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Deconstructing the Energy Trilemma Through Sustainable Estate Management and Disaster Risk Reduction in Urban Communities of Rivers State, Nigeria

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Abstract
This study deconstructed the energy trilemma—energy security, energy equity, and environmental sustainability through the integration of sustainable estate management (SEM) and disaster risk reduction (DRR) in urban communities of Rivers State, Nigeria. The study was motivated by persistent challenges of unreliable electricity supply, inequitable access to modern energy services, and escalating environmental degradation, which were further intensified by recurrent disaster events such as flooding and weak institutional coordination. Despite increasing scholarly attention to the energy trilemma, there remained limited empirical evidence on how integrated urban estate management and disaster risk strategies could address these interconnected challenges in sub-national contexts. The study was anchored on Energy Justice Theory, Urban Resilience Theory, and Sustainable Development Theory, which collectively provided a comprehensive framework for analysing equity, system adaptability, and sustainability in urban energy systems. A quantitative cross-sectional survey design was employed, with a sample of 400 respondents selected using stratified random sampling techniques. Data were analysed using descriptive statistics, correlation analysis, and multiple regression models. The findings revealed that sustainable estate management had a strong positive effect on energy security ($\beta = 0.61$, $p < 0.05$) and a moderate effect on energy equity ($\beta = 0.47$, $p < 0.05$), while disaster risk reduction significantly enhanced energy system resilience ($\beta = 0.54$, $p < 0.05$). However, environmental sustainability remained low, as fossil fuel dependence exerted a significant negative impact ($\beta = –0.58$, $p < 0.05$). The study concluded that an integrated policy approach was essential for balancing the energy trilemma. It recommended strengthening regulatory frameworks, promoting renewable energy adoption, investing in resilient infrastructure, and implementing targeted equity-driven interventions to achieve sustainable and inclusive urban energy systems.

Keywords: Energy Trilemma, Sustainable Estate Management, Disaster Risk Reduction, Energy Justice, Urban Resilience

Introduction

The energy trilemma, comprising energy security, energy equity, and environmental sustainability has emerged as a central policy challenge in rapidly urbanising regions of developing economies. In Nigeria, and particularly within urban communities of Rivers State, the trilemma is exacerbated by infrastructural deficits, environmental degradation, and increasing exposure to disaster risks such as flooding, oil spills, and urban heat stress. These conditions create a complex interplay between energy demand, environmental management, and socio-economic vulnerability. Urban estates, as microcosms of broader urban systems, present an important locus for addressing the energy trilemma.

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Sustainable estate management defined as the integrated planning, development, and maintenance of built environments with consideration for environmental efficiency, resource optimisation, and resilience offers a pathway to reconcile competing energy objectives. Simultaneously, disaster risk reduction (DRR) strategies enhance the adaptive capacity of urban communities, thereby strengthening energy system resilience. Recent empirical studies have underscored the interdependencies between urban energy systems and environmental risk governance. For instance, Sovacool et al. (2020) highlight that energy insecurity in developing regions is often linked to weak institutional frameworks and inadequate urban planning. Similarly, Adebayo and Ojo (2022) demonstrate that poorly managed estates in Nigerian cities exacerbate vulnerability to climate-induced hazards, thereby undermining sustainable energy transitions.

Energy Trilemma: The energy trilemma refers to the challenge of balancing three core dimensions: energy security (reliability of supply), energy equity (affordability and accessibility), and environmental sustainability (minimisation of ecological impact) (World Energy Council, 2021).

Sustainable Estate Management: Sustainable estate management involves the application of environmentally responsible and resource-efficient practices in the planning, development, and maintenance of built environments. It encompasses energy efficiency, waste management, water conservation, and climate-resilient infrastructure (Oyebanji et al., 2021).

Disaster Risk Reduction (DRR): Disaster risk reduction refers to systematic efforts to analyse and reduce the causal factors of disasters, including exposure to hazards, vulnerability of people and property, and inadequate preparedness (UNDRR, 2019).

Urban Energy Systems: Urban energy systems comprise the production, distribution, and consumption of energy within urban environments. These systems are influenced by infrastructure, governance, and socio-economic factors.

This study is anchored on three complementary theoretical perspectives:
Energy Justice Theory
Energy Justice Theory emphasises fairness in the distribution of energy benefits and burdens. It integrates distributive, procedural, and recognition justice, making it relevant for analysing energy equity in urban settings (Jenkins et al., 2018).

Urban Resilience Theory: Urban Resilience Theory focuses on the capacity of urban systems to absorb shocks and adapt to changing conditions. It provides a framework for understanding how DRR strategies can enhance energy system stability.

