Optimizing Building-Integrated Renewable Energy Systems (BIRES) For Climate and Environmental Security in South-East Nigeria

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ABSTRACT

The built environment in South-East Nigeria presents significant opportunities for advancing climate action through building-integrated renewable energy systems (BIRES). This study examined the optimization of BIRES for climate and environmental security among builders and civil engineers in Abia, Anambra, Ebonyi, Enugu, and Imo States. Using a cross-sectional survey design, data were collected from 150 registered professionals selected through stratified random sampling. Findings revealed low BIRES adoption and optimization awareness, with major barriers including lack of tropical climate design guidelines, absence of building code requirements, inadequate technical capacity, limited government incentives, and the high cost of imported components. Despite limited optimization practices, respondents strongly acknowledged the climate and environmental security benefits of BIRES, particularly in reducing greenhouse gas emissions, improving energy resilience, and enhancing sustainable building performance. Two-way ANOVA analysis showed that professionals with higher optimization awareness reported significantly greater perceptions of climate security benefits, while those lacking lifecycle optimization practices perceived higher environmental security risks. Both hypotheses were not accepted at $p < 0.001$. The study concludes that inadequate optimization knowledge and limited lifecycle practices hinder the effective contribution of BIRES to sustainable energy and environmental security. It recommends mandatory professional training on BIRES optimization, stronger institutional support, financial incentives, and the integration of lifecycle assessment standards into regional building regulations and professional practice frameworks.

Keywords: Building-Integrated Renewable Energy Systems (BIRES), Climate Security, Environmental Security, Renewable Energy, Sustainable Buildings.

INTRODUCTION & LITERATURE REVIEW

Nigeria is situated at a critical climate–energy crossroads where persistent energy insecurity, rapid urbanization, and escalating environmental degradation increasingly threaten sustainable development. Despite its large population and expanding built environment, over 85 million Nigerians still lack access to reliable grid electricity, while the building sector accounts for nearly 45% of urban energy consumption, much of which is inefficient and poorly regulated (Nigerian Bureau of Statistics, 2025; UNEP, 2024). Consequently, residential, commercial, and institutional buildings depend heavily on diesel-powered generators to supplement unreliable electricity supplies, thereby increasing greenhouse gas emissions, deteriorating urban air quality, and exposing occupants to environmental and public health risks (Nigerian Electricity Regulatory Commission, 2025; Ohunakin, Adaramola, & Oyewola, 2024). These interrelated challenges have intensified the need for sustainable energy technologies capable of simultaneously improving energy efficiency, mitigating climate change, and strengthening environmental security within the built environment.

Among the most promising innovations are Building-Integrated Renewable Energy Systems (BIRES), which incorporate renewable energy technologies directly into building components such as photovoltaic roofs and

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façades, solar shading devices, skylights, and integrated wind-energy systems. Unlike conventional renewable energy installations, BIRES transform buildings from passive consumers of electricity into active producers of clean energy while maintaining architectural functionality. Recent international studies have demonstrated that optimized BIRES substantially reduce operational energy demand, improve thermal comfort, lower carbon emissions, and enhance building resilience under changing climatic conditions (Ma, Yang, & Zhang, 2023; D'Agostino, Mazzarella, & Minelli, 2024). However, these benefits are largely dependent on effective optimization that considers local climatic conditions, building orientation, occupant behaviour, lifecycle performance, and maintenance requirements.

Although Nigeria possesses abundant solar irradiation and considerable renewable energy resources, the adoption and optimization of BIRES remain relatively limited. Existing installations are frequently implemented using imported design assumptions developed for temperate regions with minimal adaptation to Nigeria's tropical environmental conditions. Consequently, many systems experience reduced efficiency, accelerated degradation, and lower-than-expected energy output. Recent studies have described this situation as "guesswork installation," reflecting inadequate optimization practices, weak technical standards, and insufficient professional competence in system design, integration, and lifecycle management (Adekunle, Ajayi, & Olaniyi, 2025; Okafor & Nwosu, 2024). Although professional organizations such as the Nigerian Green Building Council (NGBC) have initiated pilot capacity-building programmes, widespread expertise in BIRES optimization remains inadequate, while awareness of emerging technologies such as building-integrated wind systems is still developing among builders and civil engineers (NGBC, 2025; Umar & Kolo, 2025).

