA have published sectoral roadmaps, with the latter proposing $4 trillion/year in clean energy investments by 2030 (IEA, 2021). Together, these developments show a shift in seeing the built environment not as a climate burden, but as a platform for regeneration and inclusive development, most especially in rapidly urbanizing regions like Nigeria.

Cumulative Carbon Concept and NZBE

The cumulative carbon concept underpins the urgency of Net-Zero transitions. Unlike the annual emissions, cumulative carbon tracks the total historical CO_2 output, and it's this long-term accumulation that drives the temperature rise. IPCC findings confirm a direct link between cumulative CO_2 and global warming, which makes early, aggressive emissions reductions essential (Henderson Engineers, 2021).

In the built environment, emissions accumulate through material sourcing, energy use, and demolition waste. NZBE approaches tackle this by targeting all phases of a building's life: using low-carbon materials, integrating renewable systems, and prioritizing carbon-conscious design from the start. Lifecycle carbon assessments allow for early-stage decision-making that slows the accumulation curve and supports long-term climate targets (UKGBC, 2023; IEA, 2021).

IPCC Reports and the NZBE Agenda

Consecutive IPCC reports have added to global understanding of the built environment's role in climate mitigation. AR5 (2014) highlighted the sector's lock-in risks and potential for mitigation. Also, SR1.5 (2018) positioned Net-Zero CO_2 by 2050 as essential for 1.5°C, pushing for shifts in materials, energy systems, and urban planning.

AR6 (2022–23) brought the built environment into sharper focus, estimating its 2019 emissions at 12 $GtCO_2$-eq (21% of global total). It introduced the SER framework (Sufficiency–Efficiency–Renewables) and stressed lifecycle emissions and behavioral strategies. The AR6 Synthesis Report (2023) further projected that building interventions could cut emissions by up to 66% by 2050. These reports all reinforce the idea that NZBE is not a "nice-to-have," but a frontline climate solution, most especially in high-growth, vulnerable regions like Nigeria.

International Climate Policy and the Paris Agreement

The Paris Agreement (2015) marked a turning point by formally embedding Net-Zero into international climate law. It committed countries to limiting warming "well below 2°C," ideally 1.5°C, and balancing emissions with removals by 2050. The built environment, as a high-emissions sector, was brought into the spotlight through sectoral pledges like the Buildings Breakthrough (COP28), which aims for net-zero emission buildings to become the global norm by 2030 (UNEP, 2023).

Countries are expected to implement their commitments through NDCs (short-term) and LT-LEDS (long-term), but it's been challenging to effect, most especially in the Global South. Challenges include access to climate finance, technology transfer, and data systems. The World Green Building Council (2023) has proposed global building policy principles that align with Paris targets, focusing on whole-life carbon, resilience, and justice.

Widespread Adoption and Institutionalization of Net-Zero

The Net-Zero principle has now moved from the margins into mainstream climate governance. Over 120 countries, thousands of cities, and major corporations have adopted Net-Zero targets (IEA, 2021). More than 30 countries have passed Net-Zero laws, while platforms like the Race to Zero and Net Zero Investment Framework (NZIF) guide cities and investors toward climate-aligned planning (IIGCC, 2024).

In the built environment, this has translated into performance-based codes, carbon assessments, and renewable integration. But challenges remain. Many Net-Zero plans still rely heavily on offsets rather than actual reductions. The Oxford Principles for Net-Zero Aligned Offsetting (2024) call for more robust, verifiable approaches that prioritize emissions cuts over removals. The Net Zero Initiative (2022) further recommends that dynamic, transparent strategies should be in systemic transformation, not just metrics.

For Nigeria and other developing nations, aligning with the global Net-Zero momentum means going beyond undertakings, vows, or promises. It calls for localized implementation, capacity-building, and inclusive transitions that account for informal housing, infrastructure gaps, and energy access constraints.

In this section, we discovered the evolution of the Net-Zero principle, from its scientific foundations to its political institutionalization, and connected it to the built environment. With global frameworks, IPCC reports, and sectoral innovations aligning under the Net-Zero banner, the path forward is clear. The challenge lies in adapting these goals for Nigerian cities like Lagos, Abuja, or Kano, where the infrastructure is still emerging and climate risks are rapidly intensifying. In this case, NZBE is not just a climate target but a development need.

Designing a Net-Zero Building

This section focuses on understanding what makes up a Net-Zero building, the key principles behind its design, and how these ideas are being applied across different contexts, including in Africa. A Net-Zero building is not just about reducing energy use; it's about making

intentional design choices that balance energy demand with supply, while also keeping carbon emissions to a minimum throughout the building's entire life.

One important distinction is between Net-Zero Energy Buildings (NZEBs) and Net-Zero Carbon Buildings (NZCBs). NZEBs generate as much energy as they consume, often using on-site renewables like solar panels. NZCBs go further by dealing with emissions from both the materials used and the operation of the building. According to the World Green Building Council (n.d.), a true NZCB must be highly energy-efficient, powered by renewables (on- or off-site), and offset any remaining emissions through credible removal methods. The Royal Institution of Chartered Surveyors (RICS, 2023) also points out that we must account for both operational emissions (heating, cooling, lighting) and embodied emissions (materials, construction, transport, etc.) because the carbon we lock into a building during construction stays with it.

The IPCC's Sufficiency–Efficiency–Renewables (SER) framework offers a practical way to guide Net-Zero building design. Sufficiency means reducing demand by avoiding oversized or wasteful buildings. Efficiency focuses on technologies like proper insulation, energy-efficient appliances, and smart HVAC systems. Renewables bring in clean energy through solar, wind, or geothermal systems. Together, these principles can help reduce energy use and improve indoor comfort, especially when combined with passive cooling strategies like cross-ventilation, shading, and natural lighting (Gil-Ozoudeh et al., 2022; Jain, 2024). Studies have also shown that compact layouts, bio-climatic orientation, and day-lighting techniques (like clerestory windows and reflective surfaces) help reduce dependence on artificial lighting and improve user experience (Wodi & Ohochukwu, 2024).

Another key idea in Net-Zero design is called Whole-Life Carbon (WLC). This approach considers both what happens during a building's use and before it's even used, like the carbon involved in making cement, transporting bricks, and assembling the structure. Embodied carbon is especially important in new buildings where early design decisions make a huge difference. This is why more designers now explore low-carbon materials like timber, earth blocks, recycled steel, and even hempcrete (Desapex, 2025). Lifecycle tools like EN 15978, ISO 14040, and the RICS Whole Life Carbon Standard help track emissions across the full building process (IEA Annex 89, 2024).

