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A Multi-Criteria Policy Coherence Index for Water–Energy–Food Nexus Governance and Energy Transition Pathways in Sub-Saharan Africa

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Abstract

Ensuring sustainable management of water, energy, and food (WEF) resources requires governance frameworks capable of addressing cross-sectoral interdependencies and policy fragmentation. This study evaluates the performance and coherence of national water, energy, and agricultural policies in Mali, South Africa, Malawi, and Tanzania, with a focus on their contribution to WEF nexus integration and energy transition pathways. A mixed-methods approach is applied, combining qualitative policy analysis, stakeholder consultations ($n = 52$), and a composite policy coherence index to assess cross-sectoral policy alignment across three river basins: the Bani River Basin (Mali), the Songwe River Basin (Malawi–Tanzania), and the Inkomati–Usuthu Water Management Area (South Africa). The results indicate that key water policy dimensions such as conservation, pollution control, and stakeholder participation demonstrate high performance (mean = 1.0) and strong coherence (SD = 0.0–0.1) across all countries. However, these values primarily reflect the presence of policy instruments rather than their effective implementation. Stakeholder evidence highlights persistent gaps in enforcement, coordination, and institutional capacity. In the energy sector, core infrastructure and participation policies exhibit high performance (mean = 1.0; SD = 0.0), while critical market instruments—including feed-in tariffs (FITs) and power purchase agreements (PPAs)—show moderate performance (mean = 0.6–0.8) and high variability (SD = 0.4–0.5), indicating regulatory inconsistency. In the agricultural sector, economic incentives achieve high performance (mean = 1.0; SD = 0.0), whereas sustainable practices such as agroecology, crop rotation, and organic fertilization remain weakly integrated (mean = 0.1–0.4; SD up to 0.5). Overall, the findings reveal that WEF nexus governance is characterized by strong structural policy alignment (mean = 0.8–1.0) but limited functional integration, reflecting a gap between policy design coherence and implementation effectiveness. Strengthening regulatory frameworks, improving cross-sectoral coordination, and enhancing investment mechanisms are critical for advancing resource efficiency and accelerating energy transition. The study provides a reproducible framework for assessing policy coherence and offers policy-relevant insights for integrated resource governance in Sub-Saharan Africa.



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1. Introduction

The water–energy–food (WEF) nexus has emerged as a critical framework for promoting sustainable development in Africa, particularly in addressing the complex interdependencies among water, energy, and food systems. The WEF nexus is widely conceptualized not only as a framework for understanding biophysical interdependencies between water, energy, and food systems but also as a governance approach that emphasizes coordination across sectors, institutions, and policy domains. While many nexus studies focus on system dynamics modelling, resource optimization, or trade-off analysis, there is growing recognition that achieving nexus outcomes depends equally on the coherence of policy and institutional frameworks that guide resource management.

In this study, the WEF nexus is approached from a policy and governance perspective, focusing on how sectoral policy instruments incorporate and reflect cross-sectoral interlinkages. Rather than explicitly modelling physical interactions between systems, the analysis evaluates whether policy design supports integrated planning, coordination, and resource allocation across water, energy, and agricultural sectors.

This approach has gained increasing prominence in both scholarly and policy discourse due to its potential to address complex and interconnected sustainability challenges such as climate change, rapid population growth, and resource scarcity, which pose substantial risks to water, energy, and food security in the region [1–3]. Given Africa’s vulnerabilities, the WEF nexus provides a pathway for integrated governance that optimizes resource use, enhances resilience, and strengthens cross-sectoral collaboration [4,5]. Policymakers and scholars have increasingly recognized this approach as instrumental in aligning national and regional strategies with global targets such as the Sustainable Development Goals (SDGs). These include SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), and SDG 13 (Climate Action) [1,6]. Recent global assessments by the International Energy Agency [7], World Bank [8], United Nations Environment Programme [9] and the Intergovernmental Panel on Climate Change [10] highlight the critical role of integrated policy frameworks in enabling low-carbon transitions and climate resilience. By fostering synergies between these sectors, the nexus lenses seek to create water, energy and food resilient systems that effectively address interconnected socio-economic and environmental challenges.

Despite its promise, the adoption of the WEF nexus approach in sub-Saharan Africa has progressed at a relatively slow pace. Its implementation faces barriers such as fragmented policies, weak governance frameworks, and insufficient institutional capacity [1,3]. However, the need to meet growing demands for water, energy, and food in a sustainable manner underscores the urgency of integrating WEF nexus governance into national and regional policies [11]. Within this nexus, the energy sector is pivotal in shaping resource interdependencies and transition pathways: it underpins water supply (e.g., pumping, treatment, desalination) and agricultural production (e.g., irrigation, processing), while also being shaped by water availability and land-use dynamics. Consequently, the coherence of energy policy instruments is essential for advancing low-carbon transitions, expanding energy access, and strengthening system resilience across sub-Saharan Africa.

Emerging studies emphasize that nexus challenges are not only technical but fundamentally governance-related, requiring coherent policy frameworks and coordinated

institutional arrangements to manage cross-sectoral interdependencies effectively [12]. At the same time, empirical evidence on the effectiveness of WEF nexus governance remains limited. Recent case studies highlight that while collaborative governance structures can support sustainability outcomes, integration is often uneven across governance levels and sectors, with persistent gaps in coordination and implementation [13]. This has led to growing calls for more systematic and comparative approaches to assessing nexus governance. In response, the recent literature has begun to develop analytical frameworks that incorporate multi-criteria decision-making, policy coherence assessment, and integrated evaluation tools to better capture trade-offs, synergies, and cross-sectoral alignment within WEF systems [14]. These approaches recognize that fragmented policy environments remain a major barrier to effective nexus implementation, particularly in transboundary and developing country contexts where institutional coordination is often limited [15]. Despite these advances, there remains a gap in the development of reproducible, governance-oriented metrics that systematically quantify policy coherence across water, energy, and food sectors while explicitly linking these dynamics to energy transition pathways. This study contributes to addressing this gap by advancing a structured multi-criteria policy coherence framework that enables comparative assessment across countries and sectors.

Awareness of the WEF nexus governance approach has been steadily growing in sub-Saharan Africa, particularly at the regional level. Regional Economic organizations such as the Southern African Development Community (SADC) and the Economic Community of West African States (ECOWAS) have made significant progress in promoting policy coherence and adopting nexus governance frameworks. Agriculture remains a cornerstone of economic growth and livelihoods in these regions, contributing approximately 20.2% to SADC's GDP in 2015 and employing about 70% of the active labour force [16]. Similarly, agriculture accounts for about 35% of ECOWAS's GDP, relying heavily on water resources, particularly for irrigated farming, and employing roughly 60% of the active labour force [17,18]. While interest in the WEF nexus continues to expand, existing studies have predominantly focused on either qualitative stakeholder analysis [19–21], descriptive policy analysis [22–24], participatory governance assessments [15,25–28], or integrated modelling approaches [29–32]. Although these contributions provide valuable insights into system dynamics and resource interdependencies, they often lack a systematic and reproducible method for evaluating policy coherence across sectors. In particular, there remains a limited body of empirical work that quantitatively assesses how policy instruments align across water, energy, and agricultural domains, and how such alignment influences system integration and energy transition pathways in the Global South, especially in Sub-Saharan Africa. This gap highlights the need for robust analytical frameworks capable of linking policy coherence to both governance performance and sustainability outcomes. Recent studies increasingly emphasize that WEF nexus research must move beyond conceptual framing and modelling exercises toward policy coherence, institutional coordination, and implementation-oriented governance assessment [12,14]. In Africa, this is particularly important because nexus implementation is shaped by fragmented mandates, uneven institutional capacity, and persistent investment constraints across water, energy, and agricultural systems [14,15,33].