Beyond technical limitations, increasing scholarly attention has focused on the environmental implications of renewable energy technologies throughout their lifecycle. While BIRES contribute significantly to de-carbonization and energy transition, poor optimization and weak lifecycle planning may introduce unintended environmental consequences including embodied carbon emissions, material toxicity, electronic waste generation, and resource depletion (Hasan & Jelle, 2024; Kumar & Singh, 2025). Photovoltaic modules and battery storage systems contain hazardous materials requiring appropriate end-of-life management, yet recycling infrastructure remains underdeveloped in many developing countries. Similarly, rebound effects associated with improved energy efficiency may inadvertently increase overall energy consumption if behavioural and operational factors are neglected (Berrill, Arvesen, & Hertwich, 2025). These findings suggest that maximizing the climate benefits of BIRES requires optimization approaches that integrate technical performance with environmental sustainability throughout the system lifecycle.

The challenges confronting BIRES implementation are particularly pronounced in South-East Nigeria, where high solar irradiance, elevated temperatures, persistent humidity, intense rainfall, dust accumulation, and unstable electricity supply significantly influence system performance and durability. Tropical climate studies consistently demonstrate that photovoltaic efficiency, component longevity, and overall system reliability depend on designs specifically optimized for local environmental conditions rather than direct adaptation of foreign models (Ma et al., 2023). Nevertheless, localized optimization frameworks, technical standards, and lifecycle assessment guidelines remain largely unavailable in Nigeria, resulting in underperforming installations and reduced confidence in integrated renewable energy technologies.

Evidence from other developing regions further illustrates the importance of policy-supported optimization strategies. Experiences in East Africa indicate that structured regulatory frameworks, localized design standards, financial incentives, and continuous professional development significantly improve BIRES adoption, operational performance, and long-term sustainability (Mukasa, Ochieng, & Ndunda, 2025). Conversely, the absence of comparable institutional support in Nigeria has limited the transition from isolated demonstration projects to large-scale implementation capable of contributing meaningfully to national climate mitigation and environmental protection objectives.

Despite Nigeria's enormous renewable energy potential, important knowledge gaps remain regarding the optimization of BIRES for climate and environmental security. Existing studies have largely emphasized technical efficiency or energy generation, with relatively little empirical attention devoted to optimization awareness among built environment professionals and its relationship with climate resilience and environmental

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sustainability. Furthermore, many BIRES installations continue to rely on design approaches that overlook local climatic realities, lifecycle environmental impacts, and integrated performance evaluation. This situation contributes to reduced photovoltaic efficiency under elevated temperatures, excessive dust-related energy losses, accelerated battery degradation caused by unstable electricity supply, and increasing concerns regarding electronic waste management. Without systematic optimization, BIRES may fail to achieve their intended environmental and climate objectives despite substantial investment in renewable energy technologies.

Against this background, the present study examines the optimization of Building-Integrated Renewable Energy Systems for climate and environmental security among builders and civil engineers in South-East Nigeria. Specifically, the study evaluates the level of BIRES adoption and optimization practices, identifies the principal barriers limiting effective implementation, and examines the relationship between professionals' awareness of optimization techniques and their perceptions of climate security benefits and environmental security risks. In addressing these objectives, the study seeks answers to two fundamental questions: the extent to which BIRES have been adopted and optimized within Nigeria's built environment and the extent to which optimization awareness influences professionals' perceptions of climate and environmental security outcomes. To provide empirical evidence, two null hypotheses were tested at the 0.05 level of significance, namely that awareness of BIRES optimization techniques has no statistically significant positive relationship with perceived climate security benefits and that inadequate lifecycle optimization practices have no statistically significant positive relationship with perceived environmental security risks among builders and civil engineers. By addressing these issues, the study contributes empirical evidence capable of informing professional practice, policy development, and regulatory reforms aimed at promoting climate-resilient, environmentally sustainable, and energy-efficient buildings in Nigeria and comparable developing economies.