In recent years, digital tools have also played a growing role in Net-Zero building design. Building Information Modeling (BIM) helps architects and engineers work together, test energy performance, and make smarter decisions from the start. Some projects even use digital twins, which means a virtual copy of the building that tracks energy use, indoor temperature, air quality, and more (Yitmen *et al.,* 2024). This helps facility managers adjust things in real-time. In parts of Africa, where resources are limited, hybrid systems that combine offline sensors and local materials are helping make smart buildings more affordable (Nwachukwu et al., 2022).

For African countries like Nigeria, designing Net-Zero buildings isn't just about following global standards; it's also about finding local solutions that work in hot, humid, and low-resource environments. Researchers and architects are now exploring indigenous strategies

such as natural ventilation, courtyard layouts, mud walls, and passive cooling through earth construction (Ganjimorad *et al.,* 2024). Compressed earth blocks, interlocking bricks, and bamboo-reinforced panels offer low-cost and low-carbon alternatives. Off-grid solar systems, biogas digesters, and hybrid microgrids are also helping buildings stay functional even when the power supply is unreliable (UN-Habitat, 2022). However, these solutions only work when building regulations are flexible, subsidies are available, and communities are actively involved in the planning process.

Despite the growing knowledge and tools, there are still real challenges. The cost of building Net-Zero structures is higher upfront, especially when you need to import materials or technology (Mahmoodi et al., 2024). Building codes in many countries are also outdated, and skills gaps in areas like climate design and carbon accounting are still common (CITB, 2021). Even when people want to build better, the supply chain for low-carbon materials is not yet strong in many African countries (Azhgaliyeva & Rahut, 2022). Overcoming these problems will require strong policy support, access to green finance, technical training, and better coordination across professionals.

Still, real examples show it is quite possible and achievable. In South Africa, the Fuchs Lubricants Headquarters and the Richmond Business Park have achieved Net-Zero or Net-Positive energy goals using solar panels, passive cooling, and green materials (Kalumba et al., 2025). In Kenya, UN-Habitat is building affordable Net-Zero homes using earth blocks and bioclimatic design (UN-Habitat, 2022). The Bullitt Center in the U.S. proves that even high-performance Net-Zero buildings can use rainwater harvesting, solar power, and composting toilets to meet climate goals (Ong'ondo, 2024).

Technological Solutions and Innovation

In recent years, technology has become a driving force behind efforts to achieve a Net-Zero Built Environment (NZBE). Whether in high-tech smart cities or low-resource urban areas, innovative tools and materials are helping architects, engineers, and planners reduce carbon emissions, improve building performance, and adapt to climate realities. This section shows key technological solutions, ranging from digital systems to low-carbon materials that are enabling the shift to net-zero in both developed and developing contexts, especially in Africa.

One of the most important digital tools in Net-Zero building design today is Building Information Modeling (BIM). BIM helps project teams simulate energy usage and emissions at the early design stage, so they can make better choices about materials and layout before construction even begins (Mansour et al., 2023). Beyond BIM, Digital Twin technology, which shows virtual copies of physical buildings, makes it possible to monitor how buildings behave in real time, track energy consumption, and adjust building systems dynamically to improve efficiency. These models are powered by the Internet of Things (IoT) and Artificial Intelligence (AI), which collect and analyze data on lighting, temperature, ventilation, and occupancy (Alnaser et al., 2024; Bibri et al., 2024). As cities get smarter, digital twins are even being used at the neighborhood scale to predict future energy demand and inform climate-resilient planning (Yevu et al., 2025).

Materials also play a big role. Traditionally, buildings rely on a high level of embodied carbon from concrete and steel. However, new materials like hempcrete, biochar concrete, vacuum-insulated panels, and dynamic glazing offer better thermal performance with fewer emissions (Tiwari, 2024; Siegner & Searcy, 2021). These materials are not just for fancy projects abroad. In many African countries, local alternatives like compressed earth blocks, interlocking bricks, and even bamboo-reinforced panels are proving effective for both affordability and sustainability (Oyedele et al., 2024; Oluwatosin et al., 2023).

Access to energy remains a challenge across much of sub-Saharan Africa, but it also opens doors for off-grid Net-Zero solutions. Solar microgrids, biogas digesters, and hybrid solar-wind systems are helping buildings operate independently of unreliable national grids (UN-Habitat, 2022). These systems are especially useful in rural areas or informal urban settlements were connecting to formal infrastructure may not be feasible. If combined with passive design, like natural ventilation, shading, and orientation, these technologies reduce operational energy use and support energy (SDG 7) goals.

A study by Bathich et al. (2025) reminds us that tech alone isn't enough. Their research emphasizes the importance of equity in digital transitions. As digital twins and smart systems grow, there's a risk they benefit only well-connected or wealthier users. That's why inclusive planning, capacity building, and accessible technology must go hand-in-hand with innovation. The same concern was reflected in Haliru's (2024) study in Abuja, Nigeria. The study used a digital twin to monitor thermal performance in a residential duplex, and found high indoor temperatures and poor daylighting. This reveals the need for climate-responsive design and training for local architects.

Regulations and policy tools are also catching up with technological advancement. Yoon & Arshid (2025) developed a framework for using digital tools like RFID, blockchain, and IoT to enforce carbon regulations in the built environment. These systems can help track emissions more transparently and support governments in meeting Net-Zero targets. Likewise, Rocco (2023) explored how digital twins linked with blockchain can track the environmental performance of bio-based materials across the construction supply chain, which in turn provides real-time data for both maintenance and climate reporting.

African countries are beginning to test their own models. In Ghana, Ohene (2024) proposed a national implementation strategy for Net-Zero Carbon Buildings (NZCBs), with practical guidelines for retrofitting existing structures and designing new ones using passive measures and PV systems. The study shows that even with limited data or infrastructure, progress is possible if financial incentives, education, and stakeholder engagement are prioritized. In Europe, Mancini (2025) demonstrated how energy simulations and climate-resilient strategies like cool roofs and ventilative cooling can prepare buildings for rising temperatures over the next 50 years. These insights are highly relevant for tropical regions like Nigeria, where climate extremes are already visible.

