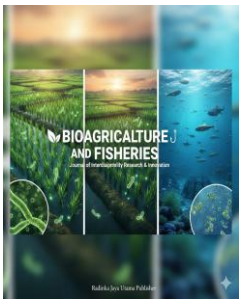

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Resource Efficiency in Energy, Water and Supply Chains in Nigeria: Pathways for Sustainable Industrial Transformation Under SDGs 7, 9 and 12

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Abstract

Resource efficiency is a vital aspect of sustainable industrialization, especially among developing nations. In the case of Nigeria, persistent inefficiencies when it comes to the use of energy, management of water, and the structure of supply chain systems have a negative impact on productivity, the environment, and the country's ability to reach Sustainable Development Goals (SDG) 7 (Affordable and Clean Energy), 9 (Industry, Innovation and Infrastructure), and 12 (Responsible Consumption and Production). This study focuses on the role integrated resource efficiency practices (focused on energy, water, and supply chains) play on the environmental and operational competitiveness of Nigeria's industrial sector. The study conceptualizes resource efficiency as a multi-faceted capability integrated within the organizational systems and is guided by the Resource-Based View, Circular Economy Theory, and Theory of Ecological Modernization. The study employs a cross-sectoral survey and a multivariate analysis. This research will explore the correlation among energy optimization, water stewardship, sustainable procurement, and organizational performance. The results of the study are anticipated to support and provide empirical evidence on the synergistic efficiencies created by the intersection of energy, water, and supply chains and provide strategic guidance to policymakers on how to implement the Nigeria Energy Transition Plan (NETP) and the sustainable industrial policy of the country. The study shows how to use nexus thinking and firm-level strategic management within the developing world, especially in Sub-Saharan Africa.

Keywords: Resource efficiency, Energy-water nexus, Sustainable supply chains, Nigeria

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Introduction

Sustainable industrial transformation has become a major global policy priority because industries are under increasing pressure to improve productivity while minimizing environmental degradation. Resource efficiency, particularly in energy use, water management, and supply chain operations, is now recognized as a critical pathway for achieving sustainable industrial development and supporting the sustainable development goals (SDGs), especially SDGs 7, 9, and 12. In developing economies such as Nigeria, inefficient utilization of these resources continues to undermine industrial competitiveness, increase production costs, intensify environmental pollution, and limit progress toward sustainable economic growth. Consequently, integrated resource efficiency has emerged as an important strategy for improving operational performance while simultaneously reducing environmental impact.

This has allowed us to develop an understanding of sustainable development as a problem of the Global South that is characterized by high population density and limited resources. According to the International Energy Agency (IEA,2023), the United Nations Environment Programme (UNEP, 2024), and the World Bank (2023), inefficient resource utilization remains one of the major barriers to sustainable industrial development, particularly in developing economies where energy, water, and logistics systems continue to experience significant operational inefficiencies.

Resource efficiency is a key component in building and strengthening the global competitive economy and global resilience in the face of climate change. The global south, especially the developing nations, has been and remains a priority investment zone to develop the global competitive economy and resilience.

Resource Efficiency and the Energy-Water Supply Chain Nexus

Recent studies on sustainability start to pay close attention to the nexus approach (UNEP, 2024; IEA, 2023). In the case of energy, water, and production systems, nexus thinking examines the relationships among the respective systems. Consider, for example, the energy production systems that call for the use of large quantities of water, and water systems for treatment and distribution that require considerable energy. The supply chain systems (integrated systems of production, transportation, and distribution) further mesh the systems above. Any inefficiencies in one of the systems are, in many cases, a problem in the others.

Unreliable power supply to water treatment facilities and thermal power generation that relies on water resources creates inefficiencies in the supply chain. In sub-Saharan region where axial belts are a priority, the longitudinal systems of the supply chain greatly increase used fuel and emitted pollutants, if not diverted completely. As cited by the United Nations Industrial Development

Organization (UNIDO, 2023), African manufacturing firms demonstrate a substantial productivity loss due to resource inefficiencies. For this reason, a combination of measures to improve resource efficiency is needed to promote optimal energy use, better water management, and improved coordination among supply chains. This type of system is also present in the Energy Transition plan of Nigeria for the years 2022 to 2060, which aims to decarbonize the energy system while also addressing the challenge of promoting the industry.

