IJESDS Vol: 1(2): 460-470, 2026
https://doi.org/10.68086/FYBW5262

https://ijesds.org

International Journal of Environmental Sciences, Development & Sustainability
An official publication of the
Faculty of Environmental Sciences
Open Access | Peer-reviewed | International
ISSN (Online): 3156-4461

RESEARCH ARTICLE

Assessing the Integration of Green Infrastructure and Renewable Energy Systems for Sustainable Urban Development in Nigerian Cities

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ABSTRACT

Nigerian cities are expanding faster than the infrastructure systems that are meant to service them, and two of the most consequential deficits are the progressive erosion of urban green cover and the persistence of an unreliable, fossil-dependent electricity supply. These two deficits are conventionally treated as separate policy problems, handled by separate ministries and financed through separate budget lines. This paper argues that they are structurally coupled and should be planned together. Using a structured desk-based synthesis of peer-reviewed evidence published between 2016 and 2025, together with national policy instruments and energy transition datasets, the study assesses the extent to which green infrastructure and renewable energy systems are currently integrated in Nigerian urban development practice, identifies the mechanisms through which integration produces compound benefits, and diagnoses the institutional barriers that keep the two agendas apart. Evidence from Nigerian and comparable tropical contexts shows that vegetated surfaces measurably reduce ambient and surface temperature, that cooling load is a dominant and rising component of urban electricity demand, and that reductions in cooling demand improve the technical and financial performance of distributed solar systems. The analysis finds that integration in Nigeria remains largely rhetorical: national instruments acknowledge both agendas but assign them to institutions with no shared spatial plan, no shared performance indicators, and no shared budget envelope. The paper proposes an integration framework organised around four coupling points, namely thermal load reduction, stormwater and asset protection, land use co-location, and community-level co-governance, and sets out an implementation pathway that is realistic for the fiscal and administrative capacity of Nigerian states. The contribution is a diagnostic and planning framework rather than a new primary measurement, and the limitations of a synthesis-based design are stated explicitly.

Keywords: *Green infrastructure; Renewable energy; Urban planning; Sustainable development; Nigeria; Distributed solar; Urban heat*

1. INTRODUCTION

Nigeria is undergoing one of the most rapid urban transitions in the world, and the pace of that transition has consistently outrun the capacity of the institutions responsible for guiding it. Analyses of the country's urban trajectory have established that the transition is neither stalled nor anomalous, but is instead a sustained demographic and economic shift whose spatial consequences are visible in every major metropolitan area (Fox et al., 2018; Farrell, 2018). The result is a built environment that expands through incremental, largely unregulated conversion of vegetated and agricultural land into impervious surface, with the environmental and public health consequences that follow from that conversion (Aliyu & Amadu, 2017; Essien, 2023). Two deficits dominate the resulting urban condition. The first is the progressive loss of urban green cover. Reviews of urban greening in Nigeria have documented a body of practice that is fragmented, poorly resourced, and rarely embedded in statutory planning, with domestic gardens, street trees, public parks, and peri-urban woodland all under pressure from land conversion (Adegun et al., 2021). Empirical land cover studies confirm the direction and magnitude of the change. In Iwo, a mid-sized city in southwestern Nigeria, vegetation cover fell from 55.79 percent of the municipal area in 1982 to 13.94 percent in 2023, while built-up area more than tripled over the same period (Ogunbode et al., 2025). Comparable trajectories have been reported for Lagos State and for other West African urban systems (Onilude & Vaz, 2020; Herrmann et al., 2020). The second deficit is energy. Despite substantial generation capacity on paper, the delivered electricity supply available to Nigerian households and businesses remains unreliable, and the shortfall is met privately through small petrol and diesel generators whose aggregate emissions, noise, and local air quality effects are substantial. Policy assessments of the sector have identified underinvestment, infrastructural decay, weak cost recovery, and macroeconomic instability as the binding constraints, and have argued that a just transition requires a materially larger renewable share alongside reform of the distribution segment (Adeshina et al., 2024). National planning documents now target net zero by 2060 and acknowledge that universal access cannot be delivered through centralised generation alone (Federal Government of Nigeria, 2022; Sustainable Energy for All, 2024).