Even with recent institutional progress, competition over water resources remains a persistent challenge at the national level, driven by conflicting demands from domestic, industrial, and agricultural sectors. This competition highlights the need for governance frameworks that promote equitable resource distribution while supporting long-term sustainability. At the same time, the limited availability of comprehensive policy coherence nexus-oriented studies and their practical implementation continues to constrain policy relevance at the national and regional scales [34,35]. Addressing this gap is critical, as frag-

mented or misaligned policy environments can constrain investment, weaken institutional coordination, and slow progress toward sustainable energy transitions and climate-resilient development [36]. While policy coherence is increasingly recognized as a key enabling condition for integrated governance, it is rarely operationalized in a way that allows for comparative and empirical assessment across sectors and countries. This study addresses this gap by developing and applying a multi-criteria policy performance and coherence framework to assess the extent to which national sectoral policy instruments align, reinforce synergies, or generate trade-offs across water, energy, and food systems in four Sub-Saharan African countries.

The analysis focuses on three case studies: the Bani River Basin (Mali), Songwe River Basin (Malawi and Tanzania), and Inkomati-Usuthu Water Management Area (South Africa). The selection of these river basins is based on their representation of diverse yet comparable contexts of WEF nexus governance in Sub-Saharan Africa. The countries were selected according to three criteria. First, they represent varied institutional, economic, and policy contexts within Sub-Saharan Africa, including differences in governance capacity, sectoral development, and energy transition dynamics. Second, each country is linked to a major river basin (Bani, Songwe, and Inkomati-Usuthu) where interdependencies between water, energy, and food systems are particularly pronounced, providing a relevant empirical setting for nexus analysis. Third, all four countries have established national policy frameworks across water, energy, and agricultural sectors, enabling systematic comparison using a consistent set of policy indicators.

Together, they provide a comparative framework capturing variation in institutional capacity, policy environments, and energy transition dynamics, while sharing common challenges related to resource interdependencies, climate vulnerability, and governance fragmentation. This diversity allows for a meaningful assessment of policy coherence across different socio-economic and institutional contexts. The findings are intended to support policymakers and researchers in enhancing governance frameworks, strengthening policy coherence, and promoting integrated resource planning and investment. The study addresses the following research questions:

- (i) How coherent are national policy frameworks across water, energy, and food sectors in selected African countries?
- (ii) To what extent do existing policies support integrated WEF nexus governance?
- (iii) What are the implications of policy coherence for energy transition and sustainable resource management?

By addressing these questions, the study contributes to the literature in three keyways. First, it advances the operationalization of the WEF nexus by introducing a structured and replicable policy performance and coherence index. Second, it bridges qualitative stakeholder insights with quantitative policy assessment, enhancing analytical robustness. Third, it explicitly links WEF governance to energy transition processes, thereby aligning with current priorities in sustainable energy research.

The study aims at conceptualising policy coherence not as an end, but as a necessary enabling condition for socio-technical transitions in WEF systems. WEF governance is to be intended as a dynamic, multi-level system evolving from fragmented sectoral regimes toward integrated and adaptive nexus governance. This transition perspective informs the present analysis by framing policy coherence as a precondition for energy transition, climate resilience, and long-term system integration.

The growing body of literature on the Water–Energy–Food nexus has increasingly shifted from conceptual and biophysical analyses towards questions of governance, policy integration, and institutional effectiveness. Recent contributions have explored policy coherence assessment, adaptive governance, integrated planning frameworks, and energy

transition strategies across diverse geographical contexts. Table 1 summarizes selected studies published between 2024 and 2026 and highlights the emerging consensus that coordinated policy frameworks and effective institutional arrangements are essential for advancing sustainable resource management and supporting energy transition objectives.

Table 1. Recent literature on WEF nexus governance, policy coherence, SDGs, and energy transition, 2024–2026.

Study	Region/Focus	Method/Approach	Main Relevance to This Manuscript
[37]	Tana River Basin, Kenya	Policy coherence analysis	Directly supports the use of policy coherence analysis for WEF nexus governance.
[38]	Sweden	Policy coherence assessment	Demonstrates how water, energy, food, land, and climate policies can be assessed for coherence.
[39]	Africa	Review and policy analysis	Shows that WEF nexus implementation in Africa requires stronger policy and governance integration.
[40]	South Africa	Mapping WEF nexus innovations	Supports the importance of local innovations, indigenous knowledge, and sustainability transitions.
[41]	Africa	Policy and regulatory review	Highlights the regulatory role of PPPs and renewable energy policy frameworks in Africa.
[42]	Sub-Saharan Africa	Econometric policy analysis	Shows how fossil fuel subsidies can delay renewable energy transition.
[43]	West Africa	Policy and regulatory analysis	Demonstrates the importance of policy harmonization for renewable energy and power pooling.
[44]	Mediterranean region	Regional assessment report	Provides recent evidence on WEF nexus governance, climate risks, and integrated responses.
[45]	Sub-Saharan Africa	Policy and finance report	Supports discussion on renewable energy finance and policy instruments in SSA.
[46]	Danube River Basin	WEF coherence assessment	Provides a recent example of nexus coherence assessment using participatory and quantitative tools.
[47]	Global/WEF governance	Conceptual and governance review	Strengthens theoretical framing of WEF governance and cross-sectoral coordination.
[14]	Global/SDGs	Nexus-SDG assessment	Links WEF nexus planning to SDG acceleration and integrated resource governance.
[48]	Water-food-energy planning	Multi-objective optimization	Shows how policy scenarios can be evaluated through WEF nexus modelling.
[49]	WEF governance	Adaptive governance analysis	Supports the role of adaptive governance in managing WEF interdependencies.
[50]	Sub-Saharan Africa	Empirical energy policy analysis	Links renewable energy policy pathways to sustainability and energy access.
[16]	Sub-Saharan Africa	Financing and policy analysis	Supports discussion on investment mechanisms and green hydrogen development.
[51]	Sub-Saharan Africa	Energy transition report	Provides international evidence on just energy transition and large-scale renewables.

Table 1. *Cont.*

Study	Region/Focus	Method/Approach	Main Relevance to This Manuscript
[52]	Global sustainability governance	Bibliometric/policy intervention analysis	Strengthens SDG/environmental policy framing.
[53]	Global/SDG 13	Econometric sustainability analysis	Demonstrates how artificial intelligence, circular economy practices, and energy intensity influence climate action (SDG 13), reinforcing the importance of integrated policy and technological frameworks for sustainable development.
[54]	Djibouti/SSA	Renewable energy transition assessment	Supports discussion on wind energy opportunities and renewable transition in SSA.
[55]	Sub-Saharan Africa	Governance-energy efficiency analysis	Shows that governance quality and green policy shape renewable energy efficiency.

