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Water-energy nexus: A review of policy and practice in Africa and the USA

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Abstract

This comprehensive review explores the intricate relationship between water and energy in the contexts of Africa and the United States, shedding light on the evolving policies and practices that shape the Water-Energy Nexus (WEN). As the demand for both water and energy intensifies globally, understanding the interdependencies and synergies between these critical resources becomes imperative for sustainable development. In Africa, the WEN presents a unique set of challenges and opportunities. The region grapples with water scarcity, unreliable energy access, and the impacts of climate change. This review assesses the diverse policy frameworks implemented across African nations to address the WEN, examining their effectiveness and identifying gaps for improvement. Furthermore, it highlights innovative practices and successful interventions that have emerged within the African context, contributing valuable insights for sustainable water and energy management. Contrastingly, the United States, with its matured infrastructure and advanced technologies, navigates the complexities of the WEN with a different set of dynamics. The review delves into the multifaceted policy landscape in the U.S., analyzing federal, state, and local initiatives aimed at optimizing the interplay between water and energy resources. Lessons learned from the American experience offer valuable benchmarks for other regions striving to enhance resource efficiency, resilience, and environmental sustainability. Key themes addressed in this review include integrated planning, technological innovations, regulatory frameworks, and community engagement. The synthesis of experiences from Africa and the USA provides a nuanced understanding of the global challenges associated with the WEN and offers a foundation for future research and policy development. Ultimately, this review underscores the importance of holistic approaches that transcend geographical boundaries, encouraging collaborative efforts to address the pressing issues at the intersection of water and energy.

Keyword: Water; Energy; Policy; USA; Africa; Review

1. Introduction

The water-energy nexus (WEN) refers to the interconnected relationship between water and energy, recognizing the interdependencies and interactions between the two resources (Leck et al., 2015). This nexus has gained global significance due to its impact on various sectors, including agriculture, industry, and urban development (Zhang et al., 2018). The WEN is crucial for sustainable development, as it influences resource management, environmental conservation, and economic growth (Keskinen et al., 2016).

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The purpose of this review is to understand the policy and practice related to the WEN in Africa and the USA. By examining the nexus approach, the review aims to identify challenges and opportunities in managing water and energy resources, particularly in the context of climate change adaptation (Rasul & Sharma, 2015). Furthermore, the review seeks to inform sustainable development strategies by analyzing the potential synergies and trade-offs between water and energy management (Rasul & Sharma, 2015). Understanding the policy and practice in Africa and the USA is essential for developing integrated solutions and supporting informed decision-making (Papadopoulou et al., 2020).

The WEN has been increasingly recognized as a critical framework for addressing resource efficiency and governance in transboundary river basins (Strasser et al., 2016). Moreover, the inclusion of health considerations in the WEN literature highlights the need for a comprehensive approach that integrates various aspects of human well-being into the nexus framework (Nuwayhid & Mohtar, 2022). The review will draw on these insights to provide a comprehensive understanding of the WEN in different contexts.

In conclusion, the WEN plays a vital role in shaping sustainable development strategies, and understanding its policy and practice in Africa and the USA is essential for addressing the challenges and opportunities associated with water and energy management. By synthesizing the existing literature on the WEN, this review aims to provide valuable insights for policymakers, researchers, and practitioners involved in resource management and environmental sustainability.

2. The Water-Energy Nexus in Africa

The water-energy nexus in Africa presents a complex web of challenges and interdependencies. Water challenges in the region include acute water scarcity and the impacts of climate change, which have implications for national and food security (McNally et al., 2019). The vicious positive feedback between water scarcity, food production constraints, undernourishment, and poverty has tended to delay socio-economic development in water-scarce regions in Sub-Saharan Africa (Falkenmark, 2013). Furthermore, the prevailing water scarcity in Africa is attributed to population-driven scarcity, where an increasing number of people jointly depend on each unit of water (Musse, 2021). This scarcity is exacerbated by insufficient water resource management, infrastructure limitations, and climate change impacts (Gulamussen et al., 2019). The impacts of climate change, economic development, and urbanization are expected to strengthen interdependencies in the water, energy, and food nexus in southern Africa, reinforcing the costs of trade-offs and complementarities across the nexus, especially with the adoption of expansionist regional hydropower and biofuel strategies (Conway et al., 2015).

In terms of energy challenges, unreliable energy access and infrastructure limitations are prominent issues. The increasing water scarcity challenges in southern Africa may have dire consequences if not well managed, as water scarcity directly affects energy production, particularly hydropower (Matchaya et al., 2019). Additionally, the economic and environmental effects of coal mining in South Africa contribute to water scarcity, further exacerbating the energy challenges in the region (Wang, 2023).

The interplay between water and energy in the African context is intricate, with water scarcity directly impacting energy production and reliability. The decrease in annual discharge across Africa due to climate change is expected to significantly affect present surface water supplies, particularly impacting hydropower production (Hamududu & Killingtveit, 2016). Furthermore, the water-energy nexus is influenced by the challenges and opportunities for revitalizing smallholder irrigation schemes in South Africa, which are the largest consumer of water in the country, accounting for about 62% of water utilization (Fanadzo & Ncube, 2018).