These two deficits are conventionally addressed by different institutions. Urban greening sits with state ministries of environment and physical planning; electricity sits with the federal power ministry, the regulator, the distribution companies, and, since the 2023 constitutional and legislative changes, with state-level electricity authorities. The separation is administratively convenient and analytically wrong. Vegetated surface reduces the thermal load that drives cooling demand, and cooling demand is the fastest-growing component of residential and commercial electricity consumption in tropical cities. Where cooling demand falls, the capacity, storage, and cost requirements of a distributed solar system fall with it. Where vegetation is lost and impervious surface expands, stormwater runoff increases and damages the ground-mounted and roof-mounted energy assets that a distributed system depends upon. The two systems are, in short, thermally, hydrologically, and spatially coupled.

This paper assesses the extent of integration between green infrastructure and renewable energy systems in Nigerian urban development, and asks three questions. First, what does the available evidence say about the magnitude and direction of the coupling between vegetated surface and urban energy performance in tropical contexts comparable to Nigeria? Second, to what degree do current Nigerian policy instruments and planning practices recognise and operationalise that coupling? Third, what institutional and financial arrangements would be required to move from parallel implementation to genuine integration, given the fiscal and administrative realities of Nigerian states?

The paper contributes a diagnostic framework rather than new primary measurement. Its value lies in bringing together two literatures that are rarely read against one another, in identifying the specific coupling points at which integration produces compound rather than additive benefits, and in setting out an implementation sequence that does not presuppose institutional capacity Nigerian states do not have. Section 2 reviews the evidence base. Section 3 sets out the method. Section 4 presents the assessment, discusses the findings and their limitations, and also draws out policy implications. Section 5 concludes.

2. LITERATURE REVIEW

Green infrastructure and urban environmental performance

Green infrastructure refers to the connected network of natural and semi-natural surfaces within and around an urban area, including street trees, parks, domestic gardens, green roofs, permeable surfaces, wetlands, and riparian corridors, that collectively deliver regulating and cultural ecosystem services. The comprehensive review by Ashinze et al. (2024) organises these services into environmental, social, and economic categories, and identifies temperature regulation, stormwater attenuation, air quality improvement, and biodiversity support as the functions with the strongest empirical support.

The cooling function is the most directly quantified. A synthesis of urban green space cooling effects across a large sample of cities established that vegetated patches consistently produce measurable reductions in both air and surface temperature relative to adjacent built surfaces, with the magnitude conditioned by patch size, configuration, and species composition (Aram et al., 2019). Work focused specifically on tropical megacities has shown that cooling effects vary substantially with background climate and with the spatial arrangement of green patches rather than their aggregate area alone (Li et al., 2022). A threshold-based analysis has further demonstrated that cooling benefit does not scale linearly with green area, and that planning for cooling requires attention to patch size thresholds and connectivity rather than simple percentage targets (Zhou et al., 2023). These findings matter for Nigerian practice because they imply that a small number of well-configured green corridors may outperform a larger but fragmented stock of leftover open space.

The hydrological function is equally well established. Urbanisation increases impervious cover, which raises peak runoff, shortens time to peak, and degrades receiving water quality (McGrane, 2016; Li et al., 2021). Blue and green solutions have been reviewed across a wide range of international contexts and consistently found to reduce flood risk while delivering co-benefits in amenity and microclimate (Przestrzelska et al., 2024). Distributional analyses have shown that the flood risk reduction benefits of green infrastructure accrue unevenly, and that deliberate targeting is required if the approach is to serve equity objectives rather than reinforce existing advantage (Reu Reu Junqueira et al., 2022).