Ultimately, achieving a Net-Zero Built Environment is not about choosing between digital and traditional approaches; it is about combining them wisely. Whether through cutting-edge simulations or indigenous design knowledge, every innovation should move us closer to

buildings that are low-carbon, energy-efficient, and adaptable to changing climates. More importantly, the solutions must be inclusive and practical for the people who need them most. As technology continues to evolve, Africa must be positioned not just as a user, but as a producer of climate-smart building solutions.

Despite their potential, the adoption of digital technologies and low-carbon innovations remains challenging in many developing countries. Technologies such as BIM, Digital Twins, AI, and IoT systems often require significant financial investment, making them less accessible to smaller developers and low-income communities (Filippova et al., 2025; Oyedele et al., 2024). Their successful implementation also depends on skilled professionals, reliable electricity supply, internet connectivity, and long-term maintenance systems, which remain limited in many parts of sub-Saharan Africa (UN-Habitat, 2022; Haliru, 2024). These challenges suggest that technological innovation alone cannot deliver a Net-Zero Built Environment. Greater investment in technical training, digital infrastructure, and affordable financing mechanisms will be necessary to support wider adoption and ensure that the benefits of these technologies are accessible across different urban contexts.

African Context and Nigerian Realities

Africa's pursuit of a Net-Zero Built Environment (NZBE) comes with both real opportunities and major hurdles. In countries like Nigeria, where infrastructure needs are high and urbanization is happening fast, the transition to low-carbon building systems is not just about meeting global climate targets; it's about improving the quality of life, reducing energy poverty, and building climate resilience from the ground up. This section explores how the NZBE agenda is unfolding in the African context, with a spotlight on Nigeria's policy commitments, institutional gaps, and emerging pathways.

Nigeria officially committed to achieving net-zero emissions by 2060, as outlined in the Climate Change Act (2021) and further reinforced in the Energy Transition Plan (2022) (Federal Republic of Nigeria, 2021). These documents provide a broad policy direction, signaling national intent to decarbonize across energy, transport, and building sectors. However, there remains a wide gap between these ambitions and what is happening on the ground. Regulatory enforcement is weak, building codes are outdated or poorly implemented, and awareness among developers, especially in informal construction, is low (CPI, 2023; Waniko, 2023).

A major obstacle lies in Nigeria's housing deficit, estimated at over 17 million units. Most of this demand is being met informally, through unregulated and resource-intensive construction practices. Local authorities often lack the manpower and expertise to enforce energy standards or monitor emissions. This means that despite national-level policy advances, much of the building sector still operates in ways that contradict Net-Zero goals. Furthermore, access to green finance remains limited, particularly for smaller developers and rural communities. Yet, Nigeria holds promise in some areas, as it has one of the most active green bond markets in Sub-Saharan Africa and is seeing growing uptake of EDGE certification in green building (New Telegraph, 2025).

To move forward, it's clear that Nigeria needs a multi-level strategy. This includes better enforcement at the state and local levels, vocational training for artisans and contractors, and design solutions that reflect Nigeria's diverse climate zones, from the humid south to the arid north. Instead of importing expensive technologies, more effort should go into developing and scaling climate-responsive, low-cost materials such as earth blocks and bamboo panels, alongside passive design methods that reduce energy demand without raising costs.

Mohammed et al. (2023) studied Cameroon, Senegal, and Côte d'Ivoire, proposing a step-by-step roadmap for transitioning to Net-Zero Energy Buildings. Their strategy includes baseline assessments, capacity building, stakeholder engagement, financing mechanisms, and strong monitoring frameworks. Their model provides a useful reference for Nigerian policy and practice.

In a broader regional view, Ouattara (2025) makes a compelling case for African cities to take advantage of their 'latecomer' status. Unlike developed countries tied to legacy infrastructure, African cities can leapfrog directly into decentralized renewables, green transport, and Net-Zero buildings. His study emphasizes aligning planning, energy, construction, and waste systems under coherent policy frameworks supported by inclusive governance and innovative finance tools like green bonds and public-private partnerships.

Meanwhile, Ikuabe et al. (2021) identified barriers to zero-carbon buildings in South Africa, which resonate strongly in Nigeria. These include a lack of awareness, weak policy enforcement, and resistance from occupants and professionals due to cost and limited understanding. The authors suggest that clear guidelines, public education, and professional training are key to addressing these gaps.

Oguntona and Akinradewo (2025) investigated the use of Metaverse technologies in South Africa's construction sector for simulating Net-Zero designs. While the technology is promising, adoption is still low due to issues like poor infrastructure, digital literacy gaps, and cost. This shows that technology must be matched with capacity development and localized adaptation if it is to be useful in African contexts.

In summary, while the challenges are many, so are the opportunities to embed sustainability into rapidly growing cities and buildings. The key is not just to import solutions, but to localize them, by building technical skills, improving access to finance, and designing with climate and community in mind. Net-Zero is not a luxury for Nigeria; it's a necessity. But getting there will require a shift in both mindset and method that bridges policy ambition with practical action, from national offices to neighborhood blocks.

Urban Planning and Infrastructure

Urban planning plays a central role in shaping the pathways toward a Net-Zero Built Environment (NZBE). It is through deliberate choices in land use, mobility, energy systems, and infrastructure that emissions can be reduced, resilience strengthened, and inclusivity fostered. In African cities like Lagos, Uyo, or Abuja, urbanization is rapid, infrastructure is stretched, and environmental pressures are high; reimagining urban systems through a Net-Zero lens is both necessary and urgent. This section explores key planning strategies,

infrastructure shifts, and digital transitions that align with the NZBE goal, while grounding insights in the Nigerian context.

Compact Urban Form and Land Use Planning

One of the most effective ways to reduce emissions in cities is to plan for density, mixed land use, and compact growth. Compact cities reduce travel distances, lower transportation emissions, and make public transit more viable. Dehghani et al. (2022) and ESCAP (2024) emphasize that dense urban form, combined with walkability and transit-oriented development (TOD), significantly reduces reliance on cars. TOD strategies cluster housing, workplaces, and services around transit hubs, making them especially relevant in sprawling cities like Lagos or Port Harcourt.