2. Case Study Context

(a) The Bani River Basin (BRB) context

The Bani is one of the longest rivers in West Africa, stretching approximately 700 km in length [56]. It flows into the inner Niger Delta at Mopti and is a large contributor to the annual flooding of the Niger Inner Delta [57]. The population is confronted with challenges associated with water scarcity, energy access, and food security [58]. The interdependence of these sectors is crucial for the country's sustainable development, given that its economy relies heavily on its river systems, particularly the Senegal and the Niger. The country's main wetland is the Inner Niger Delta (IND), located in central Mali. It covers an area of about 4 million hectares. The IND is also important for food production, not just for Mali but for West Africa as a whole. The area accounts for about 15% of the country's cereal production (maize, sorghum, millet, fonio, rice) and 80% of its fisheries catch [59]. During the dry season, the IND is also home to 50% of the national livestock herd. Competition over access and control of water resources is at the root of many of the conflicts affecting central Mali [60].

(b) The Songwe River Basin (SRB) context

The Songwe River Basin, shared between Malawi and Tanzania, provides a rich context for examining the WEF nexus due to its transboundary nature and resource interdependencies. The basin spans approximately 4200 km² and supports the livelihoods of over one million people, with agriculture serving as the primary economic activity [61]. Water resources in the basin are vital for irrigation, hydropower generation, and domestic consumption, making integrated management crucial for balancing competing demands [62,63].

Energy production, particularly hydropower, is a key focus in the basin, offering opportunities to address energy deficits while supporting agricultural productivity through irrigation schemes [61,62]. However, challenges such as seasonal water variability, climate change impacts, and governance gaps have hindered effective resource management [5,64]. Collaborative governance frameworks, such as the Songwe River Basin Development Programme (SRBDP), aim to address these challenges by promoting integrated planning and investment in infrastructure to enhance resilience and sustainability [3,65].

(c) Inkomati-Usuthu Water Management Area (IUWMA) context

The Inkomati-Usuthu Water Management Area (IUWMA), located in South Africa, is a key transboundary water system that serves as a critical resource hub for water, energy, and food production. Spanning parts of Mpumalanga Province, IUWMA is characterized by

multiple river systems, including the Komati, Crocodile, and Sabie Rivers, which also flow into neighboring Mozambique and Eswatini [66,67]. This region supports significant agricultural activities, including sugarcane and citrus farming, which rely heavily on irrigation, thereby intensifying water demand [67,68]. Energy production in IUWMA is also closely linked to water availability, as hydropower generation and thermal power plants depend on sustainable water supply systems. Additionally, the region's food security is tied to efficient water management practices and irrigation infrastructure, underscoring the importance of integrating the WEF nexus approach to balance competing water demands [66].

Governance challenges in IUWMA include fragmented water resource management, conflicting stakeholder interests, and pressures from climate variability. These challenges highlight the need for adaptive governance frameworks that incorporate WEF nexus principles to ensure resource sustainability and equitable access [69]. The IUWMA case study serves as a practical example for developing policy coherence and methodological approaches for sustainable governance across water, energy, and food systems in Africa.

2.1. Theoretical Framework

2.1.1. Conceptualizing the WEF Nexus as a Policy Interaction System

The Water–Energy–Food (WEF) nexus is increasingly recognized as a critical framework for addressing the interconnected challenges of resource scarcity, climate change, and sustainable development. While early contributions emphasized biophysical linkages and resource flows, recent advances highlight governance, institutional coordination, and policy integration as central to operationalizing the nexus [3,70]. Building on the foundational work of [71] and subsequent nexus scholarship, this study conceptualizes and operationalizes the WEF nexus as a policy interaction system that captures the synergies and trade-offs across sectoral policy instruments and their implications for integrated resource management. By framing the nexus as a policy interaction system, the study explicitly links governance structures to system-level outcomes, thereby enabling empirical assessment of nexus integration.

2.1.2. Integrated Resources Governance

The study builds on the principles of integrated resource governance, which advocate for coordinated management of interconnected systems through cross-sectoral and multi-level institutional arrangements [1,66]. This approach recognizes that fragmented governance structures are ill-suited to address complex challenges arising from the interdependence of water, energy, and food systems.

Integrated governance emphasizes:

- coordination across sectoral institutions,
- alignment of policy objectives across scales, and
- inclusive stakeholder engagement processes.

In the context of Sub-Saharan Africa, however, governance systems are often characterized by institutional fragmentation, overlapping mandates, and limited coordination capacity [72,73]. These structural constraints contribute to inconsistencies in policy design and implementation, thereby undermining the effectiveness of nexus-based approaches. In adopting this perspective, the study evaluates not only the presence of policy instruments but also their capacity to function cohesively within an integrated governance system.

2.1.3. Policy Coherence Theory

The analytical framework is further grounded in policy coherence theory, which focuses on the alignment and consistency of policy objectives and instruments across sectors [74]. Policy coherence is widely recognized as a key condition for achieving sustainable

development, particularly in contexts involving multiple interacting systems. Two key dimensions are emphasized: horizontal coherence, referring to alignment across sectors such as water, energy, and agriculture, and vertical coherence, denoting consistency across governance levels from national to regional and local institutions. High coherence indicates aligned policy signals across sectors that enable synergistic outcomes, whereas low coherence reflects fragmentation that produces unintended trade-offs, thereby bridging governance analysis and nexus theory. Importantly, policy coherence is distinguished from policy performance, which captures the presence of policy instruments rather than their integration [35,75].

2.1.4. Systems Interdependency Theory

The WEF nexus is inherently shaped by complex interdependencies among resource systems. These interconnections are conceptualized through systems interdependency theory, which highlights feedback mechanisms, non-linear dynamics, and cross-sectoral interactions [64,70]. It analyzes how these interdependencies (e.g., water for hydropower vs. irrigation agriculture, energy for water pumping vs. food production) are represented, facilitated, or constrained within policy frameworks, thereby extending systems interdependency theory into the realm of governance and policy analysis. These interactions generate feedback loops that can amplify vulnerabilities or create opportunities for synergistic resource use. From a governance perspective, this implies that sectoral policies must be evaluated within a systemic framework that accounts for cross-sectoral impacts.

2.1.5. Energy Transition Theory

Energy transition theory provides an important framework for understanding how policy coherence influences the transformation of energy systems toward low-carbon, resilient, and sustainable configurations. Beyond technological innovation, energy transitions are shaped by governance structures, regulatory stability, institutional coordination, and investment conditions. In this context, coherent policy environments play a central role in reducing uncertainty, improving planning consistency, and facilitating the deployment of renewable energy technologies [76,77].

Within the Water–Energy–Food (WEF) nexus, energy transitions are closely interconnected with water and agricultural systems. Energy policies influence irrigation systems, water treatment and distribution infrastructure, agricultural processing, and rural development, while water availability and land-use dynamics simultaneously affect energy production pathways. Consequently, fragmented or inconsistent policy frameworks can generate cross-sectoral trade-offs, constrain investment, and weaken system resilience.

This study applies energy transition theory to examine how policy instruments such as feed-in tariffs (FITs), power purchase agreements (PPAs), investment de-risking mechanisms, renewable energy planning frameworks, and grid-access regulations shape transition outcomes within interconnected WEF systems. Recent studies increasingly emphasize that coherent regulatory frameworks are essential for strengthening investor confidence, reducing transaction costs, and accelerating renewable energy deployment, particularly in developing regions [16,51]. Conversely, policy fragmentation, weak institutional coordination, and unstable regulatory environments may increase investment risk and slow the diffusion of renewable technologies [38,43].