Green infrastructure in the Nigerian context

The Nigerian evidence base is thinner but consistent in its findings. The systematic review by Adegun et al. (2021) synthesised ninety-four studies and concluded that urban green infrastructure in Nigeria delivers demonstrable benefits to environmental quality and wellbeing, but that practice is constrained by the absence of urban greening master plans, weak enforcement of open space provisions, and competing land use pressure. Studies of specific cities reinforce the point. Analyses of land cover in Osogbo and in Lagos State document the systematic conversion of agricultural and vegetated land to built-up use over multi-decadal periods (Oladehinde et al., 2019; Onilude & Vaz, 2020). Work on flooding in southwestern Nigerian cities links the loss of pervious surface directly to the frequency and severity of urban flood events (Ogunbode & Oyebamiji, 2022). Reviews of indigenous mitigation practice in tropical cities have argued that locally rooted greening strategies, including compound tree planting and shade management, retain substantial untapped potential (Akinkuolie et al., 2024).

Renewable energy systems in Nigerian urban areas

The renewable energy literature for Nigeria has been dominated by resource assessment, policy critique, and site selection. Policy analyses have converged on the conclusion that the country possesses abundant solar, wind, biomass, and hydro resources, and that the binding constraints are financial, institutional, and infrastructural rather than physical (Adeshina et al., 2024). The National Renewable Energy and Energy Efficiency Policy set out targets and instruments a decade ago (Federal Ministry of Power, 2015), and the more recent energy transition planning framework has established a long-horizon decarbonisation pathway with explicit sectoral milestones (Federal Government of Nigeria, 2022; Sustainable Energy for All, 2024).

Site selection studies have applied geographic information systems and multi-criteria decision methods to identify suitable locations for utility-scale generation. A wind farm siting model using interval type two fuzzy analytic hierarchy process was developed for the Nigerian context by Ayodele et al. (2018), and a solar photovoltaic siting framework combining geographic information systems with the analytic hierarchy process was applied to Ikorodu in Lagos State by Okharedia et al. (2025). The latter study is directly relevant to the present argument because it quantified the extent of land constraint in a peri-urban Nigerian setting, finding that a large majority of the study area was unsuitable for photovoltaic development once environmental, technical, economic, and social criteria were applied jointly. Land is not a free input in Nigerian urban energy planning, and this is precisely why competition between greening and generation must be managed rather than ignored.

The integration gap and the conceptual framework

International work on urban decarbonisation has increasingly emphasised that sectoral strategies pursued in isolation deliver less than the sum of their parts. A recent sectoral review of urban decarbonisation policies concluded that the highest performing city strategies are those that link building energy performance, land use, mobility, and nature-based solutions within a single planning instrument (Soares et al., 2025). Analyses of the relationship between urbanisation and carbon emissions across African countries have shown that the decoupling of emissions from urban growth is possible but is not automatic, and depends on the policy choices made during the period of most rapid expansion (Duan et al., 2022). Work on smart city technology integration has similarly argued that digital and natural systems produce their largest returns when planned jointly rather than sequentially (Hui et al., 2023).

The framework adopted here treats green infrastructure and renewable energy as coupled subsystems of a single urban metabolic system, connected through four coupling points. The first is thermal, in which vegetated surface reduces the cooling load that dominates tropical urban electricity demand, thereby reducing the generation and storage capacity a distributed renewable system must provide. The second is hydrological, in which vegetated and permeable surfaces attenuate runoff that would otherwise damage energy assets and access infrastructure. The third is spatial, in which land allocation decisions determine whether greening and generation compete for the same parcels or are co-located in mutually reinforcing configurations. The fourth is institutional, in which shared governance arrangements, shared indicators, and shared finance determine whether the first three couplings can be acted upon at all. These four coupling points structure the assessment presented in Section 4.

3. MATERIALS AND METHODS

Research design

The study adopts a structured desk-based synthesis design. This design was selected because the research questions concern the state of integration between two policy domains across a national urban system, a question that cannot be answered by a single city case study and for which no consolidated primary dataset exists. The design follows the logic of a critical interpretive synthesis: evidence is gathered systematically, appraised for relevance and quality, and then organised against an analytical framework developed for the purpose rather than aggregated statistically.