Okesoto et al. (2022) conducted a case study on Lagos' Mushin district, showing that retrofitting compactness into existing urban fabrics can optimize land use and reduce urban sprawl. Alongside density, green space preservation is crucial. Biswas et al. (2025) note that integrated parks, wetlands, and green corridors not only serve as carbon sinks but also support biodiversity and urban cooling.

Sustainable Infrastructure Design

Modern infrastructure under an NZBE framework must respond to climate risks, reduce embodied carbon, and promote ecological balance. Murali et al. (2025) advocate for modular and climate-adaptive buildings, which can be scaled, reused, and easily modified. Nature-based infrastructure, like bioswales, green roofs, and permeable pavements, is increasingly seen as a cost-effective solution to urban flooding and heat islands. For instance, Şen & Şat (2024) report that bioswales in Istanbul reduced surface runoff by 25%, highlighting their role in managing stormwater and improving urban resilience.

In Nigeria, Unah (2021) examined how Abuja's rapid urban growth has overwhelmed basic infrastructure, resulting in spatial imbalance and poor adherence. His findings show the need for better enforcement of planning regulations and design standards that support resilient growth patterns.

Public Transport and Low-Emission Mobility

Transport is one of the largest urban emission sources and a major equity issue. Net-Zero urban systems prioritize low-emission mobility options such as bus rapid transit (BRT), light rail, cycling, and walking. SEforALL (2024) highlights Nigeria's electric bus (e-bus) pilot in Lagos as a significant step in reducing fossil fuel use and aligning with the Energy Transition Plan. Akpan & Essien (2025) studied Uyo's urban transport patterns and found that accessibility, infrastructure quality, and commuter preferences significantly shape public transport usage. Their research recommends aligning infrastructure with commuter behavior, improving road connectivity, and expanding clean transport options.

Buhari et al. (2020) similarly argue that while Lagos is investing in public transport systems, policies must go further by enforcing non-motorized transport policies, expanding inland water and rail transport, and creating high-capacity multimodal systems to ease congestion.

Energy-Optimized Urban Layouts

Urban infrastructure must also address the energy transition. Cities can be designed to harvest and distribute renewable energy efficiently through solar rooftops, microgrids, and geothermal systems. Urban utilities such as lighting, water pumps, and waste systems can be optimized for energy efficiency using smart meters, motion sensors, and automated controls.

In the longer term, waste-to-energy solutions could also contribute. A unique example is from Atang (2024), whose thesis explores hydrogen production from urine in Nigerian cities; a decentralized approach that recycles waste into clean fuel, aligning with circular economy goals.

While compact urban development offers important opportunities for reducing emissions, implementation in many Nigerian cities is often constrained by land governance challenges, housing affordability concerns, and the rapid growth of informal settlements. A large proportion of urban residents live in areas that lack formal planning approval and access to basic infrastructure, making the implementation of low-carbon planning strategies more difficult. In addition, weak institutional capacity, limited enforcement of planning regulations, and complex land administration processes continue to affect sustainable urban development efforts. Addressing these issues will be essential if Net-Zero planning strategies are to achieve meaningful impact at scale.

Smart Cities and Digital Integration

Digital technologies are increasingly embedded in urban planning for NZBE. Tools like AI, IoT sensors, and GIS platforms help track emissions, optimize traffic, and monitor building performance. According to Bibri et al. (2023), digital integration enables cities to reduce operational inefficiencies and improve resource allocation.

Ojadi et al. (2024) discuss Abuja's smart city pilot, which applies AI to regulate traffic flow, enhance public service delivery, and optimize energy use in buildings. However, digital adoption must go hand-in-hand with local capacity building. Zakka et al. (2025) examined smart city projects in southwest Nigeria and found that factors like smart mobility, smart economy, and environmental digital literacy most strongly influenced environmental sustainability outcomes.

Still, digital planning tools are only as good as the data and systems they work with. Planners must ensure that smart city transitions are inclusive, data-secure, and responsive to informal urban realities.

Policies, Regulations, and Incentives

Achieving a Net-Zero Built Environment (NZBE) in Nigeria depends not only on technological innovation and good design but also on strong policy support, effective

regulations, and strategic financial incentives. While Nigeria currently lacks a unified national policy on Net-Zero buildings, a patchwork of climate-related frameworks is slowly converging toward this vision. This section examines the major policy instruments, regulatory frameworks, and financial mechanisms shaping the transition to NZBE in Nigeria, while highlighting implementation challenges and opportunities.

At the national level, the Climate Change Act (2021) sets a legal foundation for achieving Net-Zero emissions by 2060. It mandates carbon budgeting, climate action planning, and the establishment of a National Council on Climate Change, which now oversees the country's climate governance architecture (Federal Republic of Nigeria, 2021). This legal framework is complemented by the Energy Transition Plan (ETP), launched in 2022, which offers a sector-specific roadmap for decarbonizing Nigeria's energy, transport, and infrastructure sectors (Federal Government of Nigeria, 2022).

Specific to the built environment, the National Building Energy Efficiency Code (BEEC), introduced in 2017, outlines minimum energy performance standards for new buildings. Although enforcement is still limited, the Federal Ministry of Environment has been working to strengthen this code by developing energy labeling systems and embodied carbon guidelines (Climate Policy Initiative, 2023). Alongside this, the National Climate Change Policy (2021–2030) calls for the retrofitting of existing buildings and integrating climate resilience into housing and land-use planning (NESREA, 2024).

The National Renewable Energy and Energy Efficiency Policy (NREEEP) (2015) also plays a crucial role, aiming for a 30% renewable energy share by 2030. This target creates a strong case for rooftop solar systems, clean cooking solutions, and building-integrated renewables across urban and peri-urban areas (Federal Ministry of Power, 2015).

To support implementation, Nigeria has introduced several incentive-based tools. Most notable is its Green Bond Program, launched in 2017, which remains one of the most active in Sub-Saharan Africa. Proceeds have supported solar street lighting, energy-efficient public buildings, and afforestation projects (Federal Ministry of Environment, 2017; Debt Management Office, 2017). Additionally, new air quality control regulations restrict the import of high-emission generators and construction materials, indirectly nudging the market toward cleaner alternatives (Climate Policy Initiative, 2023).

Plans are also underway for a national carbon pricing mechanism, which would apply levies to carbon-intensive activities. The mechanism can serve as a potentially powerful tool if designed with transparency and equity (Highlaw Chambers, 2025). Donor-funded grants and technical assistance have also supported small-scale Net-Zero pilot projects, but access remains limited and uneven across regions (Cities Climate Finance Leadership Alliance, 2023).