From a nexus perspective, coherent energy policies can generate broader sustainability benefits by supporting climate-resilient irrigation systems, reducing reliance on biomass energy, improving water service delivery, and enhancing resource efficiency across sectors. In this sense, energy transition theory contributes to understanding how integrated policy

frameworks can support both decarbonization objectives and cross-sectoral resilience within WEF governance systems.

2.1.6. Synthesis and Analytical Implications

Drawing on the theoretical perspectives outlined above, the Water–Energy–Food (WEF) nexus is conceptualized in this study as a governance challenge shaped by policy interactions, institutional dynamics, and system interdependencies. Rather than focusing solely on biophysical linkages or techno-economic optimization, the analysis adopts a policy-oriented lens that emphasizes how sectoral policy instruments interact to influence resource management outcomes.

Within this framework, policy coherence is treated as a central analytical construct, reflecting the extent to which policies across water, energy, and agricultural sectors are aligned; mutually reinforcing; or, conversely, fragmented and conflicting. This perspective enables the systematic assessment of cross-sectoral policy alignment using measurable indicators, thereby moving beyond descriptive interpretations of nexus governance.

The analytical approach is guided by three key propositions. First, the presence of policy instruments alone does not guarantee effective governance; alignment across sectors is equally critical for achieving sustainable outcomes. Second, policy coherence can be operationalized and measured as an indicator of governance integration, providing a basis for comparative analysis across countries and sectors. Third, energy transition processes are not isolated phenomena but are closely influenced by policy interactions within the broader WEF nexus, particularly in contexts where water availability and agricultural demands shape energy system development.

By integrating these dimensions, the study contributes to existing nexus research by offering a governance-focused analytical framework that complements traditional modelling approaches. It provides a structured method for evaluating how policy configurations influence system-level outcomes, including resource efficiency, resilience, and sustainability.

The framework is also consistent with institutional and policy economics, where coherent policy design is understood as a mechanism for reducing transaction costs, improving regulatory predictability, and supporting efficient resource allocation across sectors [13,46,78,79]. In this sense, fragmented or misaligned policy environments may generate inefficiencies, increase uncertainty for investors and stakeholders, and ultimately constrain the effectiveness of both resource governance and energy transition pathways.

3. Materials and Methods

3.1. Analytical Framework

This study adopts a mixed method approach to assess policy performance and coherence within the WEF nexus. The analytical framework integrates Qualitative Document Analysis (QDA), stakeholder-informed evaluation, and a composite index methodology to quantify policy performance and coherence across sectors. The proposed composite index complements existing biophysical modelling approaches by assessing whether formal policy instruments are aligned in ways that enable cross-sectoral coordination, reduce trade-offs, and support integrated resource planning. In doing so, the study advances WEF nexus scholarship by linking policy coherence theory, integrated resource governance, and energy transition perspectives within a comparative empirical assessment across four sub-Saharan African countries. The index is thus positioned as a governance-oriented diagnostic tool, designed to directly assess policy effectiveness, capturing the extent to which policy instruments advance key sustainability objectives, and policy coherence, capturing the degree of formal alignment across sectors, rather than biophysical WEF interactions. The WEF nexus is conceptualized as an interconnected policy system in which coherence denotes

the degree of alignment among sectoral policy instruments, while performance captures the extent to which these instruments advance key sustainability objectives. The study is not designed as a causal econometric analysis of energy transition outcomes, but rather as a governance-oriented comparative assessment of policy coherence and institutional alignment across WEF sectors. The analytical framework therefore focuses on evaluating the extent to which sectoral policy instruments support cross-sectoral coordination, governance integration, and coherent resource management within interconnected water, energy, and food systems.

3.2. Data Collection

The analysis is based on two primary data sources:

- (i) Policy documents: National policies, strategies, legal frameworks, and sectoral plans related to water, energy, and agriculture were systematically reviewed across the four countries.
- (ii) Stakeholder engagement: Workshops and semi-structured interviews were conducted in three river basins (Bani, Songwe, and Inkomati-Usuthu). Participants included policymakers, technical experts, and representatives from public and private institutions.

A total of 52 stakeholders participated across the case studies (Table 2). Stakeholders were selected using a purposive and stratified sampling approach to ensure representation across key actor groups involved in WEF nexus governance. These included policymakers, technical experts, basin authorities, and representatives from public and private institutions. Selection criteria were based on institutional relevance to water, energy, and agricultural sectors; experience in policy design or implementation; and involvement in basin-level governance processes. Data collection was conducted through a combination of structured workshops and semi-structured interviews. Workshops were designed to facilitate policy validation, and group-based assessment of the relevance of policy instruments and implementation gaps. Semi-structured interviews followed a standardized guide focusing on policy implementation, coordination mechanisms, and perceived governance challenges. All data were documented, and where possible, transcribed and coded for analysis.

Table 2. Stakeholder workshops organized across the case studies.

Case Study	Place of Workshop	Date of Workshop	Stakeholders
Bani River Basin Area (Mali)	Piémont Hotel, Bougouni (Mali)	6–7 December 2023	23
Songwe River Basin, East Africa (Malawi & Tanzania)	Mdope Ide Hotel, Mbeya (Tanzania)	15–16 February 2024	12
Inkomati-Usuthu Water Management Area (IUWMA), Southern Africa (South Africa)	Nelspruit, South Africa	20–22 February 2024	17

Potential sources of bias were addressed through several measures. Selection bias was mitigated by ensuring balanced representation across stakeholder groups. Response bias was reduced by anonymizing inputs and facilitating open, moderated discussions. Researcher bias was minimized through the use of predefined coding frameworks and triangulation across policy documents, interviews, and workshop outputs.

3.3. Qualitative Data Analysis

A Qualitative Document Analysis (QDA) approach was employed, using an open coding procedure. To minimize subjectivity, national policies, strategies, legal frame-

works, and sectoral plans related to water, energy, and agriculture across the four countries were systematically reviewed and iteratively coded against predefined criteria, including economic incentives, institutional capacity, governance mechanisms, and sustainability practices. Interview transcripts were transcribed, coded thematically, and triangulated with document analysis to enhance reliability by ensuring consistency and reducing subjective bias. This process enabled the identification of discrepancies between policy design and implementation. Validation was further strengthened through stakeholder workshops, where participants reviewed and verified policy inventories, scoring outcomes, and preliminary findings. Discrepancies between sources were addressed through consensus-based discussions, thereby reducing individual bias and improving the robustness of the analysis.

3.4. Scoring and Composite Index Construction

Policy performance and coherence (Table 3) were assessed using a structured multi-criteria scoring framework designed to evaluate the extent to which national policy instruments support integrated WEF nexus governance. The framework combines binary scoring, weighted alignment assessment, and composite indicator analysis to provide a systematic and reproducible basis for cross-country comparison.

Table 3. Scoring criteria for policy performance and coherence.

Policy Performance	
0.9–1.0	High Performance
0.7–0.8	Moderate Performance
0.5–0.6	Partial Performance
0.3–0.4	Low Performance
0.0–0.2	Very Low Performance
Policy Coherence	
0.0–0.1	High Policy Coherence
0.2–0.3	Partial Policy Coherence
0.4–0.5	Low Policy Coherence

At the first stage of the analysis, each policy instrument was assigned a binary score:

- 1 = presence of the policy instrument;
- 0 = absence of the policy instrument.

The binary scoring system was used to determine whether a policy instrument was formally included within national policy frameworks across the water, energy, and agricultural sectors. To improve transparency, the scoring framework distinguishes between policy presence and policy alignment. The binary score captures whether a policy instrument is formally present, while the weighted alignment score reflects the extent to which that instrument supports cross-sectoral coherence. This distinction reduces the risk of interpreting policy presence as implementation effectiveness and provides a more nuanced basis for comparing performance and coherence across countries.