Existing policies in Africa aimed at addressing the water-energy nexus include national policies, regional cooperation, and case studies from select African nations. The Department of Water and Sanitation, water boards, municipalities, and special-purpose vehicles in South Africa are engaged in regulating water and its safe delivery in the water sectors (Aiyetan & Das, 2021). However, there is limited application of probabilistic graphical models, such as Bayesian networks, to water resources management studies in South Africa, indicating a potential gap in policy implementation and decision-making processes (Govender et al., 2021).

In assessing policy effectiveness, it is crucial to address the gaps and challenges while identifying opportunities for improvement. The impact of water-related challenges on rural communities' food security initiatives in Africa, particularly in water-scarce countries like Ethiopia, underscores the need for comprehensive policy measures to address these challenges (Nephawe et al., 2021). Furthermore, the threats of climate change on water and food security in South Africa highlight the urgency of effective policies to mitigate the impacts of water scarcity on food security (Balogun et al., 2024; Kwame et al., 2022).

Innovative practices such as sustainable technologies and community-led initiatives are essential for addressing the water-energy nexus in Africa. Water resilience in a changing urban context in Africa presents opportunities for sustainable urban water management and highlights the potential power of city-regions to drive transformation (Habtemariam et al., 2021; Akindote et al., 2023). Additionally, climate change adaptation strategies towards reducing vulnerability to drought in Northern Ghana emphasize the importance of innovative practices to address water scarcity and its impacts on energy and food security (Adonadaga et al., 2022).

3. The Water-Energy Nexus in the USA

The water-energy nexus in the USA is a complex and interconnected system that requires a comprehensive understanding of infrastructure, technology, and regulatory frameworks to ensure sustainable management. The infrastructure and technology in the water-energy nexus involve the coordination of energy interactions in various sectors such as subway and electric vehicles, microgrids, and smart energy hubs to meet the demand for electrical and thermal energy as well as water load (Babarinde et al., 2023; Daneshvar et al., 2022). Regulatory frameworks play a crucial role in the water-energy nexus, with the movement towards subjecting regulatory interventions to cost-benefit analysis gaining considerable traction in the USA, particularly in the regulation of drinking water quality (Ogus, 2004).

At the federal level, key initiatives and legislation have been put in place to address the water-energy nexus. The GCAM-USA v5.3_water_dispatch model represents interactions across economic, energy, water, and land systems in a consistent global framework, providing subnational detail in the United States (Binsted et al., 2021; Binsted et al., 2022). This integrated modeling approach allows for a comprehensive understanding of the interdependencies within the water-energy nexus.

State and local policies also play a significant role in the variability and adaptability of the water-energy nexus. The high productivity in Integrated Water Resources Management (IWRM) research in the USA is attributed to the dedicated human resources in universities and research institutions (Abrahams et al., 2024; Gallego-Ayala, 2013). Additionally, the management of agricultural nonpoint source pollution continues to be a chief impediment to achieving water quality standards in both the USA and Europe, highlighting the importance of state and local policies in addressing water quality issues (Hassan et al., 2024; Drevno, 2016).

The integration of water and energy planning requires coordination between agencies and comprehensive resource management. The water-energy-food (WEF) nexus has become an important concept in natural resource management, emphasizing the need to identify synergies and trade-offs among the nexus dimensions (Hamidov & Helming, 2020; Nuwayhid & Mohtar, 2022). Furthermore, the nexus approach aims to address the multiple interdependencies that exist between the water, energy, and food sectors, highlighting the importance of comprehensive resource management (Seeliger et al., 2018; Babatunde et al., 2021).

Technological innovations are crucial for addressing the water-energy nexus, particularly in renewable energy integration and water conservation technologies. The optimal stochastic water-energy nexus management model proposed in Daneshvar et al. (2022) covers energy interactions and aims to coordinately supply electrical and thermal energy demand as well as water load, demonstrating the importance of technological advancements in managing the nexus.

In conclusion, the water-energy nexus in the USA requires a multidimensional approach that encompasses infrastructure, technology, regulatory frameworks, federal, state, and local policies, integration of planning, and technological innovations to ensure sustainable management.

4. Comparative Analysis

To conduct a comparative analysis of the water-energy nexus in Africa and the USA, it is essential to consider the contrasts and commonalities, lessons learned from both regions, and the global implications for water-energy-nexus (WEN) policies and practices.

In Africa, the application of the water-energy nexus concept for water supply is limited compared to developed regions (Macharia et al., 2020). This highlights a contrast with the USA, where the nexus approach has been widely studied and applied (El-Gafy & Apul, 2021). However, both regions face challenges related to the water-energy-food (WEF) nexus, reflecting the complexity and magnitude of the issues (Keskinen et al., 2016).

Lessons learned from Africa include the importance of regional integration and development in addressing the water-energy nexus (Mabhaudhi et al., 2016). Additionally, it is increasingly acknowledged that the water-energy-climate change (WECC) nexus poses a significant risk to achieving sustainable development goals in Africa (Mathetsa et al., 2019). These lessons emphasize the need for holistic approaches to address the interconnections between water, energy, and food in the African context.