Despite these positive actions, several obstacles remain. Fragmented governance continues to slow progress, particularly at the state and local levels, where enforcement of building codes and energy standards is weak or non-existent (Climate Policy Initiative, 2023). Market readiness is also low, with limited access to low-carbon materials, skilled labor, and affordable finance deterring private developers (NESREA, 2024). Furthermore, political and institutional

barriers, such as low stakeholder awareness, overlapping mandates, and outdated codes, continue to frustrate efforts to mainstream NZBE principles.

Table 1 presents a concise mapping of major climate instruments, their alignment with national climate goals, and their relevance to Net-Zero building implementation.

Table 1: Summary of Key Nigerian Climate Policies and Their NZBE Alignment

Instrument	Proposed By	Year Proposed	Alignment with Climate Goals	Correlation with NZBE	Citations
Climate Change Act	Federal Ministry of Environment, signed by President Buhari	2021	Establishes legal framework for net-zero by 2060	Creates National Council on Climate Change, mandates carbon budgeting	(Federal Republic of Nigeria, 2021)
Energy Transition Plan (ETP)	Office of the VP, supported by SEforALL & GEAPP	2022	Sectoral roadmap for decarbonization across five sectors	Directly supports NZBE via clean energy targets and infrastructure reform	(Federal Government of Nigeria, 2022)
National Climate Change Policy (NCCP)	Federal Ministry of Environment	2021	Strategic vision for climate resilience and low-carbon growth	Integrates climate into development plans, supports NZBE priorities	(Federal Ministry of Environment, 2021)
National Renewable Energy & Energy Efficiency Policy (NREEEP)	Federal Ministry of Power	2015	Sets a 30% clean energy target by 2030	Facilitates building-integrated solar and energy access	(Federal Ministry of Power, 2015)
National Building Energy Efficiency Code (BEEC)	Federal Ministry of Power, Works & Housing	2017	Minimum performance standards for buildings	Reduces building-related emissions and operational energy demand	(Federal Ministry of Power, Works & Housing, 2017)
Green Bonds Program	Ministry of Environment, DMO, Ministry of Finance	2017 (Series 1), 2019, 2025	Finances low-carbon infrastructure and clean energy	Funds solar lighting, afforestation, efficient buildings	(Debt Management Office, 2017; Federal Ministry of Environment, 2017)
Environmental Impact Assessment Act	Federal Military Government	1992	Requires environmental screening for infrastructure	Prevents high-emission projects, encourages sustainable land use	(Federal Military Government, 1992)

Source: Author's Compilation, 2026

While Nigeria has developed several policy instruments that support climate action and low-carbon development, implementation challenges continue to affect their contribution to achieving a Net-Zero Built Environment. Existing policies provide important legal, regulatory, and financial support for climate action; however, differences in enforcement, financing, institutional capacity, and stakeholder engagement have influenced their effectiveness. Table

2 presents a critical assessment of major policy instruments and their implications for NZBE implementation in Nigeria.

Table 2: Critical Assessment of Key Nigerian Climate Policies Relevant to NZBE
Source: Author's Compilation, 2026

Policy Instrument	Key Strengths	Major Implementation Challenges	Implications for NZBE
Climate Change Act (2021)	Provides a legal framework for achieving net-zero emissions and strengthens national climate governance	Limited funding, weak institutional capacity, and poor coordination across government levels	Creates a strong foundation for NZBE but requires stronger implementation mechanisms
Energy Transition Plan (2022)	Provides a roadmap for decarbonizing energy, transport, and infrastructure sectors	High financing requirements and implementation uncertainties	Supports renewable energy integration and low-carbon infrastructure development
National Building Energy Efficiency Code (BEEC) (2017)	Establishes minimum energy performance standards for buildings	Weak enforcement, limited compliance monitoring, and low industry awareness	Has potential to reduce building-related emissions if enforcement improves
National Renewable Energy and Energy Efficiency Policy (NREEEP) (2015)	Promotes renewable energy adoption and energy efficiency measures	High technology costs and limited access to finance	Supports building-integrated renewable energy systems and cleaner energy use
Green Bond Programme	Mobilizes funding for climate and low-carbon projects	Available funding remains small compared to national infrastructure needs	Provides financing opportunities for selected NZBE projects but requires scaling up
Environmental Impact Assessment Act (1992)	Encourages environmental screening of infrastructure and development projects	Inconsistent enforcement and compliance monitoring	Supports sustainable land use and environmentally responsible development

A common challenge across these policy instruments is the gap between policy development and implementation. As shown in Table 2, weak enforcement, financing constraints, fragmented institutional responsibilities, and limited technical capacity continue to affect the effectiveness of several climate-related policies and programmes. Addressing these challenges will be essential if existing policy frameworks are to deliver meaningful emission reductions and support the transition to a Net-Zero Built Environment.

In summary, Nigeria's policy environment is gradually maturing to support the Net-Zero transition, but stronger coordination, localized enforcement, and more inclusive financing mechanisms are urgently needed. Integrating these instruments into a unified, enforceable NZBE roadmap, backed by capacity building and stakeholder awareness, will be essential if Nigeria is to meet its 2060 net-zero pledge while addressing pressing housing and development needs.

Notable Challenges associated with the NZBE-related SDGs in Nigeria:

Despite growing momentum toward climate action, Nigeria's pathway to achieving a Net-Zero Built Environment (NZBE) remains riddled with structural, financial, and institutional challenges. These barriers not only slow progress but also create ripple effects across key Sustainable Development Goals (SDGs), especially SDG 7 (Clean Energy), SDG 9 (Industry & Infrastructure), SDG 11 (Sustainable Cities), and SDG 13 (Climate Action).

A major problem is the absence of an enforceable national green building framework. While documents like the Building Energy Efficiency Guidelines (BEEG) were introduced in 2016 to improve building performance, their actual uptake across public and private projects remains very low (Muazu & Gambo, 2023). Without a unified strategy or clear regulatory enforcement, construction continues to rely heavily on energy-inefficient designs and carbon-intensive materials.