To capture variations in alignment and coherence across policy instruments, the use of standard deviation (SD) enables the quantification of policy fragmentation or alignment, providing a reproducible proxy for nexus integration. Policy coherence in this study is operationalized as the degree of consistency in the alignment of policy instruments across sectors. To capture this, SD is used as a proxy measure of dispersion in weighted policy scores. Lower SD values indicate greater consistency across policy instruments, reflecting higher coherence, while higher values indicate greater variability and fragmentation. This

approach is consistent with composite index methodologies, where dispersion metrics are used to assess the degree of alignment across multiple indicators [58,80].

Graded weights of 0.1–0.5 were introduced. The weighting scheme was developed through structured expert elicitation during stakeholder workshops involving 52 participants across the three case studies. Participants were asked to assess the degree of alignment of each policy instrument using predefined categories. The assigned weights of 0.1–0.5 reflect increasing levels of coherence, where higher values indicate fragmentation and lower values indicate strong alignment. This approach is consistent with multi-criteria evaluation methods commonly used in policy assessment literature [81]. Policy performance was calculated as the arithmetic mean of policy instrument scores:

$$PI_c = \frac{1}{n} \sum_{i=1}^n S_{ic} \quad (1)$$

where:

PI_c is the policy performance index for country c , S_{ic} is the score assigned to policy instrument i in country c , and n is the total number of policy criteria.

Policy coherence was estimated using the SD of policy scores:

$$PC_c = \sqrt{\frac{1}{n} \sum_{i=1}^n (S_{ic} - \bar{S}_c)^2} \quad (2)$$

where PC_c represents policy coherence for country c , and $\bar{S}_c$ is the mean policy score. Lower SD values indicate stronger coherence because they reflect greater consistency across policy instruments.

3.5. Sensitivity and Robustness Analysis

To ensure consistency with the composite index methodology described in Section 3.4, a sensitivity analysis was conducted to evaluate the robustness of the results with respect to the weighting scheme applied to policy alignment scores. As the weights (0.1–0.5) were derived through structured expert elicitation, it is important to assess the extent to which variations in these weights may influence the overall findings. In this analysis, the assigned weights were systematically varied within a $\pm 10\%$ range while preserving their relative ordering (i.e., lower values representing stronger alignment and higher values indicating weaker coherence). For each variation scenario, the composite policy performance (mean score) and policy coherence (standard deviation) were recalculated across all policy instruments and case study countries.

The results show that the relative ranking of countries and policy dimensions remained unchanged across all tested scenarios, and only marginal variations were observed in the absolute values of the composite indices. High-performing policy dimensions continued to exhibit strong performance (mean ≈ 0.9 – 1.0) and low dispersion (SD ≈ 0.0 – 0.1), while lower-performing dimensions maintained their relative positions. This stability suggests that the results are not driven by the specific choice of weights but rather reflect underlying structural patterns in policy design and alignment. The consistency of findings across multiple weighting scenarios therefore supports the robustness and reliability of the analytical framework. This approach is consistent with established robustness testing practices in composite indicator construction and multi-criteria decision analysis [79,82].

These robust results provide additional confidence in the interpretation of policy performance and coherence presented in Section 4, indicating that the observed patterns are structurally consistent and not driven by methodological assumptions. Nevertheless, it is acknowledged that the weighting scheme remains dependent on expert judgment. Future work could further strengthen robustness by exploring alternative approaches, such as data-driven or entropy-based weighting methods.

4. Results and Discussion

It is important to note that the quantitative results presented in this section assess policy design coherence, that is, the extent to which policy instruments formally incorporate relevant WEF-related provisions. These scores do not directly measure implementation effectiveness. Implementation performance is examined through qualitative evidence from stakeholder workshops and interviews, which provides insight into institutional, financial, and governance constraints affecting the practical realization of policy objectives. Accordingly, instances where policy documents score highly but stakeholders report weak outcomes should be interpreted as reflecting a gap between formal policy alignment and implementation capacity.

4.1. Multicriteria Comparative Analysis of National Water Policies' Performance and Coherence

The analysis of national water policy instruments across the four countries indicates consistently high levels of formal policy coverage across several governance dimensions. Core policy areas including conservation and restoration, pollution control, hydrological monitoring, and stakeholder participation record high performance (mean = 1.0) and near-perfect coherence (SD = 0.0–0.1). These findings suggest that national frameworks broadly incorporate internationally recognized principles of water governance. However, such results should be interpreted with caution. These high scores primarily reflect the presence of policy provisions, rather than their effective implementation. Evidence from stakeholder consultations reveals persistent gaps in enforcement, coordination, and operational capacity. Similar divergences between formal policy alignment and implementation outcomes have been documented in recent studies of nexus governance in Sub-Saharan Africa, where institutional fragmentation often limits policy effectiveness despite strong formal frameworks [1,4]. This finding is consistent with recent policy coherence assessments showing that formal water-policy alignment can coexist with implementation gaps where institutional capacity, enforcement, and inter-sectoral coordination remain weak [37,47,79].

More differentiated patterns emerge in policy areas such as economic incentives and institutional capacity. These dimensions exhibit moderate-to-high performance (mean = 0.8–0.9) but greater variability (SD = 0.3–0.4), indicating uneven application across national contexts. This variability reflects differences in fiscal capacity, administrative structures, and regulatory maturity, which have been identified as key determinants of policy effectiveness in water governance systems [2].

At the country level, South Africa demonstrates strong internal consistency across policy instruments (mean $\approx$ 1.0; SD = 0.0–0.2), reflecting a relatively mature institutional framework. Nevertheless, stakeholder inputs point to coordination challenges and implementation bottlenecks, suggesting that structural coherence does not automatically translate into functional effectiveness. This finding aligns with the broader governance literature highlighting the gap between policy formulation and implementation in multi-level systems [11].

In Mali, water policies show high alignment with regional frameworks, contributing to relatively strong coherence ($SD \approx 0.2\text{--}0.3$). Yet, implementation challenges including weak enforcement and limited financial resources reduce their effectiveness at the national level. Similar patterns have been observed in transboundary basin governance, where regional alignment often coexists with domestic institutional constraints [61].

Tanzania and Malawi also display high formal policy performance (mean $\approx 0.9\text{--}1.0$), but weaker integration across sectors. Stakeholder feedback indicates that sectoral policies often operate independently, limiting coordination and reducing overall coherence. This fragmentation has been identified as a recurring challenge in nexus governance, particularly in developing contexts where institutional mandates remain compartmentalized [34].

Overall, the findings indicate that water policies across the case studies exhibit strong structural coherence but limited functional integration, highlighting the need for improved coordination mechanisms and implementation capacity.

Table 4 presents the full scoring matrix, while the discussion focuses on the indicators with the strongest policy relevance and highest cross-country variability.

4.2. Multi-Criteria Comparative Analysis of National Energy Policies' Performance and Coherence

The analysis of energy policy instruments reveals a more heterogeneous landscape compared to the water sector. While several policy dimensions such as infrastructure investment, research support, and stakeholder participation demonstrate high performance (mean = 1.0) and strong coherence ($SD = 0.0$), other critical instruments show significant variability.

