

Integrating Small Modular Reactors (Smrs) Into Africa's Water And Energy Nexus For Sustainable Development

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Abstract

Sub-Saharan Africa faces a critical intersection of energy insecurity, freshwater scarcity, and inadequate liquid waste management, all of which undermine sustainable development. Small Modular Reactors (SMRs) offer a flexible, low-carbon solution capable of addressing these challenges by providing reliable baseload electricity and process heat for desalination and wastewater treatment.

This paper proposes an integrated deployment framework for SMRs within Africa's water-energy nexus, combining technical feasibility, geospatial suitability, and governance readiness. A PESTLE-informed geospatial model identifies high-potential zones in Ghana, Nigeria, and South Africa, incorporating political stability, nuclear readiness, water stress, and infrastructure capacity. A comparative institutional analysis evaluates the roles of ECOWAS, the West African Power Pool (WAPP), and the African Union's Agenda 2063 in advancing SMR deployment.

Findings indicate strong technical suitability in select regions but highlight persistent barriers, including fragmented regulations, financing constraints, and limited public acceptance. To address these, the paper outlines three pathways: (1) harmonized regional nuclear governance to streamline oversight and build trust; (2) innovative financing through blended capital and public-private partnerships to lower entry risks; and (3) decentralized SMR-powered water-energy hubs aligned with circular economy principles to enhance local resilience.

By reframing SMRs as enablers of integrated water and energy resilience rather than as electricity generators alone, this research underscores their potential to accelerate Africa's climate adaptation, industrialization, and sustainable development.

Keywords: Circular Economy, Governance, Regional Integration, Sustainable Development, Sub-Saharan Africa, Small Modular Reactors, Water-Energy Nexus,

INTRODUCTION

1.1 Background and Context

Sub-Saharan Africa is currently grappling with significant issues related to energy insecurity, freshwater scarcity, and inefficient wastewater management, which threaten sustainable development. Despite having rich natural resources, the local energy and water systems are inadequate to meet the escalating demands. Reliance on hydropower, which is a major part of the energy mix, is becoming unreliable due to climate change impacts such as variability and droughts. Although thermal generation from fossil fuels temporarily alleviates some energy needs, it introduces vulnerabilities to fuel price

fluctuations and jeopardizes climate goals. Furthermore, conventional wastewater treatment facilities are energy-intensive and struggle to keep up with the rapid urbanization and industrial growth. To address these intertwined challenges, innovative solutions, particularly the deployment of Small Modular Reactors (SMRs), are proposed. SMRs offer low-carbon, reliable baseload electricity and can also provide process heat that facilitates desalination and advanced wastewater treatment. This positions them as comprehensive infrastructures that can simultaneously tackle energy security and water resilience issues. Internationally, SMRs are recognized as flexible and low-carbon energy solutions, particularly beneficial for remote and resource-limited areas. They have shown promise in various pilot projects for desalination and wastewater treatment in the Middle East and Asia. However, their potential integration into African water-energy frameworks has not been thoroughly examined. The regional governance structures, including initiatives like Agenda 2063, and energy collaborations like the West African Power Pool (WAPP) present opportunities for implementing SMR projects. Nonetheless, challenges such as regulatory and financial barriers, as well as public acceptance issues—especially in countries with weak nuclear governance persist.

This research proposes a novel framework to deploy SMRs within Sub-Saharan Africa's water-energy nexus, asserting that their integration into decentralized water systems and circular economy strategies could bolster water resilience, support the valorization of liquid waste, and contribute to the development of climate-resilient infrastructure.

Chapter 2. Literature Review

Conventional water-energy systems in Africa are centralized and carbon-intensive, causing challenges in providing reliable water services, especially in rural and peri-urban areas. Existing nuclear energy frameworks predominantly focus on grid-scale electricity, neglecting non-electric uses like desalination and wastewater treatment. This research aims to explore the deployment of Small Modular Reactors (SMRs) in the African context as a means to enhance water security and manage liquid waste amid pressing freshwater scarcity and energy insecurity.