In the USA, the water-energy-food nexus has been widely studied, reflecting the importance of these sectors and the complexity of the challenges they face (Keskinen et al., 2016). Furthermore, the USA has developed models and methodologies for assessing the impacts of policy interventions on the water, energy, and land/food sectors (Miralles-Wilhelm et al., 2018). These lessons highlight the significance of quantitative approaches and policy assessments in managing the WEN nexus.

The global implications for WEN policies and practices are significant. The water-energy-food nexus has emerged as a productive discourse and methodology in academic research, science-policy dialogues, and development agendas (Grenade et al., 2016). It is essential to ensure the explicit inclusion of water quality within the WEF nexus, considering local contexts rather than striving for a one-size-fits-all global framing for analysis (Arnbjerg-Nielsen et al., 2022). Moreover, the nexus approach promotes cross-sectoral integration, emphasizing the need for comprehensive decisions in managing WEN systems (Artioli et al., 2017).

In conclusion, the comparative analysis of the water-energy nexus in Africa and the USA reveals contrasts in the application and development of the nexus approach. Lessons learned from both regions underscore the importance of regional integration, holistic approaches, and quantitative assessments. The global implications emphasize the need for inclusive and context-specific policies and practices to address the complexities of the WEN nexus.

5. Future Directions

The water-energy nexus is a critical area of study that requires attention to emerging trends, recommendations for policymakers, and areas for further research and study. Advancements in technology play a crucial role in shaping the future of the water-energy nexus. emphasized the importance of understanding the water-energy nexus for urban water systems and its environmental impacts, providing informative recommendations for future policy directions (Lee et al., 2017). Additionally, highlighted the significance of heat-integrated water allocation networks and solution strategies, which are essential for comprehensively reviewing recent contributions and future directions related to the water-energy nexus (Kermani et al., 2018).

Evolving climate scenarios also significantly impact the water-energy nexus. discussed the impacts of climate change on irrigation and crop production, emphasizing the implications for energy use and greenhouse gas emissions (Yan et al., 2018). This highlights the need for policymakers to consider climate change in the context of the water-energy nexus.

Recommendations for policymakers are crucial for effective management of the water-energy nexus. stressed the importance of advancing the water-energy nexus in the context of urban metabolism and extending past literature reviews to capture water and energy integration policy (D'Souza, 2020). This underscores the need for policymakers to integrate water and energy policies for sustainable development.

Areas for further research and study in the water-energy nexus are essential for advancing knowledge and addressing complex challenges. suggested future strategies for water resource management to consider the concept of the water-energy nexus for sustainability planning and development (Lee et al., 2018). Additionally, provided a systematic review of methods for nexus assessment, emphasizing the rapid expansion of the water-energy-food nexus in scholarly literature and policy settings as a novel way to address complex resource and development challenges (Albrecht et al., 2018).

In conclusion, the water-energy nexus requires attention to advancements in technology, evolving climate scenarios, recommendations for policymakers, and areas for further research and study to ensure effective management and sustainable development.

6. Recommendation

The review highlighted diverse challenges in the Water-Energy Nexus (WEN) across Africa and the USA, ranging from water scarcity and unreliable energy access in Africa to the matured infrastructure and technological complexities in

the USA. Examining policy frameworks revealed variations in approach, with Africa emphasizing regional cooperation and the USA emphasizing federal, state, and local integration. Both regions showcased successes and shortcomings in addressing WEN challenges. Innovative practices in both Africa and the USA were identified, showcasing sustainable technologies and community-led initiatives. These success stories offer valuable lessons for global WEN management. Africa's experiences emphasized the need for adaptive policies, community engagement, and a focus on renewable energy sources to address the unique challenges faced by the continent in managing water and energy resources. The USA's experiences highlighted the importance of coordinated planning, regulatory frameworks, and technological innovations in achieving a balanced and sustainable WEN.

Recognizing the global nature of water and energy challenges, there is a need for enhanced international collaboration. Shared knowledge, technology transfer, and financial support can aid regions facing similar WEN issues. Policymakers globally should adopt a holistic approach, considering both water and energy needs in tandem. Integrated planning at national, regional, and local levels should be prioritized to ensure comprehensive resource management. Encouraging innovation is crucial for sustainable WEN management. Investments in research and development of new technologies, as well as the promotion of renewable energy sources, can drive positive change on a global scale. Building local capacity, particularly in regions with limited resources, should be a priority. Education, training, and empowerment of communities can enhance their ability to implement sustainable WEN practices. Policies and practices should be designed with adaptability and resilience in mind. Given the uncertainties associated with climate change, dynamic strategies that can withstand evolving challenges are essential.

7. Conclusion

In conclusion, the review emphasizes the importance of a nuanced understanding of the Water-Energy Nexus, drawing on the experiences of Africa and the USA. By learning from successes and challenges, and by implementing the recommended actions, a more sustainable and resilient global WEN management system can be achieved.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest is to be disclosed.

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