The pressure of rapid urbanization worsens the situation. Nigeria's major cities, from Lagos to Abuja, are expanding fast, often without proper climate-smart planning or infrastructure to support that growth. This has left the country with a housing deficit of over 20 million units, and most new buildings are not energy efficient or climate-resilient (Muazu & Gambo, 2023). Add to this the poor state of waste management and energy access, and it becomes clear why cities are struggling to align with SDG 11 and SDG 12 on sustainable consumption and urban health.

On the financial side, budgetary constraints limit action. The federal government currently finances only about 25% of its infrastructure needs, leaving a significant gap that private developers are often unwilling or unable to fill, especially for green building projects (Idahosa, 2025). Similarly, most builders lack access to climate finance or incentives to transition toward low-carbon alternatives.

Another major issue is the skills gap in the construction sector. While green technologies like passive design and solar integration are gaining attention, very few vocational training centres offer specialized programs on these tools. As a result, many projects fall back on conventional techniques, even when sustainable alternatives are available (Carbon Literacy Project, 2024).

Many Nigerians, especially young people and residents in informal settlements, remain unaware of sustainable practices or how to demand better planning from decision-makers (Connected Development et al., 2025). This limits community buy-in and reduces the pressure needed to make climate-smart policies mainstream.

Governance remains a critical bottleneck. There is poor coordination between federal ministries and subnational agencies, leading to fragmented policy implementation and

inconsistent building code enforcement (Federal Ministry of Environment, 2021). Even though a few states have developed climate action plans, emissions tracking and reporting are still inconsistent, and most local governments lack the technical capacity to act independently. When compared to other developing countries, like Kenya and Indonesia, which have started integrating sustainability into urban planning, backed by stronger institutions and dedicated climate finance. Nigeria, on the other hand, grapples with a triple burden: economic instability, weak institutions, and recurring humanitarian crises like displacement due to insurgency (UNFCCC, 2021).

For SDG 7, which focuses on affordable and clean energy, the country continues to rely heavily on fossil fuels, with limited access to cleaner alternatives in both rural and peri-urban areas. This dependency slows down the decarbonization of buildings and perpetuates the widespread use of diesel generators, particularly in urban areas plagued by frequent power outages (Federal Government of Nigeria, 2022).

Under SDG 9, which addresses industry, innovation, and infrastructure, the challenges lie in poor infrastructure funding, outdated construction codes, rigid regulatory frameworks, and a weak culture of research and development. These constraints limit the adoption of green construction materials and advanced digital technologies such as Building Information Modeling (BIM) and digital twins. Currently, only about a quarter of Nigeria's infrastructure needs are met through public investment (Idahosa, 2025), leaving a significant gap in innovation.

Concerning SDG 11, which aims to promote sustainable cities and communities, Nigeria's urban growth is often unplanned, resulting in sprawling cities dominated by informal settlements. These environments are especially vulnerable to heatwaves, flooding, and poor air quality. The country faces a housing deficit of over 20 million units, most of which are constructed without adherence to energy efficiency or resilience standards (Muazu & Gambo, 2023).

For SDG 13, focused on climate action, fragmented climate governance and weak data systems hinder progress. Few states in Nigeria have climate mitigation plans, and even fewer have systems in place for consistent emissions tracking (Federal Ministry of Environment, 2021). This undermines the country's ability to meet its Nationally Determined Contributions (NDCs) and 2060 Net-Zero targets.

SDG 10, which targets reduced inequalities, reveals another layer of complexity. Climate policy and planning often fail to consider the needs of marginalized populations, including women, youth, and internally displaced persons. Infrastructure developments sometimes result in forced displacements without proper compensation, further entrenching social and economic disparities (HumAngle, 2024).

Finally, SDG 4, centered on quality education, reveals a critical but often overlooked challenge: the lack of climate literacy and accredited training in green construction. Most Nigerian universities and technical institutions do not offer courses in energy modeling, sustainability, or climate-responsive building design, resulting in a workforce that is

underprepared to design, construct, or maintain Net-Zero buildings (Carbon Literacy Project, 2024).

These challenges are deeply interconnected. For instance, persistent energy poverty (SDG 7) not only delays climate action (SDG 13) but also exacerbates inequality (SDG 10). Likewise, inadequate investment in infrastructure (SDG 9) feeds into unplanned urban growth (SDG 11), and without foundational climate education (SDG 4), even the most well-intentioned policies may struggle to gain traction or achieve meaningful outcomes.

In summary, Nigeria's barriers to achieving a Net-Zero Built Environment are not just technical in nature; they span across social, institutional, and economic domains. Addressing them will require coordinated, multi-sectoral action rooted in education, equity, policy reform, technological investment, and inclusive planning. The next section examines how global case studies and best practices may provide transferable insights to help Nigeria advance its Net-Zero transition.

Case Studies and Global Best Practices of Net-Zero Built Environment

To understand how the Net-Zero Built Environment (NZBE) can be practically achieved, it is useful to examine real-world examples that demonstrate both innovation and feasibility. Case studies from diverse regions highlight different paths toward net-zero buildings: from advanced economies like the U.S. and Australia to emerging contexts like India and the UK. The selected case studies were chosen to represent different geographical regions, climatic conditions, policy environments, and implementation approaches to Net-Zero Built Environment development. Together, they provide examples of how technological innovation, policy support, sustainable design, and stakeholder engagement have been applied across different contexts. The cases were also selected based on the availability of documented outcomes and their potential relevance to emerging economies such as Nigeria.

Adlai E. Stevenson High School – Illinois, USA

Located in Lincolnshire, Illinois, the East Building Addition at Adlai E. Stevenson High School is the first verified net-zero energy school building in the state. Certified in 2021, the 56,800 sq. ft. facility uses solar panels, biophilic features, VRF systems, and passive daylighting to eliminate net energy demand. Notably, it operates at a net-positive energy balance, cutting $65,000 in electricity costs annually. Beyond performance, the building doubles as a sustainability education tool, aligning with SDGs 4, 7, 11, and 13 (Illinois Green Alliance, 2023; Bootes, 2024).

435 Indio Way – California, USA

This retrofitted office complex in Sunnyvale, California, proves that NZBE is not just for new builds. Originally constructed in the 1970s, the building was upgraded using electrochromic glazing, automated skylights, and passive cooling strategies. The 113.2 kW rooftop solar system allows it to generate more energy than it consumes, about 300,000 kWh annually. The

retrofit enhanced property value and tenant demand, highlighting NZBE's economic viability (NZEB India, 2024; HPB Magazine, 2016).