The study proposes an integrated framework that incorporates SMRs into desalination, advanced liquid waste processing, and circular economy practices. The first objective involves assessing the feasibility of SMR-powered facilities through PESTLE-informed geospatial analysis to identify optimal locations based on hydrological stress, population density, and environmental factors. The second objective examines regional governance and national regulatory environments influencing SMR deployments, focusing on institutions like ECOWAS and WAPP.

Additionally, this research examines the alignment of SMR systems with circular economy principles and the UN Sustainable Development Goals as part of the broader Agenda 2063 framework. To guide the inquiry, four central research questions are posed: (1) what parameters define optimal SMR deployment zones for water-energy applications? (2) What legal and institutional barriers hinder SMR adoption and how can they be overcome? (3) How can platforms like ECOWAS and WAPP facilitate capacity-building and regulatory harmonization? (4) How can SMR integration promote liquid waste valorization and decentralized water-energy systems? A detailed strategic roadmap for deploying SMRs will also be proposed, balancing technological viability with governance and financing considerations.

2.1 Introduction

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TABLE 2.1 ILLUSTRATIVE GLOBAL SMR APPLICATIONS FOR WATER SYSTEMS

Country/Project	SMR Type	Application Focus	Lessons for Africa
Russia – Akademik Lomonosov	Floating SMR	Electricity + Desalination	Coastal and remote deployment feasible
UAE – Post-Barakah Plan	Land-based SMR	District water + energy supply	Dual-use integration with urban water
China – Linglong One (ACP100)	Modular SMR	Industrial steam + wastewater	Supports circular industrial applications

Source: Authors own work

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2.6 Gaps and Contribution of the Study

Current literature on small modular reactors (SMRs) and African sustainability transitions shows three principal gaps: (1) limited framing of SMRs as integrated solutions for the water–energy nexus (including desalination, industrial water reuse, and liquid waste management); (2) a shortage of interdisciplinary frameworks that combine geospatial analysis, technical feasibility, and governance; and (3) inadequate examination of regional cooperation mechanisms (ECOWAS, SADC, African Union) as facilitators of harmonized nuclear governance and cross-border energy integration. This study responds by developing a PESTLE-informed geospatial suitability model and performing an institutional analysis of Africa’s nuclear governance landscape. Framing SMRs within circular economy, energy sovereignty, and regional integration discourses, the research produces policy-relevant insights on nuclear-enabled sustainability in the Global South and maps potential avenues for Russia–Africa energy diplomacy to bolster national resilience and regional cooperation.

2.7 Summary

The reviewed literature affirms the transformative potential of SMRs for Africa while underscoring substantial technical, institutional, and regional barriers to deployment. Bridging these gaps requires integrating technical innovation with regional governance strategies and circular economy principles to unlock SMRs’ contributions to sustainable water and waste systems. The next chapter describes the methodological approach centered on the PESTLE geospatial model and institutional analysis used to address these interlinked challenges.

3. Methodology

This study focuses on examining the potential deployment of Small Modular Reactors (SMRs) within the water-energy nexus of Sub-Saharan Africa. The research deliberately concentrates its geographical focus on Ghana and South Africa, two countries that represent divergent yet instructive trajectories in nuclear energy development. These nations were selected due to their strategic significance within the wider Sub-Saharan context and their potential to provide valuable insights for broader regional application. The investigation centers on SMR technology, which is emerging as a promising solution for both energy production and water resource management. The study emphasizes the modularity and scalability of these reactors, highlighting their potential to address pressing water resource challenges beyond traditional energy generation.

Methodologically, the research privileges a qualitative-dominant paradigm that integrates secondary data analysis with expert insights. It contextualizes findings through institutional and geospatial frameworks, focusing particularly on the convergence of Energy and water sectors within the broader context of sustainable development and climate resilience.

The thematic focus of the study is the energy-water nexus, which is examined through the lens of sustainable development goals. Temporally, the investigation is framed within a near- to medium-term horizon, spanning approximately the next decade to a decade and a half. This timeframe allows for a realistic assessment of emerging technologies and evolving regulatory environments.