Evidence identification and selection

Peer-reviewed literature was identified through searches of indexed databases using combinations of the terms green infrastructure, urban greening, renewable energy, distributed solar, urban heat island, land use change, and Nigeria, restricted to material published between 2016 and 2025. Policy instruments and transition datasets were obtained from the responsible federal agencies and from the international partners supporting Nigerian energy transition planning. Sources were retained where they reported empirical results for Nigeria or for a tropical urban context of comparable climate and development level, or where they set out a policy position with direct bearing on Nigerian practice. Sources reporting only on temperate high-income contexts were retained only where they established a general mechanism rather than a context-specific magnitude.

Analytical procedure

Retained sources were coded against the four coupling points set out in Section 2.4. For each coupling point the analysis recorded, first, the strength and direction of the evidence for the physical or economic mechanism; second, the extent to which Nigerian policy instruments recognise the mechanism; and third, the extent to which Nigerian implementation practice acts upon it. This three-layer coding permits a distinction between mechanisms that are unrecognised, mechanisms that are recognised rhetorically but not operationalised, and mechanisms that are actively implemented. The coding scheme is set out in Table 1.

Table 1. Analytical coding scheme applied to retained sources

Coupling point	Mechanism assessed	Evidence layer	Policy layer	Practice layer
Thermal	Vegetated surface reduces cooling load and therefore renewable capacity requirement.	Strength and magnitude of cooling effect	Recognition in national and state instruments	Evidence of implementation
Hydrological	Permeable surface attenuates runoff that damages energy assets	Runoff and asset damage evidence	Recognition in drainage and energy planning	Evidence of implementation
Spatial	Land allocation determines competition or co-location	Land suitability and constraint evidence	Recognition in land use plans	Evidence of implementation
Institutional	Shared governance, indicators, and finance enable joint action	Governance and finance evidence	Existence of joint mandates	Evidence of joint delivery

Limitations of the design

Three limitations follow from this design and are stated at the outset rather than deferred to the conclusion. First, a synthesis reports the state of an evidence base and cannot generate magnitudes that the underlying studies did not measure. Where this paper reports quantities, they are drawn from the cited primary studies and attributed accordingly. Second, the Nigerian evidence base is uneven in its geographic coverage, with southwestern cities substantially better represented than northern and eastern ones, and the assessment inherits that unevenness. Third, the policy and practice layers rely on published instruments and reported implementation, which may understate informal or unreported activity at state and local government level. These limitations bound the claims made in Sections 4 and 5.

4. RESULTS AND DISCUSSION

The thermal coupling

The evidence layer for the thermal coupling is strong. Cooling effects of vegetated surfaces are consistently observed across climatic contexts, and the tropical evidence indicates that configuration matters at least as much as aggregate area (Aram et al., 2019; Li et al., 2022; Zhou et al., 2023). The direction of the relationship between vegetated surface loss and thermal load is not in dispute. What is less well quantified for Nigerian cities specifically is the elasticity of building cooling energy demand with respect to ambient temperature reduction, and this represents a genuine gap in the national evidence base rather than a settled quantity that this paper can supply.

The policy layer shows partial recognition. National urban policy documents and state development plans reference green space provision and energy efficiency, but they do so in separate chapters with separate indicators and no analytical link between them. No reviewed instrument treats vegetated surface as a demand-side energy measure, which is what the physical evidence indicates it is. The practice layer shows almost no implementation. Greening interventions in Nigerian cities are justified on amenity, flood, and aesthetic grounds; the reviewed literature contains no Nigerian example of a greening intervention appraised, financed, or evaluated against an energy demand metric.

The hydrological coupling

The evidence layer is again strong. Impervious surface expansion raises runoff volume and peak flow and degrades receiving water quality (McGrane, 2016; Li et al., 2021), and blue-green interventions reduce flood risk across a wide range of settings (Przestrzelska et al., 2024). For Nigerian cities, the link between vegetation loss and flood incidence has been documented directly (Ogunbode & Oyebamiji, 2022). The specific vulnerability of distributed energy assets to flooding, including inverter and battery installations at ground level and access disruption to maintenance, is a mechanism that follows logically from the flood evidence but which the reviewed Nigerian literature has not measured. This is identified here as a research priority rather than as an established finding.