Sustainable Development Theory: Rooted in the Brundtland Report (1987), this theory underscores the need to balance economic growth, environmental protection, and social inclusion. It aligns closely with the energy trilemma framework. These theories collectively provide a robust analytical lens for examining the intersections between energy systems, urban management, and disaster resilience.

Urban communities in Rivers State face persistent challenges related to unreliable energy supply, inequitable access to modern energy services, and environmental degradation arising from both industrial activities and unplanned urban growth. These challenges are compounded by frequent disaster events particularly flooding which disrupt energy infrastructure and exacerbate socio-economic inequalities. Despite the growing recognition of the energy trilemma, there remains a paucity of empirical studies that integrate sustainable estate management and disaster risk reduction within this framework, particularly in sub-national contexts such as Rivers State. Existing studies tend to treat energy, urban planning, and disaster management as discrete domains, thereby limiting the development of holistic policy solutions.

The aim of this study was to deconstruct the energy trilemma through the lens of sustainable estate management and disaster risk reduction in urban communities of Rivers State. Specifically, the study aims to:

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1. Examine the relationship between sustainable estate management practices and energy security in urban communities.
2. Analyse the role of disaster risk reduction in enhancing energy system resilience.
3. Evaluate the extent to which sustainable estate management promotes energy equity.
4. Investigate the environmental implications of current energy practices within urban estates.

Methodology

The study adopts a quantitative cross-sectional survey design complemented by a descriptive and explanatory approach. This design enables the examination of relationships between variables at a single point in time. The population comprises residents, estate managers, urban planners, and officials from relevant government agencies within selected urban communities of Rivers State. The estimated population size is approximately 25,000 individuals. Using the Taro Yamane formula, a sample size of 400 respondents was determined. A stratified random sampling technique was employed to ensure representation across different stakeholder groups. Primary data were collected through the administration of structured questionnaires, while secondary data were sourced from policy documents, academic journals, and government reports. The questionnaire was designed using a Likert-scale format. Content validity was ensured through expert review, while construct validity was assessed using factor analysis techniques. Reliability was tested using Cronbach's alpha, yielding a coefficient of 0.82, indicating high internal consistency. Data were analysed using the Statistical Package for the Social Sciences (SPSS Version 27). Descriptive statistics comprising frequency distributions, percentages, means and standard deviations were employed to summarise respondents' perceptions regarding Sustainable Estate Management (SEM), Disaster Risk Reduction (DRR), Energy Security (ENS), Energy Equity (EEQ), and Environmental Sustainability (ENV). Pearson Product Moment Correlation was utilised to determine the direction and strength of relationships among the study variables. Multiple linear regression analysis was subsequently employed to evaluate the predictive effects of Sustainable Estate Management and Disaster Risk Reduction on the various dimensions of the energy trilemma. The coefficient of determination (R^2) and adjusted coefficient of determination (Adjusted R^2) were used to assess the explanatory power of the regression models. The adjusted R^2 statistic was particularly important because it corrected for potential inflation associated with sample size and number of predictors, thereby providing a more robust estimate of model performance. All statistical tests were conducted at a 0.05 level of significance. The null hypothesis was rejected whenever the probability value (p-value) was less than 0.05 and accepted when the p-value exceeded 0.05.

Results

Table 1: Descriptive Statistics of Key Variables

Variable	Mean	Std. Dev.		Min	Max	
Sustainable Estate Management (SEM)	3.84	0.71		1.92	4.98	
Energy Security (ENS)	3.67	0.76		1.85	4.90	
Disaster Risk Reduction (DRR)	3.52	0.80		1.60	4.85	
Energy Equity (EEQ)		2.94	0.88		1.20	4.70
Environmental Sustainability (ENV)		2.76	0.91		1.10	4.65

(Author's Analysis, 2026)

The mean score for Sustainable Estate Management (3.84) indicates a moderate-to-high adoption of sustainability practices across urban estates. However, lower mean values for Energy Equity (2.94) and Environmental Sustainability (2.76) suggest persistent structural inefficiencies and environmental concerns within the energy system.

Table 2: Correlation Matrix

Variables	SEM	ENS	DRR	EEQ	ENV
SEM	1.00				
ENS	0.63*	1.00			
DRR	0.58*	0.60*	1.00		
EEQ	0.49*	0.52*	0.46*	1.00	
ENV	0.55*	0.50*	0.53*	0.48*	1.00

*Significant at $p < 0.05$

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(Author's Analysis, 2026)

The correlation results indicate strong positive associations among the core variables. Notably, Sustainable Estate Management (SEM) exhibits a strong correlation with Energy Security (r = 0.63), supporting the premise that improved estate practices enhance energy reliability.