Despite its comprehensive design, the study acknowledges several inherent limitations. The reliance on secondary data presents challenges related to data currency, completeness, and granularity, which vary across the Sub-Saharan landscape. The qualitative dimension, derived primarily from expert interviews conducted in Ghana and South Africa, while rich in contextual nuance, may constrain the broader generalizability of findings across the diverse African continent.

The country-specific focus, while strategically justified, necessitates caution when extrapolating conclusions to other states with distinct political, economic, and infrastructural realities. Additionally, the nascent status of SMR technology introduces uncertainties regarding designs, regulatory environments, and deployment pathways, which may affect both feasibility assessments and policy recommendations.

The geopolitical and institutional landscape governing regional cooperation and energy integration remains fluid, potentially reshaping the conditions underpinning SMR adoption beyond the temporal scope of this research. Furthermore, the study's dependence on secondary sources and limited primary data collection may omit valuable insights that could enrich the analysis.

In conclusion, while this research endeavors to provide a rigorous exploration of SMR deployment within the energy-water nexus, it does so with a transparent acknowledgment of its methodological and contextual constraints. By focusing on specific case studies and employing a multifaceted approach, the study contributes valuable insights into the potential role of SMRs in advancing sustainable development goals in Sub-Saharan Africa, while maintaining a realistic understanding of its limitations. The research underscores the need for continued exploration and validation of findings through further empirical investigation and broader stakeholder engagement to fully realize the potential of SMRs in addressing Africa's water and energy challenges.

Chapter 4. Findings and Analysis

4.1 Introduction

This chapter presents the findings of the PESTLE-structured geospatial suitability analysis and comparative institutional assessment conducted to evaluate the potential deployment of Small Modular Reactors (SMRs) for sustainable water security and liquid waste management in Sub-Saharan Africa. Drawing on geospatial modelling, secondary data, and expert interviews with:

- Douw Vermaak, Political Counsellor at the South African Embassy in Moscow, Russian Federation;
- Dr. Robert Sogbadji, Deputy Director, Nuclear and Alternative Energy, Ghana's Ministry of Energy and Green Transition; the analysis is structured into three parts:

1. Geospatial suitability analysis — identifying high-potential zones and spatial disparities;
2. Institutional readiness assessment — evaluating continental, regional, and national governance frameworks;
3. Integrated policy pathways — outlining actionable steps for SMR-enabled sustainability transitions.

The findings reveal considerable disparities in SMR deployment potential, shaped by overlapping political, economic, technological, environmental, and social factors. Governance capacity, infrastructural readiness, and regulatory harmonization emerge as decisive determinants of deployment feasibility. Notably, regional frameworks such as ECOWAS, WAPP, and the African Union's Agenda 2063 present latent but underutilized platforms for scaling SMR-enabled circular water-energy systems.

4.1.1 Expert Insights: South African Diplomatic Perspectives on SMR Deployment

To deepen the contextual understanding, this study incorporates expert insights from the South African diplomatic mission, as articulated by Douw Vermaak, who underscores the heterogeneous nuclear energy trajectory across Africa. "Africa's nuclear energy trajectory is progressing, but the pace differs sharply between countries," Vermaak explains. He identifies Egypt's El Dabaa nuclear project as "a continental benchmark for technology deployment, financing structures, and skills development," highlighting its role as a model for other nations.

Vermaak emphasizes the practical advantages of SMRs, particularly for countries with weaker electricity grids: "SMRs can provide reliable baseload power, stabilize renewable-heavy systems, and serve as an anchor for industrialization in energy-constrained regions." He further stresses that "Africa's success in SMR adoption will hinge on proven international projects establishing cost and schedule credibility," underscoring the importance of demonstrated feasibility to build confidence.