METHODOLOGY

Research Design

The study adopted a cross-sectional descriptive survey design using a structured questionnaire. This design enabled the collection of quantitative data from builders and civil engineers to examine BIRES optimization practices and related perceptions at a single point in time.

Area of Study

The study was conducted in the South-East geopolitical zone of Nigeria, comprising Abia, Anambra, Ebonyi, Enugu, and Imo States.

Population of the Study

The population comprised 150 registered builders and civil engineers practicing in South-East Nigeria. Specifically, the study targeted professionals registered with the Nigerian Institute of Building (NIOB) and the Council for the Regulation of Engineering in Nigeria (COREN). Inclusion criteria included a minimum of five years of professional experience and active engagement in building design, construction, or engineering practice within the region.

Sampling Technique and Sample Size

A stratified random sampling technique was adopted, with strata based on the five South-East states to ensure equitable regional representation. A sample size of 150 respondents was determined using Krejcie and Morgan's sampling framework and proportionally allocated across the strata.

Instrument for Data Collection

The instrument for data collection was a structured questionnaire titled "BIRES Optimization and Security Questionnaire (BOS-SQ)," designed to obtain relevant information from registered builders and civil engineers in South-East Nigeria. The questionnaire comprised three sections. Section A elicited demographic and

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professional information from respondents. Section B assessed BIRES adoption and optimization practices, while Section C measured respondents' perceptions of climate security benefits and environmental security risks associated with Building-Integrated Renewable Energy Systems. Items in Sections B and C were rated on a five-point Likert scale ranging from Strongly Disagree (1) to Strongly Agree (5).

Validity and Reliability of the Instrument

The questionnaire was subjected to face and content validation by two experts in building technology and renewable energy systems from the university of Nigeria, Nsukka, departments of civil and electrical Engineering respectively. Their observations and recommendations were incorporated to improve the clarity, relevance, and adequacy of the instrument before its final administration. To establish reliability, a pilot study was conducted using 20 registered builders and civil engineers operating in Lagos, Nigeria who possessed characteristics similar to the study participants. Data obtained from the pilot study were analyzed using Cronbach's alpha reliability technique. The instrument yielded an overall reliability coefficient of 0.80, indicating a high level of internal consistency and confirming that the questionnaire was suitable for data collection.

Data Collection Procedure

Data were collected through both physical administration and online distribution (Google Forms) using the professional networks and associations of builders and civil engineers in South-East Nigeria. Respondents were provided with adequate information regarding the purpose of the study before completing the questionnaire.

Data Analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 25. Descriptive statistics, including means, and standard deviations, were used to answer the research questions, while two-way Analysis of Variance (ANOVA) was employed to test the hypotheses at the 0.05 level of significance.

Ethical Considerations

Ethical principles guiding research involving human participants were strictly observed throughout the study. Informed consent was obtained from all participants before data collection, either in written form for physically administered questionnaires or through a digital consent checkbox for online responses. Participation was entirely voluntary, and respondents were informed of their right to withdraw from the study at any stage without penalty. Furthermore, anonymity and confidentiality were maintained by ensuring that no personal identifiers were collected or linked to individual responses. The information obtained was used solely for academic purposes and securely handled throughout the research process.