Jhansi Library – Uttar Pradesh, India

India's first net-zero public library in Jhansi offers a model for rapid, low-cost, and sustainable public infrastructure in developing countries. Completed in 90 days, the 12,000 sq. ft. structure uses radiant cooling, vertical wind turbines, rainwater harvesting, and solar PV. With an 85% reduction in carbon emissions, the project also integrates greywater recycling and local materials, making it relevant to both climate goals and community needs (Bootes, 2023; Times of India, 2024).

BedZED – London, UK

The Beddington Zero Energy Development (BedZED) is a pioneer in low-carbon urban living. This eco-village in South London includes 100 homes, offices, and community spaces powered by passive solar, biomass CHP systems, and green roofs. Since its completion in 2002, BedZED has cut energy use by 90% and water consumption by 50% compared to traditional developments. It also prioritizes local sourcing, active transport, and community engagement. These principles are highly transferable to sustainable city planning (Bioregional, 2023; UNEP, 2021).

Melbourne Net-Zero Homes – Australia

In Melbourne, a small cluster of residential homes achieved net-zero emissions by integrating passive design, solar PV, and modular construction. Each home exported more energy than it consumed, with a carbon payback of under 10 years. The project emphasizes lifecycle carbon calculations, right-sizing of battery storage, and affordability, making it a strong case study for cost-effective residential NZBE (Alam et al., 2024).

Table 3: Comparative Summary of International NZBE Case Studies
Source; Author's Compilation, 2026

Case Study	Country	Key Strategy	Reported Outcome	Policy/Institutional Support	Relevance to Nigeria
Adlai E. Stevenson High School	USA	Solar PV, passive daylighting, VRF systems, biophilic design	Net-positive energy performance and annual energy cost savings	State-level green building initiatives and sustainability standards	Demonstrates the role of energy-efficient educational buildings
435 Indio Way	USA	Deep retrofit, electrochromic glazing, passive cooling, rooftop solar	Generates more energy than it consumes annually	Supportive retrofit and energy-efficiency policies	Highlights the importance of retrofitting existing buildings
Jhansi Library	India	Solar PV, radiant cooling, rainwater harvesting, local materials	85% reduction in carbon emissions	Government support for sustainable public infrastructure	Demonstrates that NZBE is achievable in resource-constrained settings

Case Study	Country	Key Strategy	Reported Outcome	Policy/Institutional Support	Relevance to Nigeria
BedZED	United Kingdom	Passive solar design, biomass CHP, green roofs, active transport	90% reduction in energy use and 50% reduction in water consumption	Strong planning regulations and sustainability policies	Offers lessons for sustainable housing and community-scale development
Melbourne Net-Zero Homes	Australia	Passive design, solar PV, battery storage, modular construction	Net-zero residential performance with short carbon payback period	Building regulations and renewable energy incentives	Demonstrates cost-effective low-carbon housing solutions

The case studies reveal several common themes. First, successful NZBE projects combine energy-efficient design with renewable energy systems rather than relying on a single intervention. Second, supportive policies and institutional commitment play a critical role in project success. Third, both new construction and building retrofits can meaningfully contribute to emissions-reduction goals. These lessons suggest that Nigeria's transition to a Net-Zero Built Environment will require a combination of technological innovation, supportive governance, and context-specific design solutions.

Global Best Practices: Lessons from Around the World

Across the globe, successful NZBE strategies share a few core principles: lifecycle thinking, carbon accountability, and strong regulatory frameworks. Over 22 countries have now developed Whole Life Carbon (WLC) roadmaps to guide emission reductions across design, materials, operations, and end-of-life stages (WorldGBC, 2023). This shift reflects a broader move toward circular construction, where reuse and carbon transparency are prioritized.

Retrofitting is also a top priority. With over 80% of 2050's buildings already constructed, nations like the U.S. are investing in retrofits through initiatives like the Affordable Home Energy Shot, aimed at halving retrofit costs (DOE, 2023). Cities such as San Diego are piloting neighborhood-scale solar microgrids, showing how distributed energy systems can support resilience.

Material innovation is another key frontier. Technologies like geopolymer cement, hydrogen steel, and bio-based insulation are reducing embodied emissions by up to 80% (UNEP, 2022). Electrification of heating and cooling using heat pumps, paired with renewables, is further shrinking operational footprints (IEA, 2023).

Governance and policy support are essential. Performance-based codes, carbon caps, and Net-Zero Carbon Buildings Commitments now guide over 175 signatories globally, helping to enforce accountability through targets and disclosures (WorldGBC, 2023). Smart grids and building automation systems round out the picture, enabling real-time performance monitoring and energy optimization.

African Adaptations: Nairobi and Cape Town

In Africa, cities like Nairobi and Cape Town are localizing these global practices. Nairobi has begun embedding NZBE principles in urban development through pilot housing projects that feature passive cooling, solar PV, and greywater systems. Yet only 7% of stakeholders report fully integrating these practices due to limited awareness and funding (Njogu et al., 2025). The Kenya Green Building Society (KGBS) is responding with Whole Life Carbon roadmaps and electrification playbooks aimed at scaling adoption.

Cape Town, meanwhile, has committed to net-zero performance in all new buildings by 2030, backed by strict bylaws and a climate action strategy that prioritizes job creation, solar energy, and circular construction (City of Cape Town, 2021; C40 Cities, 2020). The ReBuilt Cape Town project and Net-Zero Future Alliance are actively promoting green infrastructure and academic-industry partnerships to mainstream regenerative design.

Key Lessons for Nigerian Built Environment: Like Indio Way and BedZED, Nigeria must focus not just on new construction but also on retrofitting informal and aging buildings. Also, Cape Town's strict bylaws show how strong governance drives real outcomes. Jhansi Library proves that Net-Zero is achievable in resource-limited settings, if designed smartly. From Nairobi's greywater systems to Melbourne's smart battery storage, these examples show that climate-smart design must be adapted to local economic, cultural, and climatic conditions.

Roadmap for Achieving a Net-Zero Built Environment in Nigeria

This section outlines a roadmap for achieving a Net-Zero Built Environment (NZBE) in Nigeria, based on the findings from reviewed literature in the earlier sections and supported by Nigeria's climate, socio-economic, and institutional realities. Rather than replicate high-income country blueprints, this roadmap prioritizes local adaptation, policy innovation, inclusive planning, and grassroots capacity building, all framed around four key Sustainable Development Goals: SDG 7 (Clean Energy), SDG 9 (Infrastructure & Innovation), SDG 11 (Sustainable Cities), and SDG 13 (Climate Action).