From South Africa's experience, Vermaak draws attention to the necessity of robust institutional frameworks: "Strong, independent regulation supported by a single accountable operator is critical." He cautions against the pitfalls of premature technology pursuit without assured markets, referencing the Pebble Bed Modular Reactor programme's challenges. Whole-of-government coordination is equally vital, with "energy, finance, environment, and foreign affairs structures working in synchrony" to ensure project viability.

Financing emerges as a central theme, described by Vermaak as "the primary bottleneck, with long-term vendor-backed credit and sovereign guarantees essential to bankability." Early policy clarity and regulatory readiness are necessary to "lower investor risk and shorten timelines," while simultaneous technical capacity building, through operator training linked to ongoing international SMR projects, is paramount.

A novel dimension of SMR deployment highlighted in the interview concerns the energy-water nexus. Vermaak articulates SMRs' dual potential: "SMRs can deliver both electricity and process heat, enabling integrated desalination and wastewater treatment systems," positioning them as pragmatic responses to water scarcity challenges. Potential pilot sites, such as Ghana's Nsuban nuclear site, could "anchor a power-and-water hub serving mining operations and urban development," provided environmental considerations are addressed.

Moreover, Vermaak identifies regional institutions as crucial enablers: “ECOWAS, SADC, and the African Union can streamline nuclear adoption by aligning technical codes, safety standards, and emergency planning protocols.” International engagement through the IAEA and BRICS offers pathways for “capacity building, favorable financing, and technology transfer.”

Finally, he stresses the importance of public engagement and socio-economic framing: “Consistent transparency builds public trust,” and SMRs should be framed as “integrated power–water–jobs platforms” that support a just energy transition, delivering community benefits beyond electricity generation.

These expert insights provide an authoritative and contemporary lens on the multifaceted factors influencing SMR deployment in Africa, complementing the quantitative geospatial and institutional analyses presented herein.

4. Summary of PESTLE and Institutional Findings

The PESTLE-informed geospatial model revealed clear spatial differentiation in the technical and governance feasibility of SMR deployment across Sub-Saharan Africa. Coastal Ghana and Nigeria emerged as the most promising regions due to their combined advantages of moderate political stability, established nuclear planning roadmaps, proximity to desalination demand centers, and access to port and energy transmission infrastructure. Semi-arid corridors in South Africa, particularly the Western and Northern Cape provinces, also demonstrated high environmental and technological suitability, supported by an advanced nuclear regulatory environment and existing grid capacity.

In contrast, the model indicated lower suitability scores across Central and East African states, where weak governance indicators, limited infrastructure, and high environmental vulnerability constrain immediate SMR feasibility. The social and legal dimensions—including public acceptance and absence of harmonized nuclear safety regulations—were the lowest scoring variables continent-wide, underscoring the importance of institutional reform and public engagement.

The comparative institutional analysis reinforced these spatial patterns. Regional frameworks such as ECOWAS and its specialized agencies—WAPP, ERERA, and ECREEE—were found to possess the latent coordination capacity for cross-border energy integration but lack dedicated nuclear governance mandates. Ghana and South Africa scored highest on institutional readiness, reflecting mature regulatory bodies aligned with IAEA standards, while Nigeria demonstrated intermediate potential due to ongoing but fragmented institutional reforms. The African Commission on Nuclear Energy (AFCONE), although central to continental oversight, remains under-resourced and limited in enforcement capability.

Collectively, these findings highlight a dual challenge: while technical feasibility for SMR-based water–energy systems is advancing in select countries, governance fragmentation, financing constraints, and public trust deficits remain the principal barriers to large-scale adoption. The results justify a regionalized approach that leverages the institutional strengths of anchor countries to build continental regulatory coherence and investor confidence in SMR-enabled infrastructure.

4.2 Geospatial Suitability Analysis

4.2.1 Overview

The PESTLE-informed multi-criteria decision analysis (MCDA) revealed spatial variations in both the technical and socio-political feasibility of SMR deployment across Sub-Saharan Africa. The modelling integrates infrastructure accessibility, population density, water stress levels, regulatory frameworks, and nuclear capacity readiness.