RESULTS & DISCUSSIONS

RESULTS

Table 1

Mean Ratings on BIRES Adoption, optimization practices and barriers to its implementation among builders and civil engineers (N = 150)

S/N	Item statements	$\bar{X}_1$	$\bar{X}_2$	SD_1	SD_2
1.	BIRES level of adoption by professional	2.03	2.19	0.71	0.77
2.	BIRES level of optimization practices by Professionals	1.81	1.97	0.66	0.69

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3. Awareness optimization level by professionals	2.28	2.46	0.79	0.83
4. Climate-zone design adaptation level by professional	1.83	2.01	0.68	0.72
5. Lack of tropical climate design guidelines barrier	4.36	4.28	0.69	0.73
6. High cost of imported components barrier	4.08	4.12	0.75	0.77
7. Optimization training barrier	4.04	3.92	0.80	0.84
8. Building and installation code barrier	4.24	4.18	0.72	0.78
9. Life cycle assessment practices availability	1.74	1.96	0.62	0.71
10. Awareness of lifecycle assessment by professionals	4.01	3.95	0.77	0.82

The findings in table 1 indicate that BIRES adoption and optimization practices among builders and civil engineers in South-East Nigeria remain low. Although civil engineers reported slightly higher adoption and optimization scores than builders, both groups exhibited inadequate utilization of optimization techniques. The major barriers identified include lack of tropical-climate design guidelines, high cost of imported components, inadequate professional training, weak lifecycle assessment awareness, and absence of building code requirements.

Table 2

Two-Way ANOVA on Optimization Awareness, Professional Category and Perceived Climate Security Benefits

Source	SS	df	MS	F	Sig.	Dec.
Optimization awareness	18.36	2	9.180	18.72	0.001	Do not accept H_{01}
	0.58	1	0.584	1.19	0.277	
Professional category	0.31	2	0.156	0.32	0.726	
Awareness x professional category	70.18	2	0.491			
		143				
Error						

In table 2, since $H0_1$ has p .0001 < .05, the hypothesis was rejected. this implies that optimization awareness significantly influences perceived climate security benefits, while professional category and the interaction effect do not significantly influence perceptions.

Table 3

Mean Ratings on climate security benefits and environmental security risks according to professional category and optimization awareness level (N = 150)

S/N Item statements	$\bar{X}_1$	$\bar{X}_2$	SD_1	SD_2
11. Reduction in diesel generator dependency	4.32	4.47	0.62	0.57
12. Reduction in greenhouse emissions	4.18	4.39	0.68	0.55
13. Improved energy independence	4.28	4.53	0.64	0.51
14. Enhanced climate resilient	4.11	4.26	0.69	0.58
15. E-waste management control	4.20	4.05	0.71	0.74

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16. Toxicology risk concerns from renewable Components	4.11	4.02	0.68	0.69
17. Resources depletion concerns	3.95	3.88	0.72	0.70
18. Issues of recycling infrastructure	4.31	4.26	0.61	0.65

Respondents in table 3 generally agreed that optimized BIRES can significantly improve climate security through reduction of diesel generator dependence, enhanced energy independence, and reduction of greenhouse gas emissions. Respondents with high optimization awareness reported substantially higher perceptions of climate and environmental security benefits than those with low awareness. However, concerns regarding e-waste management, component toxicity, and inadequate recycling infrastructure remain prominent among both professional groups.

Table 4

Two-Way ANOVA on lifecycle optimization practices, professional category and perceived environmental security risks

Source	SS	df	MS	F	Sig.	Dec.
Optimization awareness Professional category Awareness x professional category Error	16.37 0.73 0.44 69.12	2 1 2 2 142	8.184 0.73 0.22 0.49	16.84 1.49 0.45	0.001 0.224 0.639	Do not accept H_{02}

In table 4, the hypothesis was not accepted. This is because $H0_2$ has p .0001 < .05. Thus, lifecycle optimization practices significantly influence perceived environmental security risks, whereas professional category and the interaction effect are not statistically significant.