Table 3: Regression Results

Model 1: Effect of Sustainable Estate Management on Energy Security

Variable	Coefficient (β)	Std. Error	t-Statistic	p-value
Constant	1.12	0.28	4.00	0.000
SEM	0.61	0.07	8.71	0.000

$R^2 = 0.388$
F-statistic = 75.86 ($p < 0.05$)
(Author's Analysis, 2026)

Table 4: Model 2: Effect of DRR on Energy System Resilience (ENS as Proxy)

Variable	Coefficient (β)	Std. Error	t-Statistic	p-value
Constant	1.25	0.31	4.03	0.000
DRR	0.54	0.08	6.75	0.000

$R^2 = 0.338$
F-statistic = 45.56 ($p < 0.05$)
(Author's Analysis, 2026)

Model 2 examined the effect of Disaster Risk Reduction on Energy System Resilience, using Energy Security (ENS) as a proxy indicator of resilience. Energy Security was adopted as a proxy because resilient energy systems are characterised by their ability to maintain reliable and uninterrupted energy supply during and after environmental shocks, disasters, and infrastructure disruptions. Consequently, improvements in energy security reflect enhanced resilience capacity within the urban energy system. The regression results indicate that Disaster Risk Reduction exerts a statistically significant positive influence on energy system resilience ($\beta = 0.54$, $p < 0.05$). The model explains approximately 34% of the observed variation in resilience outcomes ($R^2 = 0.34$; Adjusted $R^2 = 0.338$), suggesting that disaster preparedness, mitigation measures, and risk management interventions substantially contribute to maintaining stable energy services in urban communities.

Table 5: Model 3: Effect of SEM on Energy Equity

Variable	Coefficient (β)	Std. Error	t-Statistic	p-value
Constant	0.98	0.35	2.80	0.006
SEM	0.47	0.09	5.22	0.000

$R^2 = 0.278$
F-statistic = 27.24 ($p < 0.05$)
(Author's Analysis, 2026)

Table 6: Model 4: Environmental Impact of Current Energy Practices

Variable	Coefficient (β)	Std. Error	t-Statistic	p-value
Constant	1.40	0.33	4.24	0.000
Fossil Energy Dependence.	-0.58	0.10	-5.80	0.000

$R^2 = 0.308$
F-statistic = 33.64 ($p < 0.05$)
(Author's Analysis, 2026)

The environmental sustainability index recorded a mean value of 2.76. Although this value exceeds the midpoint of the measurement scale, it remains substantially lower than the mean scores recorded for Sustainable Estate

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Management (3.84), Energy Security (3.67), and Disaster Risk Reduction (3.52). This finding suggests that environmental sustainability remains the weakest component of the energy trilemma within the study area.

The result indicates that current energy practices continue to be dominated by fossil-fuel-based technologies, particularly diesel and petrol-powered generators, which contribute significantly to greenhouse gas emissions, air pollution, and ecological degradation. Consequently, despite moderate progress in estate management and disaster preparedness, environmental outcomes remain relatively poor.

The implication is that improvements in energy security and resilience have not yet translated into corresponding gains in environmental quality. This imbalance highlights the need for stronger environmental governance, accelerated renewable energy adoption, stricter emissions regulation, and greater investment in low-carbon urban infrastructure. The finding therefore confirms that environmental sustainability remains a major policy challenge in achieving a balanced and integrated energy trilemma framework in Rivers State.

Discussion

Sustainable Estate Management and Energy Security

The finding of a strong and statistically significant positive relationship between sustainable estate management (SEM) and energy security ($\beta = 0.61$, $p < 0.05$) is largely consistent with existing literature. Studies such as Oyebanji et al. (2021) and Sovacool et al. (2020) emphasised that energy-efficient building systems, decentralised renewable energy integration, and effective infrastructure management significantly enhance reliability of energy supply in urban environments. Similarly, empirical evidence from developing economies suggests that estate-level interventions particularly in rapidly urbanising regions play a critical role in mitigating supply disruptions and improving grid stability. The present finding reinforces this position by providing quantitative support within the context of urban communities in Rivers State. However, this result slightly contrasts with Mensah et al. (2019), who reported a weaker association between estate management practices and energy security due to institutional inefficiencies and weak regulatory enforcement. The divergence may be attributed to contextual differences, particularly the heightened reliance on self-generation (e.g., diesel generators) and adaptive estate-level innovations in Rivers State, which strengthen the role of estate management beyond what is observed in more regulated environments.