FIG. 4.1 A PESTLE-STRUCTURED GEOSPACIAL SUITABILITY MODEL FOR SMR DEPLOYMENT IN SUB-SAHARAN AFRICA.

Source: Author's elaboration based on PESTLE-informed analysis (Karikari, 2025).

Figure 4.1 illustrates the composite structure of the adapted PESTLE framework, which integrates these dimensions into a coherent assessment model tailored to the unique deployment challenges and opportunities of SMRs in the Sub-Saharan context.

4.2 Expert Interview Analysis: PESTEL Perspectives on SMR Deployment in Africa

The article discusses the multifaceted dimensions influencing Small Modular Reactor (SMR) adoption in Africa, as explored by experts Vermaak and Sogbadji.

4.2.1 Political Dimensions

The success of SMR implementation hinges on effective governance and political stability. Vermaak notes South Africa's commitment through environmental authorizations for new nuclear sites, while Sogbadji emphasizes the need for regional organizations like ECOWAS and the African Union to address regulatory fragmentation.

4.2.2 Economic Dimensions

Financing is identified as a critical barrier, requiring vendor-backed credit and innovative models to offset high initial costs. Vermaak highlights South Africa's nuclear infrastructure, while Sogbadji points to Ghana's roadmap as a model for integrating SMRs with local development.

4.2.3 Social Dimensions:

Public acceptance is crucial, with Vermaak citing South Africa's outreach efforts during nuclear extensions to build trust. Both experts advocate for positioning SMRs as integrated socio-economic platforms to gain community support.

4.2.4 Technological Dimensions

The article stresses the importance of technical feasibility in project deployment. Vermaak notes the necessity for regulation and operator training, while Sogbadji underlines the importance of adhering to IAEA standards.

4.2.5 Environmental Dimensions

SMRs are presented as solutions for water scarcity by enabling desalination. Both experts call for comprehensive environmental assessments and transparent waste management to ensure sustainability in their deployment.

4.2.6 Legal Dimensions

Regulatory harmonization among African states is essential for deploying small modular reactors (SMRs). Vermaak highlighted AFCONE's limited operational capacity due to funding and enforcement issues, which hampers its support for nuclear adoption. Enhancing AFCONE's technical authority and initiating regional peer reviews could promote SMR integration into water-energy strategies. Sogbadji mentioned that ECOWAS's organizations like WAPP and ECREEE could help coordinate nuclear energy policies. However, the lack of unified nuclear safety regulations poses a significant legal challenge, indicating the necessity for continent-wide frameworks to support cross-border nuclear projects and attract investors.

The expert interviews reveal that the success of Small Modular Reactor (SMR) deployment in Sub-Saharan Africa is influenced by the interplay of political will, economic feasibility, social acceptance, technological capacity, environmental responsibilities, and legal frameworks. Case studies from South Africa and Ghana highlight the need for integrated policy pathways, regional collaboration, and innovative financing. The findings suggest that effective SMR-enabled transitions in water and energy demand coordinated strategies that align with Africa's socio-political and environmental nuances.

1. Regional Regulatory Harmonization – Establish ECOWAS-wide nuclear liability, licensing, and safety standards under the African Commission on Nuclear Energy's (AFCONE) technical leadership to ensure uniform compliance and safeguard operational integrity.
2. Innovative Financing Mechanisms – Mobilize blended finance instruments, sovereign-backed guarantees, and public-private partnerships to address the capital intensity of SMR projects and enable equitable access for smaller economies (AfDB, 2025).
3. Decentralized Water-Energy Hubs – Deploy SMR-powered desalination and wastewater treatment hubs in water-stressed regions, integrated with circular economy principles to maximize resource efficiency.