DISCUSSION

The findings of this study reveal that the adoption and optimization of BIRES among builders and civil engineers in South-East Nigeria remain relatively low despite the region's significant renewable energy potential. The low mean scores recorded for BIRES adoption and optimization practices suggest that integrated renewable energy technologies have not yet been widely incorporated into routine building design and construction practices. Furthermore, optimization measures such as photovoltaic orientation, tilt adjustment, dust mitigation, lifecycle costing, and performance monitoring were inadequately implemented. These findings indicate that many professionals continue to rely on conventional construction approaches rather than integrating renewable energy systems through evidence-based optimization strategies. The identified barriers, including the absence of tropical climate design guidelines, high costs of imported components, inadequate professional training, weak policy implementation, and limited lifecycle assessment practices, further demonstrate that institutional and technical constraints continue to hinder effective BIRES deployment. These observations are consistent with the findings of Adekunle et al. (2025), who described renewable energy integration in Nigeria as largely dependent on non-standardized installation practices due to inadequate technical guidance and limited professional capacity.

The results further demonstrate that optimization awareness significantly influences professionals' perceptions of climate security benefits. Respondents with higher levels of optimization awareness reported greater confidence in the ability of BIRES to reduce greenhouse gas emissions, improve energy efficiency, strengthen

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energy independence, and enhance climate resilience. This finding suggests that knowledge and technical competence are fundamental determinants of successful renewable energy integration within the built environment. Professionals who understand optimization principles are more likely to appreciate the long-term benefits of properly designed renewable energy systems than those with limited technical exposure. The non-significant influence of professional category further indicates that awareness, rather than occupational specialization, determines perceptions of climate security benefits. This finding supports previous studies by Ma, Yang, and Zhang (2023), who concluded that optimized renewable energy systems achieve substantially better environmental performance than poorly optimized installations, irrespective of the professional discipline responsible for implementation.

The study also reveals that builders and civil engineers generally acknowledge the substantial contribution of BIRES to climate security through reduced dependence on diesel generators, lower greenhouse gas emissions, improved energy independence, and enhanced resilience of buildings to energy supply disruptions. These findings are particularly important within the Nigerian context, where frequent electricity outages have resulted in widespread dependence on fossil-fuel-powered backup generators. Consequently, optimized BIRES present an opportunity not only to reduce operational energy costs but also to contribute to national commitments toward climate change mitigation and sustainable urban development. Nevertheless, respondents expressed persistent concerns regarding environmental security issues, particularly electronic waste management, hazardous materials contained in photovoltaic modules and batteries, and inadequate recycling infrastructure. These concerns demonstrate that renewable energy technologies should not be evaluated solely on the basis of operational energy savings but also from a comprehensive lifecycle perspective that considers environmental impacts during production, operation, maintenance, and disposal. This observation is consistent with Hasan and Jelle (2024), who emphasized that lifecycle optimization is essential for ensuring that renewable energy technologies deliver net environmental benefits.

Another important finding is the significant relationship between lifecycle optimization practices and perceived environmental security risks. Respondents who reported limited lifecycle optimization practices also expressed greater concern regarding environmental risks associated with renewable energy technologies. This finding reinforces the growing recognition that environmental sustainability extends beyond energy generation to include responsible resource utilization, waste minimization, recycling, and end-of-life management. In developing countries such as Nigeria, where formal recycling infrastructure remains inadequate, failure to incorporate lifecycle considerations into BIRES planning may create new environmental challenges even while addressing climate change. Consequently, optimization strategies should incorporate lifecycle assessment, material selection, maintenance planning, and circular economy principles to maximize both climate and environmental security outcomes. Similar conclusions were reached by Zabalza and Valero (2025), who reported that lifecycle assessment provides a more comprehensive evaluation of renewable energy systems than conventional energy-efficiency indicators alone.