The policy layer shows recognition of flood risk but not of the asset protection implications for energy infrastructure. Drainage master planning and energy planning proceed independently. The practice layer shows some implementation of drainage improvement in major cities, but none of the reviewed cases coordinate that implementation with the siting of distributed energy assets.

The spatial coupling

The spatial coupling is where the tension between the two agendas is most acute and where the evidence is most directly useful. The Ikorodu photovoltaic siting study demonstrates that once environmental, technical, economic, and social criteria are applied simultaneously, the proportion of a peri-urban Nigerian landscape available for utility-scale solar development is a minority of the total area (Okharedia et al., 2025). Land cover analyses show that the same peri-urban belt is where vegetation loss is concentrated (Ogunbode et al., 2025; Oladehinde et al., 2019). Utility-scale generation and green corridor protection are therefore competing for a constrained and shrinking land resource in exactly the same zone.

This finding reframes the integration problem. Integration is not simply a matter of doing both things; it requires an explicit allocation rule. The evidence supports a two-track allocation in which rooftop and other already built surfaces are prioritised for generation, thereby avoiding competition entirely, while ground-level land in the peri-urban belt is prioritised for green corridor protection, with utility-scale generation directed to degraded and non-vegetated parcels identified through suitability analysis. Table 2 summarises the assessment across all four coupling points.

Table 2. Assessment of integration across the four coupling points

Coupling point	Evidence strength	Policy recognition	Implementation	Assessed status
Thermal	Strong for mechanism, weak for Nigerian magnitudes	Separate treatment of greening and efficiency	None identified	Unoperationalised coupling
Hydrological	Strong for flood mechanism, absent for asset damage	Flood risk recognised, energy link absent	Drainage works uncoordinated with energy siting	Partially recognised, unintegrated
Spatial	Strong, with direct Nigerian suitability evidence	Land use plans silent on the trade-off	Ad hoc, project by project	Active competition, unmanaged
Institutional	Strong international evidence on joint governance	Mandates split across ministries and tiers	No joint delivery vehicles identified	Structural barrier to all other couplings

The institutional coupling

The institutional assessment is the least encouraging and the most consequential. Green infrastructure and renewable energy in Nigeria are governed by different ministries, at different tiers of government, under different legal instruments, with different funding channels and no shared performance indicator. The devolution of electricity regulation to the state level following recent legislative reform creates, in principle, an opportunity for closer alignment with state physical planning functions, since both now sit within the same tier of government. The reviewed evidence contains no example of a Nigerian state that has yet acted on that opportunity.

International experience indicates that the enabling conditions are a single spatial plan that both sectors are bound by, a small set of shared indicators that both sectors report against, and a pooled or co-appraised budget line (Soares et al., 2025; Moallemi et al., 2020). None of these three conditions is currently met in any Nigerian state identified in the reviewed literature. This is the central finding of the assessment: the barrier to integration in Nigeria is not evidentiary and not primarily technical, but institutional.

Discussion of findings

The assessment supports three propositions. The first is that the physical case for integration is substantially stronger than current Nigerian practice reflects. The cooling, hydrological, and land constraint mechanisms are each supported by evidence that is either directly Nigerian or drawn from closely comparable tropical contexts. The gap is not in the science but in the translation of the science into planning instruments.

The second proposition is that integration in the Nigerian context has a distinctive character that distinguishes it from the integration agenda pursued in high-income cities. In cities with reliable centralised electricity, green infrastructure reduces grid demand at the margin. In Nigerian cities, where a substantial share of delivered electricity comes from privately owned small generators, a reduction in cooling load translates directly into reduced household fuel expenditure and reduced local air pollution, and it does so in a way that is immediately visible to the household concerned. The welfare and political economy case for integration is therefore stronger in Nigeria than in the contexts where most of the integration literature was written. This is an argument for prioritisation, not for postponement.