Market-oriented instruments, including feed-in tariffs (FITs), power purchase agreements (PPAs), and investment de-risking mechanisms, exhibit moderate performance (mean = 0.6–0.8) and higher variability ($SD = 0.4\text{--}0.5$). This dispersion reflects inconsistencies in regulatory frameworks and policy commitment across countries. Similar findings have been reported in recent energy transition studies, where regulatory uncertainty and inconsistent policy design are identified as major barriers to renewable energy deployment [16]. The variability observed in FITs, PPAs, and de-risking instruments reflects wider challenges in African energy transitions, where regulatory uncertainty, fossil fuel subsidies, weak policy harmonization, and limited investment guarantees can slow renewable energy deployment [43,46].

From a transition perspective, these inconsistencies are particularly significant. FITs and PPAs play a central role in attracting private investment and facilitating renewable energy expansion. Weak or inconsistent implementation of these instruments increases investor risk and limits the scalability of clean energy systems, especially in emerging markets [16].

In Malawi and Tanzania, energy policies exhibit high formal coherence (mean = 1.0; $SD = 0.0$), suggesting strong internal alignment. However, stakeholder feedback highlights limited cross-sectoral integration and constraints related to financing and institutional capacity. This discrepancy underscores the importance of distinguishing between policy design and implementation, a challenge widely observed in energy governance systems in developing regions [2].

South Africa presents a more complex profile, with moderate performance (mean = 0.4–0.8) and higher variability ($SD = 0.4\text{--}0.5$). While this reflects a fragmented policy environment, the strong performance of targeted initiatives such as the Just Energy Transition Investment Plan (mean = 1.0) demonstrates strategic commitment to decarbonization. This duality is consistent with findings from countries undergoing structural energy transitions, where policy innovation coexists with institutional constraints [16].

Table 4. Performance and coherence of national water policies in selected African Countries.

Policy Instruments/Assessment Criteria	Mali		South Africa				Malawi			Tanzania			Mean (Horizontal Policy Performance)	Stdev.p (Horizontal Policy Coherence)
	NWP	NWSMP	NWP	NWRS	GWS	WCDMS	NWP	WRA	WRR	NWP	WSS	WSDP		
(1) Economic incentives (subsidies, funding, tax breaks, grants and credit guarantee schemes)	1	1	1	1	1	1	1	1	1	0	1	1	0.9	0.3
(2) Strengthening Institutional capacity	1	1	1	1	1	1	1	0	0	1	1	1	0.8	0.4
(3) Transparency and accessibility of information	1	1	1	1	1	1	1	1	1	1	0	1	0.9	0.3
(4) Basin and aquifer management	1	1	1	1	1	1	1	1	1	1	0	1	0.9	0.3
(5) Public–private and civil society partnerships	1	1	1	1	1	1	1	1	0	1	1	1	0.9	0.3
(6) Tenure and property rights	1	1	1	1	1	0	1	1	1	1	1	0	0.8	0.4
(7) Inclusive and equitable access to financial services, natural and economic resources	1	1	1	1	1	1	1	1	0	1	1	1	0.9	0.3
(8) Conservation, restoration, equitable and sustainable use of water resources	1	1	1	1	1	1	1	1	1	1	1	1	1.0	0.0
(9) Water pollution control	1	1	1	1	1	1	1	1	1	1	1	1	1.0	0.0
(10) In situ monitoring of national surface and/or groundwater availability	1	1	1	1	1	1	1	1	1	1	1	1	1.0	0.0
(11) Data, research, technology generation and information dissemination	1	1	1	1	1	1	1	1	1	1	1	1	1.0	0.0
(12) National budget for financing water resources infrastructure.	1	1	1	1	1	0	1	1	0	1	1	1	0.8	0.4
(13) Enforcement of water resources’ laws, guidelines and standards	1	1	1	1	1	1	1	1	1	1	1	1	1.0	0.0
(14) Inclusive stakeholder participation	1	1	1	1	1	1	1	1	1	1	1	1	1.0	0.0
(15) Equitable benefits sharing mechanisms	1	1	1	1	1	1	1	1	1	1	1	1	1.0	0.0
(16) Surface and ground water permits	0	0	1	1	1	1	1	0	1	1	1	1	0.8	0.4
(17) Payments for water services	0	1	1	1	1	1	1	1	1	1	1	1	0.9	0.3
(18) Protect and conserve ecologically sensitive areas	1	1	1	1	1	1	1	1	1	1	1	1	1.0	0.0
(19) Stormwater management to reduce flooding	1	1	1	1	1	0	1	1	1	1	0	1	0.8	0.4
(20) Improve water availability through aquifer recharge	1	1	1	1	1	1	1	1	1	1	0	1	0.9	0.3
(21) Smart water management technology to support real-time monitoring, forecasting, and risk assessment of hydrological including rainfall, water level, inflow and outflow.	0	1	1	1	1	1	1	1	1	1	1	1	0.9	0.3
(22) Strengthening hydrological forecast and early warning system	1	1	1	1	1	0	1	1	1	1	0	1	0.8	0.4
Mean (Vertical Policy Performance)	0.9	1.0	1.0	1.0	1.0	0.8	1.0	0.9	0.8	1.0	0.8	1.0	0.9	0.1
Standard Deviation (Vertical Policy Coherence)	0.3	0.2	0.0	0.0	0.0	0.4	0.0	0.3	0.4	0.2	0.4	0.2	0.2	0.2

GWS; Ground Water Strategy, NWRS; National Water Resource Strategy, NWSMP; National Water and Sanitation Master Plan, NWP; National Water Policy, WCDMS; Water Conservation and Demand Management Strategy, WSS; Water Supply and Sanitation, WSDP; Water Sector Development Programme, Water Resources Act (WRA), Water Resources Regulations (WRR).

In Mali, energy policies show relatively high performance (mean ≈ 0.9) but reveal gaps in market-based instruments such as FITs and PPAs. These gaps limit private sector participation and constrain the development of renewable energy markets. This aligns with regional studies emphasizing the importance of stable regulatory frameworks for energy investment in Sub-Saharan Africa [18].

Overall, the results suggest that while foundational policy structures exist, inconsistencies in key regulatory instruments may hinder effective energy transitions, reinforcing the need for stronger policy alignment and market-oriented reforms. These findings are consistent with recent studies highlighting regulatory uncertainty as a key barrier to renewable energy deployment in developing regions [7].

Table 5 presents the full scoring matrix, while the discussion focuses on the indicators with the strongest policy relevance and highest cross-country variability.

4.3. Multicriteria Comparative Analysis of National Agricultural Policies' Performance and Coherence

The assessment of agricultural policy instruments across Mali, South Africa, Malawi, and Tanzania reveals notable disparities in both policy performance and coherence. Economic incentives such as subsidies, grants, and credit mechanisms are consistently embedded across all four countries, achieving high performance (mean = 1.0) and perfect coherence (SD = 0.0). This uniformity reflects a shared policy emphasis on supporting agricultural productivity through financial instruments, a trend widely observed in developing economies where input-based approaches dominate policy frameworks [17].

In contrast, policy instruments promoting sustainable agricultural practices exhibit more varied performance. Climate-smart agriculture, agroecological practices, and improved seed systems show moderate performance (mean = 0.7–0.8) with high variability (SD ≈ 0.4). These findings align with recent nexus and agricultural water-management studies showing that climate-smart agriculture, agroecology, and resource-efficient practices are often recognized in policy language but remain unevenly mainstreamed in implementation frameworks [39,48,49]. This indicates increasing recognition of sustainability-oriented approaches, although their integration remains uneven. Similar findings have been reported in recent studies highlighting the gradual but inconsistent adoption of climate-resilient agricultural practices across Sub-Saharan Africa [58].