Compliance with Sustainable Development Goals

Similarly, the African Development Bank (2023) emphasizes that improving industrial resource productivity is fundamental to accelerating Africa's green industrialization agenda and achieving sustainable economic growth. Among the three goals, improved resource efficiency provides pathways for convergence. Water and energy efficient technologies and systems reduce consumption of these resources (SDG 7, SDG 12), and supply chain systems that are optimized enhance the competitiveness of the industry (SDG 9). As a pivotal component to Africa's green industrialization, resource productivity has been emphasized by the African Development Bank (2023) a sustainable development goal for the continent.

In Nigeria, policy reforms and pledges to various facets of sustainability have yet to bring positive change in relation to the effective use of energy and water and the supply chain systems. Empirical studies do not examine the systems as a whole but arrive at conclusions about the systems that are perpendicular to the core of the issue. Also, the literature is sparse on the firm level analysis of the inter-linkages of resource efficiencies and the operational as well as environmental performance of the firm. Failed policies are without empirical basis.

Despite numerous policy initiatives aimed at improving industrial productivity and environmental sustainability and environmental sustainability in Nigeria, resource inefficiencies in energy consumption, water utilisation, and supply chain management remain widespread. Existing studies have largely investigated these dimensions independently, with limited attentions given to their interconnected effects on operational and environmental performance. Consequently, policymakers and industrial managers lack sufficient empirical evidence regarding the integrated influence of resource efficiency on sustainable industrial transformation. Addressing this gap is essential for designing evidence-based policies capable of accelerating Nigeria's transition toward a resource-efficient and low-carbon industrial economy. This research attempts to address that by exploring the inter-linkages of energy efficiency, water stewardship, and sustainable supply chain management in Nigeria.

Aim and Objectives of the Study

The study examines Integrated Resource Efficiency (IRE) as applied to three critical resources: energy, water, and supply chains and the associated environmental sustainability and operational performance effects in Nigeria's industrial sector.

The specific objectives of the study are to:

1. To determine the level of energy efficiency implementation among Nigerian firms.

2. To evaluate the water resource management in industrial activities.
3. To examine the adoption of sustainable supply chain management practices among Nigeria manufacturing firms.
4. To determine the effects of energy efficiency, water stewardship, and sustainable supply chain management on firms' operational and environmental performance.
5. To recommend strategies for enhancing integrated resource efficiency in support of SDGs 7, 9 and 12.

Research Questions

1. To what extent is energy efficiency practiced by Nigerian firms?
2. How is water resource management integrated into the production process?
3. To what extent are the practices of supply chain management sustainable?
4. What are the effects of integrated energy efficiency, water stewardship, and sustainable supply chain management on firms' operational and environmental performance?

Research Hypotheses

H_1. Nigerian firms that adopt energy efficiency practices have improved operational performance.
H_2. Firms that adopt water stewardship practices have improved environmental performance.
H_3. Firms that adopt sustainable supply chain practices have improved competitiveness.
H_4. Firms that are integrated in energy, water, and supply chain efficiency have improved sustainability performance.

Theoretical Framework

For the purpose of this study, the integrated framework of Resource-Based View (RBV), Circular Economy Theory (CET), and Ecological Modernization Theory (EMT) is used.

Circular Economy Theory (CET)

Geissdoerfer et al. (2017) describe Circular Economy Theory as the removal of the linear production model and the optimization of the production model's regenerative capacity through production systems designed to be regenerative. CET advocates for replacing the traditional linear production model with regenerative production systems that prioritize resource recovery, recycling, reuse, and waste minimization (Geissdoerfer et al., 2017).

Ecological Modernization Theory (EMT)

Ecological Modernisation Theory (EMT) Ecological Modernisation Theory (EMT) posits that the economy can expand and develop through protective and restructuring measures related to environmental and ecological systems by modernising economic practices (Mol & Jänicke, 2021).

Integration with the Research

CET establishes the basis for understanding circularity, whereas EMT emphasises modernism and resource efficiency. Collectively, these frameworks contextualise Nigerian enterprises and justify integrated resource efficiency concerning the maintenance and enhancement of competitiveness.
The integration of the Resource-Based View, Circular Economy Theory, and Ecological Modernization Theory provides a comprehensive explanation of how firms develop strategic

capabilities for sustainable competitiveness. The Resource-Base View explains how efficient management of valuable organizational resources creates competitive advantage. Circular Economy Theory emphasizes resource recovery, recycling, and waste minimization, while Ecological Modernization Theory argues that technological innovation and environmental protection can coexist with economic growth. Together, these theories provide a robust framework for explaining why integrated resource efficiency enhances both environmental sustainability and organizational performance.