The third proposition concerns sequencing. Because the institutional coupling is the binding constraint, interventions that require deep institutional coordination will fail before they begin, while interventions that can be delivered within a single existing mandate can proceed immediately. Rooftop generation combined with shade tree planting on the same institutional campus, for example a polytechnic, a teaching hospital, or a state secretariat, requires no interministerial agreement because a single institution controls both the roof and the grounds. Such demonstration sites generate the local performance data that the national evidence base currently lacks, and they do so without waiting for governance reform.

Several limitations qualify these propositions. The synthesis design cannot establish Nigerian-specific magnitudes for the thermal coupling, and the absence of measured cooling energy elasticities for Nigerian building stock is a material gap. The geographic unevenness of the Nigerian evidence base means that the findings are better supported for southwestern cities than for northern ones, where the climatic context, building typology, and cooling demand profile differ substantially. The assessment of the practice layer relies on published accounts and may understate unreported implementation at local government level. Finally, the framework proposed here has been derived from evidence rather than tested against implementation outcomes, and its validity remains to be established empirically.

Policy Implications and Proposed Framework

Six implications follow from the assessment, ordered by the institutional capacity each requires.

- Treat vegetated surface as a demand-side energy measure. State energy plans and physical development plans should report a common indicator linking green cover to cooling load, so that greening investment can be appraised against energy as well as amenity objectives.
- Adopt a rooftop first allocation rule for urban generation. Prioritising already built surfaces for photovoltaic deployment removes the competition between generation and greening for scarce peri-urban land identified in the suitability evidence.
- Protect peri urban green corridors through statutory designation. The land cover evidence shows that the peri urban belt is where vegetation loss concentrates, and that unprotected open space is converted rather than retained.
- Coordinate drainage investment with distributed energy siting. Ground-mounted inverters, batteries, and mini grid assets should be sited with reference to flood hazard mapping, and drainage upgrades should be sequenced ahead of energy asset deployment in high hazard zones.
- Establish institutional demonstration sites. Campuses, hospitals, and government complexes that control both roof and grounds can implement integrated greening and generation within a single mandate and generate the local performance data the national evidence base lacks.
- Use state-level electricity devolution as the integration vehicle. With electricity regulation and physical planning now capable of sitting within the same tier of government, states are the appropriate level at which to establish a single spatial plan, shared indicators, and a co-appraised budget envelope.

These implications are ordered deliberately. The first five can be initiated within existing mandates and budgets. The sixth requires deliberate institutional design and is the reform on which the durability of the others ultimately depends.

5. CONCLUSION

This paper has assessed the integration of green infrastructure and renewable energy systems in Nigerian urban development and has found that integration is, at present, largely rhetorical. The physical coupling between the two systems is well supported by evidence: vegetated surfaces reduce the thermal load that drives cooling demand, permeable surfaces protect the assets on which distributed generation depends, and land availability constrains both agendas within the same peri-urban belt. Nigerian policy instruments recognise the two agendas separately, assign them to institutions that do not share a spatial plan, indicators, or budget, and consequently deliver neither the compound benefits nor the avoided conflicts that integration would produce.

The central finding is that the binding constraint is institutional rather than evidentiary or technical. This has a practical consequence: the most productive near-term interventions are those that can be delivered within a single existing mandate, and the most important medium-term reform is the establishment, at state level, of a single spatial plan and shared indicator set to which both sectors are accountable.

Three research priorities follow. Nigerian building stock cooling energy elasticities with respect to ambient temperature reduction need to be measured directly. The vulnerability of distributed energy assets to urban flooding in Nigerian conditions needs to be quantified. And the integration framework proposed here needs to be tested against implementation outcomes at demonstration sites rather than remaining a construct derived from synthesis. Until those three gaps are addressed, integration in Nigerian cities will continue to rest on mechanisms that are plausible and internationally evidenced but locally unmeasured.

6. COMPETING INTERESTS

None to declare

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