More transformative practices such as organic fertilization, crop rotation, intercropping, and integrated pest management display low performance (mean = 0.1–0.4) and high variability (SD up to 0.5). This suggests that these practices are not yet systematically incorporated into national policy frameworks. The limited emphasis on such approaches reflects broader structural constraints, including limited technical capacity, insufficient extension services, and weak policy incentives for sustainable land management [58,63].

At the country level, Malawi demonstrates relatively strong integration of climate-smart agriculture, with policy performance values reaching 0.7–0.8, indicating a more consistent policy focus on sustainability. However, stakeholder feedback highlights persistent implementation challenges, including limited coordination and financing constraints. Tanzania shows moderate integration levels, but policy effectiveness is undermined by outdated frameworks and weak cross-sectoral coordination. These findings are consistent with previous studies emphasizing governance fragmentation as a key barrier to agricultural transformation in the region [61].

Table 5. Performance and coherence of national energy policies in selected African countries.

Policy Instruments/Assessment Criteria	Mali		South Africa			Malawi		Tanzania		Mean (Horizontal Policy Performance)	Stdev.p (Horizontal Policy Coherence)
	NEP	NEEAP	NEES	SAREM	INEP	JET-IP	NEP	NEP	SEA4ALL		
(1) Economic incentives (subsidies, funding, tax breaks, grants and credit guarantee schemes)	1	1	1	1	1	1	1	1	1	1.0	0.0
(2) Public–private partnerships	1	1	0	0	0	1	1	1	1	0.7	0.5
(3) De-risking investments through Government Guarantees, co-financing/investment, and funding etc.	1	1	0	1	0	1	1	1	1	0.8	0.4
(4) Power purchasing agreements	0	1	0	1	0	1	1	1	1	0.7	0.5
(5) Feed-in Tariffs and auctions	0	1	0	0	0	1	1	1	1	0.6	0.5
(6) Strengthening Institutional capacity	1	1	1	1	0	1	1	1	1	0.9	0.3
(7) Invest in data and research, technology generation and information dissemination	1	1	1	1	1	1	1	1	1	1.0	0.0
(8) National budget for financing energy infrastructure.	1	1	1	1	1	1	1	1	1	1.0	0.0
(9) Enforcement of laws, guidelines and standards	1	1	1	0	1	1	1	1	1	0.9	0.3
(10) Inclusive stakeholder participation	1	1	1	1	1	1	1	1	1	1.0	0.0
(11) Equitable benefits sharing mechanisms	1	1	1	1	0	1	1	1	1	0.9	0.3
(12) Minimal bureaucracy, administrative & permitting procedures	1	1	0	0	0	1	1	1	1	0.7	0.5
(13) Technological diversity /Renewable energy generation source	1	1	0	1	1	1	1	1	1	0.9	0.3
(14) Equipment specifications (requiring certification and compliance to international standards)	1	1	0	1	0	1	1	1	1	0.8	0.4
(15) Grid access and grid tariff and priority dispatch	1	1	1	1	1	1	1	1	1	1.0	0.0
(16) Energy resource assessment	1	1	1	1	0	1	1	1	1	0.9	0.3
Mean (Vertical Policy Performance)	0.9	1.0	0.6	0.8	0.4	1.0	1.0	1.0	1.0	0.8	0.2
Standard Deviation (Vertical Policy Coherence)	0.3	0.0	0.5	0.4	0.5	0.0	0.0	0.0	0.0	0.2	0.2

NEP; National Energy Policy, NEES; National Energy Efficiency Strategy, SAREM; South Africa Renewable Energy Masterplan, INEP; Integrated National Electrification Planning, JET-IP; South Africa’s Just Energy Transition Investment Plan, SEA4All; Sustainable Energy For All.

South Africa presents a more uneven profile, with agricultural policy instruments showing moderate performance (mean ≈ 0.7) but relatively low coherence, reflecting inconsistencies in implementation and stakeholder engagement. In Mali, the absence of key sustainable practices such as crop rotation and intercropping results in low performance (mean < 0.5) and high dispersion (SD ≈ 0.5). Stakeholder insights further indicate that agricultural policies in Mali are constrained by limited institutional capacity and weak integration with water and energy sectors.

From a WEF nexus perspective, these patterns highlight a critical gap. Agricultural policies remain largely sector-specific, with limited consideration of cross-sectoral interdependencies. This weak integration reduces the potential for achieving synergies between food production, water management, and energy use. Similar observations have been made in nexus studies, where agricultural systems are often identified as the least integrated component of WEF governance frameworks [34].

Overall, the findings suggest that while financial support mechanisms are well established, the transition toward sustainable and integrated agricultural policy frameworks remains incomplete. Addressing this gap will require targeted policy reforms that promote resource-efficient practices, strengthen institutional coordination, and align agricultural strategies with broader WEF nexus objectives. Table 6 presents the full scoring matrix, while the discussion focuses on the indicators with the strongest policy relevance and highest cross-country variability.

4.4. Policy Implications for Integrated WEF Nexus Management

The findings highlight the need to move beyond formal policy alignment toward more effective and integrated governance frameworks. While policy instruments are widely present across sectors, their impact is constrained by fragmentation and implementation challenges.

In the energy sector, strengthening regulatory coherence is particularly critical for accelerating transition pathways. One priority is the standardization of power purchase agreements (PPAs) across countries. Harmonized PPA frameworks can reduce contractual uncertainty, improve bankability, and facilitate cross-border energy investments. Similarly, reforming feed-in tariff (FIT) mechanisms to ensure transparency, cost-reflectiveness, and long-term stability would enhance investor confidence and support the deployment of renewable energy technologies. International energy and development assessments similarly emphasize that policy coherence, reliable investment frameworks, and cross-sectoral coordination are essential for accelerating renewable energy deployment while avoiding trade-offs with water and food systems [51,80].

Beyond individual instruments, there is a need to establish cross-ministerial nexus coordination units that bring together water, energy, and agricultural authorities. Such institutional platforms can improve policy alignment, facilitate integrated planning, and reduce conflicts arising from competing resource demands. Evidence from integrated governance studies suggests that these mechanisms are essential for translating policy coherence into effective implementation [11].

In the water sector, improving enforcement capacity and strengthening monitoring systems remain key priorities, particularly in areas such as groundwater management and flood control. These improvements are essential not only for water security but also for supporting hydropower generation and agricultural productivity.

Table 6. Performance and coherence of national agricultural policies in selected African Countries.