Policy Reform and Institutional Coordination

To move from intention to implementation, Nigeria must urgently develop a national Net-Zero Building Strategy backed by state-level and local frameworks. The strategy should not take a one-size-fits-all approach but rather reflect the country's climatic zones, enabling passive design standards tailored to Nigeria's ecological diversity. Building codes like the BEEC should be expanded to include whole-life carbon, and climate policies such as the Climate Change Act need stronger enforcement mandates, coordination across ministries, and budgetary clarity. State governments must also be empowered to localize these frameworks through planning reforms and regulatory tools.

Passive Design and Localized Building Solutions

Given Nigeria's tropical climate and urban informality, there is a need to promote passive cooling techniques, climate-responsive forms, and modular layouts that reduce energy use.

Design strategies like courtyard housing, natural ventilation, and shared green spaces are viable for both rural and urban settings. To reduce embodied carbon, compressed earth blocks, recycled concrete, bamboo panels, and other locally available materials should be prioritized, especially for informal settlement upgrades and low-cost housing. This calls for updating procurement policies and building registries to favor low-emission construction materials.

Technological Adaptation and Scalable Infrastructure

Nigeria's NZBE strategy must emphasize off-grid and hybrid technologies, particularly in energy-poor communities. Solar microgrids, biogas digesters for cooking, and rainwater harvesting systems can meet basic energy and water needs while supporting circularity. Smart city pilots in Lagos, Abuja, or Port Harcourt can demonstrate how Building Information Modeling (BIM) and digital twins can support emissions tracking and real-time energy optimization. Universities and private firms can co-develop open-source BIM tools for local markets, while retrofitting industries can be incentivized to create prefabricated panels and precast concrete systems to reduce site emissions.

Climate Literacy and Vocational Training

Technical capacity remains a critical gap. Universities should revise the curriculum to integrate climate adaptation, sustainable design, and green construction practices. At the same time, vocational centers should offer certifications in net-zero building, from solar installation to eco-brick production, targeting artisans, engineers, architects, and surveyors. A national apprenticeship program, with support from local governments and the private sector, could boost youth employment and provide the human capital needed for NZBE implementation.

Inclusive Community Engagement and Governance

The NZBE transition must be bottom-up and inclusive. Local governments should involve communities in co-creating neighborhood-level upgrades. For women and youth, this roadmap proposes cooperative solar enterprises and skills-for-green-work exchanges, respectively. For urban poor and slum residents, climate-resilient upgrading using earth blocks and green courtyards can reduce displacement and improve liveability. Engagement should also focus on trust-building, especially where infrastructure projects have historically excluded vulnerable groups.

Financing Mechanisms and Incentives

A shift towards green mortgages, climate-linked loans, and a Net-Zero Health Fund will help bridge the public-private financing gap. The existing green bond market should be expanded to support decentralized renewable energy and affordable housing retrofits. Fiscal incentives such as tax rebates for low-carbon materials and import waivers for smart energy tech can make adoption more attractive to developers. Local financial institutions should also be encouraged to bundle green products with microloans tailored to informal builders and artisans.

Alignment with the SDGs

This roadmap describes how the SDGs are aligned with the Net-Zero agenda:

- SDG 11 (Sustainable Cities) by promoting informal settlement upgrading and adaptive land use;
- SDG 13 (Climate Action) through carbon reduction strategies embedded in construction, energy, and urban planning;
- SDG 7 (Clean Energy) via decentralized renewables like solar and biogas;
- and SDG 9 (Industry, Innovation and Infrastructure) through retrofitting industries, low-carbon manufacturing, and digital infrastructure rollouts.

In summary, the path to Net-Zero in Nigeria will not be driven by imported templates, but by flexible, community-led, and climate-informed actions that reflect local knowledge and realities. The roadmap (Figure 2) offered here builds from the ground up, combining pragmatic design strategies, policy innovation, and inclusive governance. With sustained political will, technical investment, and citizen engagement, Nigeria can set a model for how developing nations can drive equitable climate transitions.

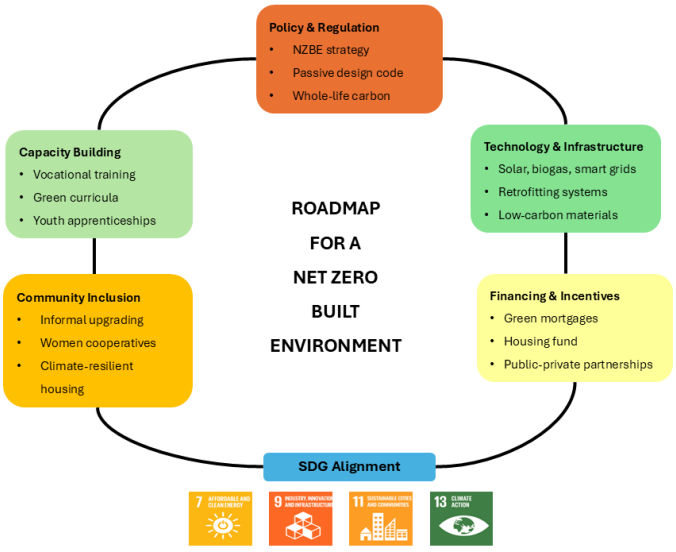


Figure 3: A proposed Roadmap for a Net-Zero Built Environment that aligns with the SDGs in Nigeria.

Source: Authors' Comceptualization, 2026

Conclusion

Achieving a Net-Zero Built Environment (NZBE) in Nigeria is not just about cutting emissions; it's about creating cities and communities that are inclusive, resilient, and sustainable. This review has shown that while Nigeria faces deep challenges, most especially weak enforcement, limited finance, and low technical capacity, there are clear opportunities to act.

By combining local solutions like passive design and compressed earth blocks with smart technologies, better policies, and community inclusion, Nigeria can align its built environment with key SDGs. A bottom-up approach is highly recommended, an approach that reflects Nigeria's climatic diversity and social realities.

The proposed roadmap offers a way forward: reform policies, empower local actors, invest in training, and scale adaptable technologies. With the right support, the built environment can shift from being a problem to a platform for climate action and sustainable development.

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