4.3 Summary of Expert Interview Insights

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3. Decentralized SMR-Powered Water-Energy Hubs

Barrier addressed: Infrastructural asymmetry, water stress, and low social acceptance of nuclear technologies. The PESTLE environmental and social indicators revealed that water scarcity and public mistrust are major non-technical challenges. Deploying decentralized SMR-powered desalination and wastewater hubs in high-stress regions such as coastal Ghana, inland Nigeria, and South Africa's semi-arid provinces addresses both simultaneously. These hubs localize benefits by providing clean water, electricity, and employment, demonstrating tangible community gains. Integrating circular-economy principles (resource recovery, waste-heat reuse) further enhances environmental performance and public legitimacy. Visible local benefits and participatory governance structures can gradually shift public perceptions, fostering a social license to operate for nuclear technologies. Together, these pathways create a complementary reform architecture: Regulatory harmonization mitigates fragmented governance. Blended finance reduces capital-related risk and mobilizes private participation. Decentralized water-energy hubs improve infrastructure equity and build community trust. Collectively, they transform current structural weaknesses into enabling conditions for SMR-enabled sustainability transitions across Africa.

5.2 Summary of Key Findings

The study set out to examine the strategic potential of SMRs in addressing Africa's interconnected challenges of energy insecurity, freshwater scarcity, and inadequate liquid waste management. Three core findings emerged:

1. Geospatial Suitability for SMR Deployment

The PESTLE-structured multi-criteria assessment identified coastal and semi-arid regions particularly in Ghana, Nigeria, and South Africa as promising zones for SMR integration. These regions demonstrate high water stress, proximity to dense population centers requiring decentralized water infrastructure, and favorable policy support for nuclear development.

2. Institutional Readiness and Regional Governance

While ECOWAS and the African Union (AU) offer foundational structures for coordinated action, deployment is constrained by fragmented nuclear regulation, under-resourced agencies such as AFCONE, and uneven national technical capacities. However, strong national frameworks in Ghana and Nigeria could serve as anchor points for sub-regional demonstration projects.

3. Sustainability and Circular Economy Potential

In the framework advanced by this study, Small Modular Reactors (SMRs) are not conceived merely as electricity generation assets; rather, they are positioned as catalysts for integrated circular resource systems. By providing stable baseload power and process heat, SMRs can drive advanced wastewater treatment, desalination, and climate-resilient infrastructure deployment. This reconceptualization situates SMRs as pivotal enablers of Africa's transition toward a circular economy, where resource recovery, waste valorization, and closed-loop systems underpin sustainable development. The alignment

of SMR applications with the African Union's Agenda 2063 and the United Nations Sustainable Development Goals particularly SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), and SDG 9 (Industry, Innovation, and Infrastructure) underscores their potential to catalyze integrated sustainability pathways across the Global South (African Union, 2023; AfDB, 2025).

5.3 Policy Recommendations

Building upon the empirical findings, the study proposes a suite of policy actions targeting national governments, regional organizations, and international development partners.

At the governance level, a Pan-African SMR Regulation Task Force should be established under the auspices of the African Commission on Nuclear Energy (AFCONe), drawing upon the technical expertise of ECOWAS, the Southern African Development Community (SADC), and the International Atomic Energy Agency (IAEA) to harmonize safety, liability, and licensing regimes across member states. Embedding SMR applications within existing African regional energy protocols such as the West African Power Pool (WAPP) and the Continental Power Systems Masterplan would further facilitate coordinated, cross-border adoption.

From a demonstration perspective, high water-stress zones such as northern Ghana and inland Nigeria present immediate opportunities for SMR-powered desalination, wastewater treatment, and irrigation infrastructure. Public-private partnerships (PPPs) should be structured to co-locate modular desalination units with SMRs, ensuring both municipal and industrial users benefit from reliable, sustainable water-energy services.

On the capacity-building and financing front, technical training programs should be expanded through the African Regional Cooperative Agreement (AFRA) and IAEA fellowships, with a focus on SMR operation, water-energy modeling, and nuclear safety management. Concurrently, African financial institutions such as Afreximbank and the African Development Bank (AfDB) should establish dedicated investment windows for nuclear-water infrastructure. Strategic cooperation with Russia, leveraging its operational experience in SMR deployment, could further accelerate the co-development of reactors tailored to African climatic, infrastructural, and socio-political conditions.