Review of Empirical Literature

A growing amount of empirical material since 2021 indicates that integrated resource efficiency is an emerging cross-cutting issue in the regulation of energy, water, and supply chains. Integrated resource efficiency demonstrates superior sustainability outcomes compared to single-sector approaches.

Energy Efficiency in Developing Economies

The scholarship on sustainability persists in emphasizing energy efficiency. The International Energy Agency (IEA, 2023) forecasts that enhancements in energy intensity across industries could yield more than that. In Sub-Saharan Africa, the combination of inefficient grid technologies and a reliance on fossil fuels increases the economic and environmental burden of production.

Resent empirical evidence further demonstrates that improvements in industrial energy efficiency contributes significantly to productivity growth, reduced operational costs, and environmental sustainability in developing economies (Mato et al., 2023; Adeyeye, 2025).

Research carried out regarding the Energy Transition Plan (2022) indicates increased interest in the adoption of solar hybrid systems within the manufacturing sector in Nigeria. However, there remain challenges regarding some financing barriers and inconsistency in the policies. Improvements in industrial energy efficiency can also be achieved through digital technologies such as smart meeting, predictive maintenance, industrial automation, and Internet of Things (IoT) applications, which enhance real-time monitoring and optimize resource utilization (Frank et al., 2019). For example, energy loss can be reduced through the adoption of smart metering, Internet of Things (IoT) based systems for monitoring, and predictive maintenance (Frank, et al. 2019). Unfortunately, such systems are even less implemented in Nigeria in part due to insufficient infrastructure and an absence of the necessary technical skills.

Water Resource Efficiency

Both the use of water resources and water scarcity during the COVID-19 pandemic have raised a number of sustainability concerns in a number of industries, including manufacturing. As reported by the United Nations Environment Programme (UNEP, 2024), of the total water resources used by industries, the manufacturing sector utilizes approximately 19% of it. Using water without appropriate treatment in Africa leads to pollution and water resource depletion. Research conducted between 2020 and 2025 has observed positive impacts on the environment through water stewardship practices such as recycling, rainwater harvesting, and technologies that enable zero liquid discharge.

Recent studies within the Nigerian and broader African context further indicate that effective management of the water-energy-food nexus strengthens environmental sustainability while improving industrial resilience (David et al., 2024; Esan et al., 2024; Orimoloye, 2022).
The industrial clusters in Lagos, Port Harcourt, and Kano, Nigeria, face challenges of groundwater depletion and contamination. Research indicates that insufficient enforcement of environmental regulations has impeded the extensive adoption of water conservation equipment.

Sustainable Supply Chain Management

Subsequent to the COVID-19 epidemic, there has been a surge in studies pertaining to Sustainable Supply Chain Management (SSCM). The COVID-19 pandemic exposed the inadequacies in global logistics systems. A 2024 World Bank study highlights the importance of adaptable and resource-efficient supply networks. These supply chains are essential to the World Bank's objective of economic recovery post-pandemic. Empirical research from 2021 to 2026 shows that environmentally friendly procurement practices, collaboration with suppliers, and reverse logistics have proven to be beneficial for both environment and financial performance (Khan et al., 2022). Additionally, the incorporation of digitalization and block chain technology improves material traceability and decreases waste during production processes.
In Nigeria, the supply chain problems are further worsened by the insufficient transport means and congestion at the ports. Logistic inefficiencies have been shown to increase production costs by 20–30% (African Development Bank, 2023). Companies that have implemented lean supply chain practices have experienced positive changes both in the turnover of their inventory and in the carbon footprint. According to Udoinyang (2024) better water stewardship governance improves the environmental performance of Nigerian institutions.
Emerging technologies, including Artificial Intelligence, blockchain, and knowledge management systems, are increasingly improving supply chain transparency, resilience, and environmental sustainability within manufacturing industries (Oladapo et al., 2024; Younes et al., 2025).