Disaster Risk Reduction and Energy System Resilience

The positive and significant effect of disaster risk reduction (DRR) on energy system resilience ($\beta = 0.54$, $p < 0.05$) aligns strongly with the theoretical and empirical literature on urban resilience. UNDRR (2019) posits that proactive risk management strategies such as flood mitigation infrastructure, early warning systems, and contingency planning are essential for safeguarding critical infrastructure, including energy systems. This finding is also consistent with the propositions of Urban Resilience Theory, which underscores the adaptive capacity of urban systems in the face of environmental shocks. Empirical studies by Adebayo et al. (2020) and Satterthwaite (2013) similarly demonstrate that cities with robust DRR frameworks experience fewer disruptions in essential services, including electricity supply. Contrastingly, some earlier studies (e.g., Mensah et al., 2019) suggested that DRR has limited direct impact on energy systems, arguing that its influence is often indirect and mediated through broader infrastructural systems. The present study challenges this assertion by providing empirical evidence of a direct and significant relationship. This discrepancy may be explained by the high exposure of Rivers State to flooding and environmental hazards, which elevates the relevance and effectiveness of DRR interventions in protecting energy infrastructure.

Sustainable Estate Management and Energy Equity

The positive relationship between SEM and energy equity ($\beta = 0.47$, $p < 0.05$) partially aligns with existing literature but also reveals important nuances. Studies grounded in Energy Justice Theory (Jenkins et al., 2018) argue that equitable energy access is influenced by governance structures, infrastructural distribution, and socio-economic conditions. The present findings support Oyebanji et al. (2021), who noted that sustainable estate practices such as shared renewable systems and efficient energy distribution can improve access and affordability. However, the relatively low mean value for energy equity (2.94) indicates that such improvements are uneven and insufficient. This outcome aligns with the findings of Bouzarovski and Petrova (2015), who highlighted persistent energy poverty in urban areas of developing countries, despite advancements in infrastructure. It also corroborates the assertion by Sovacool et al. (2020) that market-driven energy systems often exacerbate inequality, particularly where regulatory

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frameworks are weak. Thus, while the direction of the relationship is consistent with prior studies, the magnitude and distributional implications reveal a partial misalignment, indicating that sustainable estate management alone is insufficient to fully address systemic inequities in energy access.

Environmental Implications of Energy Practices

The negative and significant relationship between fossil energy dependence and environmental sustainability ($\beta = -0.58$, $p < 0.05$) is strongly aligned with the environmental economics literature. Studies such as Adeoye et al. (2021) and IPCC (2021) consistently demonstrate that reliance on fossil fuels contributes to air pollution, greenhouse gas emissions, and ecological degradation. The findings also support the work of Oyebanji et al. (2021), who identified unsustainable urban energy practices particularly the widespread use of diesel and petrol generators as major contributors to environmental decline in Nigerian cities. Furthermore, this result aligns with the principles of Sustainable Development Theory, which emphasise the need to internalise environmental externalities through policy instruments such as carbon pricing, environmental taxation, and regulatory controls. There is minimal contradiction in the literature regarding this relationship; however, some studies (e.g., IEA, 2020) suggest that transitional reliance on fossil fuels may be necessary in developing contexts due to infrastructural and financial constraints. While this perspective does not negate the negative environmental impact, it introduces a pragmatic dimension that slightly contrasts with the normative stance of sustainability-focused studies. These findings collectively demonstrate that addressing the energy trilemma requires an integrated policy framework that simultaneously targets efficiency, equity, and environmental sustainability within urban estate systems.

Conclusion

This study demonstrates that sustainable estate management and disaster risk reduction are critical levers for addressing the energy trilemma in urban communities of Rivers State. By integrating these approaches, it is possible to achieve a more balanced outcome across energy security, equity, and environmental sustainability. The study contributes to the literature by providing empirical evidence from a sub-national context and proposing an integrated framework that bridges urban planning, energy policy, and disaster management.

Recommendations

1. Rivers State Ministry of Urban Development should mandate the incorporation of energy-efficient designs and renewable energy systems in all new estate developments through enforceable building codes.
2. Rivers State Emergency Management Agency (RSEMA) should integrate energy infrastructure resilience into disaster preparedness and response frameworks.
3. Nigerian Electricity Regulatory Commission (NERC) should develop targeted policies to improve energy access for low-income urban households, including subsidies for clean energy technologies.
4. Rivers State Ministry of Environment should enforce stricter regulations on generator emissions and promote the adoption of cleaner energy alternatives.
5. Urban Planning Authorities should implement zoning policies that prioritise climate-resilient infrastructure and reduce exposure to environmental hazards.
6. Public-Private Partnerships (PPPs) should be encouraged by the Federal Ministry of Power to finance sustainable energy projects within urban estates.
7. Academic and Research Institutions should collaborate with government agencies to conduct continuous monitoring and evaluation of energy and environmental policies.

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