FIG. 5.1 POLICY RECOMMENDATIONS FOR SMR DEPLOYMENT IN SUB-SAHARAN AFRICA.

Source: Author's elaboration based on PESTLE framework and institutional analysis (Karikari, 2025).

As illustrated in Figure 5.1, the proposed SMR deployment strategy for Africa emphasizes legal harmonization, pilot demonstration projects, and regional capacity-building.

5.4 Theoretical and Practical Contributions

From a theoretical standpoint, the study advances literature on the nuclear-water-energy nexus in the Global Southland enriches Africa-focused energy diplomacy by emphasizing regional institutional integration as a catalyst for nuclear-enabled sustainability.

From a practical perspective, it introduces a replicable PESTLE-informed geospatial framework for identifying SMR deployment zones and provides a policy roadmap for multi-level governance reforms to support sustainable nuclear infrastructure in Africa.

5.5 Limitations

The expert interviews reveal that the success of Small Modular Reactor (SMR) deployment in Sub-Saharan Africa is influenced by the interplay of political will, economic feasibility, social acceptance, technological capacity, environmental responsibilities, and legal frameworks. Case studies from South Africa and Ghana highlight the need for integrated policy pathways, regional collaboration, and innovative financing. The findings suggest that effective SMR-enabled transitions in water and energy demand coordinated strategies that align with Africa's socio-political and environmental nuances.

5.6 Future Research Directions

5.7 Concluding Remarks

The expert interviews reveal that the success of Small Modular Reactor (SMR) deployment in Sub-Saharan Africa is influenced by the interplay of political will, economic feasibility, social acceptance, technological capacity, environmental responsibilities, and legal frameworks. Case studies from South Africa and Ghana highlight the need for integrated policy pathways, regional collaboration, and innovative financing. The findings suggest that effective SMR-enabled transitions in water and energy demand coordinated strategies that align with Africa's socio-political and environmental nuances.

This study contributes to the growing body of scholarship on Africa's energy transition by positioning Small Modular Reactors (SMRs) as strategic instruments for achieving energy sovereignty, sustainable water security, and improved liquid waste management. Through a PESTLE-informed geospatial suitability model and institutional analysis, the research demonstrates how regionally integrated deployment of SMRs within ECOWAS, WAPP, ERERA, and ECREEE frameworks can enhance both national and regional energy resilience. The study advances the concept of "energy diplomacy through micro-regional integration," showing that collaborative governance can make nuclear innovation a catalyst for economic stability and environmental sustainability in West Africa.

The sustainable development of Africa depends on integrated infrastructure systems capable of addressing multiple vulnerabilities simultaneously. Small Modular Reactors, when aligned with forward-looking water policy and regional cooperation, hold the

potential to transform Africa's energy and water landscape enhancing climate resilience, public health, and industrialization.

Realizing this vision demands more than technological readiness; it requires a coherent continental strategy that integrates energy diplomacy, regulatory harmonization, and institutional innovation. By presenting a grounded interdisciplinary framework for SMR deployment, this study contributes to Africa's pursuit of water and energy sovereignty and offers a foundation for future policy and research initiatives in nuclear-enabled sustainability.

Nevertheless, the research acknowledges significant limitations. The high capital costs of SMR technologies, limited public acceptance due to nuclear perception risks, and institutional readiness gaps across many African states remain critical barriers to immediate implementation. Moreover, data limitations in modeling cross-border energy-water nexus impacts restrict the generalizability of certain findings.

Future research should therefore focus on comprehensive cost-benefit frameworks, public engagement strategies, and pilot-scale deployment models to assess socio-economic and environmental performance of SMRs in real-world African contexts. Cross-sectoral collaboration between governments, regional energy agencies, and international partners such as Rosatom and the IAEA will be essential to bridge the gap between technological feasibility and public legitimacy. By addressing these challenges, future studies can strengthen the foundation for an inclusive, secure, and sustainable African nuclear energy future that supports regional integration and long-term energy independence.

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