Nexus-Based Approaches

The rapidly developing literature on the energy-water-supply chain nexus shows that integrated management systems can provide synergistic benefits. D'Amato et al. (2020) show that, when systems are optimized together, energy and water systems supply greater efficiency than when systems are optimized individually. Similarly, the integration of a circular economy in supply chains improves the reuse of materials and the recovery of energy. Integrated studies that empirically focus on energy, water, or supply chains in Nigeria are few and far between. Though there has been some improvement, research on the combined effects of operational and environmental performances of firms, using quantitative methods, is still scarce.
Although recent Nigerian studies have examined isolated dimensions of resource efficiency and industrial sustainability, there remains limited empirical evidence integrating energy efficiency, water stewardship, and sustainable supply chain management within a single analytical framework (Onukwulu et al., 2025; Olota, 2026). Also, empirical studies specifically examining these interactions within Nigerian industries remain limited. This study therefore extends existing literature by providing integrated empirical evidence from Nigerian industrial sector.

Methodology

A cross-sectional survey research design was employed in this study focusing on registered manufacturing and industrial firms in all six geo-political zones in Nigeria. Approximately 1,250 medium and large scale firms registered with the Manufacturers Association of Nigeria (MAN), and with industrial directories as of 2025, made up this study's target population. Applying Yamane's (1967) sampling formula, 303 firms were determined as the sample size at a 95% confidence level. In regard to sector (energy intensive manufacturing, agro-processing, chemicals, and logistics) and regional representation, stratified random sampling was used. Along with a review of the relevant literature, a structured questionnaire was used to collect data. This was subdivided into 5 (five) sections: demographic data, energy efficiency practices, water management systems, sustainable supply chain management, and performance outcomes, where a 5 (five) point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree) was employed for each section. An ethical review board granted ethical approval for this study, as all respondents provided informed consent prior. Confidentiality and anonymity were guaranteed in this study. Three experts in sustainability and supply chain management verified the content validity of the instrument. Construct validity was assessed by means of exploratory and confirmatory factor analyses. Reliability was evaluated by means of Cronbach's alpha, the coefficients of which ranged from 0.82 to 0.91, which is above the acceptable limit of 0.70. The data collection period ran from January to April 2026. Out of 303 questionnaires sent out in both electronic and physical form, 268 were received, with 254 being usable (83.8% effective response rate). Hypothesized relationships were tested using SEM (structural equation modelling) with SPSS 28 and AMOS.

Table 1: Demographic Representation of Respondents (N = 254)

Variable	Category	Frequency	Percentage (%)
Sex	Male	162	63.8
	Female	92	36.2
Age	25-34	48	18.9
	35-44	96	37.8
	45-54	78	30.7
	55+	32	12.6
Education	Bachelor's	104	40.9
	Master's	112	44.1
	PhD	38	15.0
Occupation	Operations Manager	88	34.6
	Sustainability Officer	46	18.1
	Supply Chain Manager	72	28.3
	Energy/Utility Manager	48	18.9

Source: *Author's fieldwork, 2026*

Questionnaire Distributed: 303

Returned: 268
Valid for Analysis: 254
In Table 1, demographic data of respondents from Nigeria's industrial sector is shown. Male respondents (63.8%) are nominated, reflecting their evident dominance in industrial management. Most respondents (37.8%) are aged 35 to 44 years, which is the mid-career level, and most respondents (59.1%) hold postgraduate degrees, which increases the reliability of the responses. The largest occupational group were operational managers (34.6%) followed by supply chain managers (28.3%). The response rate was 83.8%, which increases the statistical validity and representativeness of the study.

Table 2: Structural Equation Modelling Results

Hypothesis	Path Coefficient (β)	t-value	p-value	Decision
H_1	0.42	5.87	<0.001	Supported
H_2	0.35	4.92	<0.001	Supported
H_3	0.39	5.14	<0.001	Supported
H_4	0.51	6.78	<0.001	Supported

Table 2 contains the SEM results for four hypotheses. H_1 is supported since energy efficiency positively impacted operational performance ($\beta = 0.42$, $p < 0.001$). Water stewardship practices positively impacted environmental performance ($\beta = 0.35$). The integration of sustainable supply chain practices resulted in a positive impact on competitiveness ($\beta = 0.39$). The variable integrated nexus (energy-water-supply chain efficiency) has the highest combined impact at ($\beta = 0.51$), supporting H_4. The results provide evidence for synergistic improvement in performance through holistic management of resources.
The structural equation model demonstrated satisfactory goodness-of-fit indices, indicating that the proposed conceptual model adequately explained the relationships among the study variables. All hypothesized relationships were statistically significant, suggesting that integrated resource efficiency positively influences operational efficiency, environmental sustainability, and industrial competitiveness.