The findings have important implications for policy, professional practice, and research. First, there is an urgent need for government agencies and regulatory institutions to develop localized BIRES optimization standards that reflect Nigeria's tropical climatic conditions rather than relying on imported design assumptions. Second, professional bodies responsible for regulating builders and engineers should strengthen continuing professional development programmes on renewable energy optimization, lifecycle assessment, and sustainable building technologies. Such training would improve professionals' technical competence and enhance confidence in renewable energy implementation. Third, incentives such as tax relief, import duty reductions on renewable energy components, and financial support for locally manufactured technologies could significantly reduce implementation barriers identified in this study. Finally, future studies should expand the geographical scope beyond South-East Nigeria and incorporate additional built environment professionals, including architects, quantity surveyors, and mechanical and electrical engineers, to provide a broader understanding of BIRES optimization across the Nigerian construction industry. Such studies may also employ longitudinal or mixed-method research designs to examine changes in optimization practices over time and to generate deeper insights into factors influencing successful renewable energy integration.

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CONCLUSION

The study examined the optimization of Building-Integrated Renewable Energy Systems (BIRES) for climate and environmental security within the South-East geopolitical zone of Nigeria, focusing specifically on 150 registered builders and civil engineers. The findings indicate that although BIRES adoption in the region remains relatively low, there is a strong recognition among built environment professionals of its potential to promote sustainable energy use, reduce greenhouse gas emissions, and improve climate resilience. Most respondents acknowledged that properly optimized BIRES can significantly reduce dependence on diesel generators, enhance energy independence, and contribute to environmentally responsible building practices. These findings demonstrate that the potential benefits of BIRES are widely appreciated, even though practical implementation remains limited.

A major outcome of the study is the identification of a significant optimization gap between awareness of renewable energy technologies and their effective application in professional practice. Only a small proportion of respondents reported using systematic optimization techniques during the planning, installation, and management of BIRES. Similarly, lifecycle environmental considerations, including e-waste management, material toxicity, recycling, and resource conservation, received relatively limited attention despite respondents' awareness of the environmental risks associated with poorly managed renewable energy systems. This finding suggests that current BIRES implementation practices in South-East Nigeria are not sufficiently supported by comprehensive optimization strategies capable of maximizing both technical performance and environmental sustainability.

The statistical analyses further confirmed that optimization awareness significantly influences professionals' perceptions of climate security benefits, while inadequate lifecycle optimization practices are significantly associated with increased perceptions of environmental security risks. These findings demonstrate that technical knowledge and optimization competence are critical determinants of successful BIRES implementation. The study therefore establishes that improving optimization awareness among builders and civil engineers is likely to strengthen confidence in renewable energy technologies and promote more effective integration of BIRES into building projects. At the same time, incorporating lifecycle assessment principles into planning, construction, operation, and end-of-life management is essential for minimizing unintended environmental impacts and ensuring long-term sustainability.

Overall, the study concludes that the principal barriers limiting effective BIRES implementation in South-East Nigeria are not technological but institutional, educational, economic, and regulatory. Inadequate professional training, limited optimization awareness, high costs of imported renewable energy components, absence of localized tropical climate design guidelines, and weak policy implementation collectively constrain the widespread adoption and optimization of integrated renewable energy systems. Addressing these barriers will require coordinated efforts among government agencies, professional regulatory bodies, higher education institutions, and the private sector to develop policies and programmes that promote sustainable renewable energy integration within the built environment.

The study contributes to existing knowledge by providing empirical evidence on the relationship between optimization awareness, climate security, and environmental security among built environment professionals in Nigeria. Its findings offer valuable insights for policymakers, researchers, educators, and practitioners seeking to accelerate the transition toward low-carbon and climate-resilient buildings. Consequently, the study recommends continuous professional capacity building on BIRES optimization, integration of renewable energy and lifecycle assessment into construction-related curricula, development of localized optimization standards, strengthening of national building regulations, and increased investment in renewable energy research and local manufacturing. Although the study was limited to builders and civil engineers in South-East Nigeria, it provides a useful foundation for future investigations involving other built environment professionals and wider geographical coverage. With appropriate institutional reforms and sustained investment in optimization practices, BIRES can become an effective strategy for improving energy security, mitigating climate change, and promoting environmental sustainability within Nigeria's built environment.

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