Discussion

This study's findings indicate stronger support for the statistical evidence in Table 2, which had all hypothesized relationships positive and significant at $p < 0.001$. The strong path coefficient for energy efficiency ($\beta = 0.42$) indicates that firms that invest in the optimization of energy systems have operational gains, which coincides with the findings of International Energy Agency (IEA, 2023) which use energy productivity as an industrial competitiveness driver. The positive impact of water stewardship practices ($\beta = 0.35$) also agrees with Udoinyang (2024) which states that better water stewardship governance improves the environmental performance of Nigerian institutions. Sustainable supply chain integration ($\beta = 0.39$) supports Khan et al. (2022) which associates green procurement and logistics in facilitating competitiveness at the firm level in low and middle-income

countries. These findings are consistent with recent evidence from Nigerian industries, which suggests that integrated resource management strategies significantly improve operational resilience and long-term industrial sustainability (Olota, 2026).

The integrated nexus effect ($\beta = 0.51$), the highest single coefficient, presents the best evidence of the recent nexus-based studies (D'Amato et al., 2020; UNEP, 2024) as it establishes that simultaneous optimization of energy, water, and supply chain systems, rather than isolated single-system interventions, provides the best outcome for sustainability. Most of these findings sustain the validity of the theoretical integration of RBV, Circular Economy Theory, and Ecological Modernization Theory (postulations) in the implementation of Nigeria's SDG 7, 9, and 12.

Conclusions

This study demonstrates that integrated resource efficiency significantly contributes to sustainable industrial transformation in Nigeria. The findings indicate that coordinated improvements in energy efficiency, water stewardship, and sustainable supply chain management enhance operational performance, environmental sustainability, and organizational competitiveness. The study further establishes that integrated resource management provides greater sustainability benefits than isolated resource optimization initiatives. These findings reinforce the importance of adopting holistic industrial policies that simultaneously address multiple dimensions of resource efficiency.

Consequently, policymakers, industrial managers, and development agencies should prioritize integrated resource efficiency as a strategic mechanism for achieving sustainable development goals 7, 9 and 12 while promoting long-term industrial competitiveness in Nigeria.

This study contributes to the literature by providing an integrated framework for examining the combine influence of energy efficiency, water stewardship, and sustainable supply chain management on sustainable industrial transformation in Nigeria. Unlike previous studies that consider these demonstrations separately, the study demonstrates their synergistic effects on operational and environmental performance, thereby providing evidence to support integrated resource-efficiency policies for developing economies.

Recommendations

In line with the findings of the study, the paper recommended that:

1. Government should expand fiscal incentives, including tax credits, grants, and concessional financing, to encourage industries to adopt energy-efficient and water-efficient technologies.
2. Regulatory agencies should strengthen compliance monitoring through regular environmental audits and enforcement of industrial resource efficiency standards.
3. Manufacturing firms should institutionalize periodic resource-efficiency, water infrastructure, and transportation systems to reduce operational inefficiencies across industries supply chains.
4. Greater investment should be made in reliable electricity, water infrastructure, and transportation systems to reduce operational inefficiencies across industrial supply chains.
5. Industries should accelerate digital transformation by adopting smart metering, Internet of Things technologies, Artificial Intelligence, and digital supply chain monitoring systems.

6. National industrial policies should mainstream integrated resource efficiency into Nigeria's Energy Transition Plan and broader sustainable industrial development strategies to accelerate progress towards SDGs 7, 9 and 12.

Conflicts of interest

The author declares no conflict of interest.

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Author contribution

Nathan Udoinyang: Conceptualization; Methodology; Data curation; Formal analysis; Investigation. Ndinwa Ifeanyichukwu Blessing: Visualization; Writing-original draft preparation. Chikaodinaka Okwunka: Writing—review and editing; Validation; Supervision. The author has read and agreed to the published version of the manuscript.

Declaration of generative AI in scientific writing

The author acknowledges having used the Generative AI tool Quillbplt-AI for grammar/language improvement. The author is solely responsible for all published content and has verified the accuracy and authenticity of the AI output.

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