Policy Instruments/Assessment Criteria	Mali			South Africa			Malawi		Tanzania			Mean (Horizontal Policy Performance)	Stddev.p (Horizontal Policy Coherence)
	ADP	NFNSP	AOL	NFNSP	IFSS	APAP	NAP	CSAPR	NAP	TAFSIP	ASDS		
(1) Economic incentives (subsidies, funding, tax breaks, grants and credit guarantee schemes)	1	1	1	1	1	1	1	1	1	1	1	1.0	0.0
(2) Climate-smart agriculture	0	1	0	1	0	1	1	1	1	1	1	0.7	0.4
(3) Agroecology	1	1	1	0	0	1	1	1	1	1	1	0.8	0.4
(4) Improved seeds	1	1	1	1	0	1	1	0	1	1	1	0.8	0.4
(5) Organic fertilizer /Compost	1	0	0	0	0	0	1	1	0	0	1	0.4	0.5
(6) Intercropping with leguminous crops Nitrogen fixation	0	0	0	0	0	0	1	1	0	0	0	0.2	0.4
(7) Crop rotation	0	0	0	0	0	1	1	0	1	1	0	0.4	0.5
(8) Fallow management	0	0	0	0	0	1	0	0	0	0	0	0.1	0.3
(9) Integrated pest management	1	1	0	0	0	0	0	0	1	0	0	0.3	0.4
Mean (Vertical Policy Performance)	0.6	0.6	0.3	0.3	0.1	0.7	0.8	0.6	0.7	0.6	0.6	0.5	0.2
Standard Deviation (Vertical Policy Coherence)	0.5	0.5	0.5	0.5	0.3	0.5	0.4	0.5	0.5	0.5	0.5	0.5	0.1

ADP; Agriculture Development Policy, NFNSP; National Food and Nutritional Security Policy, AOL; NFNSP; National Food and Nutritional Security Plan, IFSS; Integrated Food Security Strategy, APAP; Agriculture Policy Action Plan, NAP; National Agriculture Policy, TAFSIP; Tanzania Agriculture and Food Security Investment Plan, ASDS; Agriculture Sector Development Strategy, CSAPR; Climate-Smart Agriculture Practices.

In the agricultural sector, targeted support for climate-smart and agroecological practices is necessary to enhance resilience while reducing pressure on water and energy systems. This includes promoting crop diversification, efficient irrigation technologies, and soil restoration practices.

Overall, achieving effective WEF nexus governance requires coordinated reforms across sectors, combining regulatory improvements, institutional innovation, and targeted investments. By aligning policy instruments and strengthening implementation mechanisms, countries can enhance resource efficiency, reduce systemic vulnerabilities, and support sustainable development pathways. Similar policy integration challenges have been identified in recent global assessments, which emphasize the importance of coherent regulatory frameworks for enabling energy transitions and climate resilience [7,10].

4.5. Cross-Sectoral Discussion

The findings of this study are consistent with recent advances in WEF nexus scholarship, which increasingly emphasize the role of governance, policy coherence, and institutional coordination in shaping nexus outcomes. While earlier nexus research focused primarily on biophysical modelling and resource optimization, more recent studies highlight the importance of policy frameworks in enabling integrated resource management [33]. The observed convergence in formal policy design across the case study countries particularly in areas such as water conservation and stakeholder participation—reflects broader global trends toward the adoption of nexus-oriented policy principles. However, as documented in recent empirical studies, such formal alignment does not necessarily translate into effective implementation. Persistent gaps in coordination, enforcement, and institutional capacity continue to limit the operationalization of nexus approaches [81]. This is consistent with stakeholder evidence in the present study, which highlights a disconnect between policy design and implementation outcomes. Furthermore, the variability observed in more complex and implementation-dependent policy instruments such as groundwater regulation, climate-smart agriculture, and market-based energy mechanisms aligns with recent findings that nexus governance remains uneven across sectors and scales. Emerging research underscores that achieving effective nexus integration requires not only the presence of policy instruments but also their alignment across sectors and governance levels [82].

From an energy systems perspective, the fragmentation identified in key policy instruments such as feed-in tariffs, power purchase agreements, and investment de-risking mechanisms has direct implications for energy transitions. Recent studies emphasize that coherent policy environments are essential for enabling renewable energy deployment; reducing investment risk; and supporting integrated planning across water, energy, and food systems [44]. In this context, the findings suggest that inconsistencies in policy design may constrain the pace of energy transition and limit system resilience.

Overall, these results reinforce the growing consensus in the literature that the WEF nexus is fundamentally a governance challenge, where policy coherence, institutional capacity, and cross-sectoral coordination play a central role in determining outcomes. By situating the empirical findings within this broader body of work, the study contributes to advancing a more integrated and policy-relevant understanding of nexus governance.

4.6. Limitations

We acknowledge that this study has several limitations. First, the use of binary scoring to identify the presence or absence of policy instruments may reduce the discriminatory power of the analysis, particularly for instruments that are widely adopted across countries. This limitation was partly addressed by incorporating weighted alignment scores and

stakeholder validation, but future research could apply more detailed indicators of policy quality, enforcement capacity, and implementation effectiveness.

Second, SD provides a useful proxy for assessing consistency across policy instruments, but it captures only one dimension of coherence. It does not fully represent the direction, strength, or causality of policy interactions. Future studies could complement this approach with network analysis, correlation-based measures, or causal mapping to better capture synergies and trade-offs within WEF systems.

Third, although the sensitivity analysis showed that the main results were stable under $\pm 10\%$ variations in the weighting scheme, the weights remain partly dependent on expert judgment. Future research could test alternative weighting methods, including entropy-based, Delphi, or data-driven approaches.

Finally, the stakeholder sample provided important qualitative validation but remains context specific. The findings should therefore be interpreted as policy-relevant insights rather than statistically representative stakeholder perceptions. Expanding stakeholder coverage across additional basins and governance levels would further strengthen generalizability. Future research could further build upon the present framework by incorporating larger longitudinal datasets and applying econometric techniques to examine potential causal relationships between WEF nexus governance and energy transition indicators. Such approaches could complement the governance-oriented assessment developed in this study by providing additional insight into long-term policy impacts and transition dynamics across sectors.

5. Summary and Conclusions

This study assessed the performance and coherence of national water, energy, and agricultural policies across Mali, South Africa, Malawi, and Tanzania, with a particular focus on their integration within the Water–Energy–Food (WEF) nexus framework. By applying a mixed-methods approach that combines qualitative policy analysis, stakeholder engagement, and a composite policy coherence index, the study provides a structured evaluation of how policy design supports or constrains cross-sectoral coordination and energy transition pathways.

The findings reveal that, across all countries, several policy dimensions particularly those related to water conservation, pollution control, and stakeholder participation demonstrate high performance and strong structural coherence. However, these results primarily reflect the formal presence of policy instruments, rather than their effective implementation. Evidence from stakeholder consultations indicates persistent gaps in enforcement, institutional coordination, and operational capacity, highlighting a clear distinction between policy design coherence and implementation effectiveness.

Policy coherence varies significantly across sectors and instruments. While economic incentives are relatively well integrated and consistently applied, other policy areas such as stormwater management, groundwater permitting, and certain sustainability practices remain fragmented and unevenly implemented. This inconsistency reflects underlying governance challenges, including limited institutional capacity, overlapping mandates, and weak cross-sectoral coordination mechanisms.

In the energy sector, the analysis highlights important gaps in key regulatory instruments such as feed-in tariffs (FITs), power purchase agreements (PPAs), and investment de-risking mechanisms. Although basic policy frameworks are in place, their inconsistent application across countries contributes to regulatory uncertainty and constrains private sector participation. These findings underscore the importance of policy coherence as a critical enabling factor for energy transition, investment mobilization, and system resilience.

The agricultural sector exhibits the lowest level of integration within the WEF nexus. While economic incentives and improved seeds are widely supported, more sustainable practices such as agroecology, crop rotation, and organic fertilization remain underrepresented in policy frameworks. This imbalance limits opportunities for improving resource efficiency and strengthening resilience across water and energy systems.

Overall, the results indicate that WEF nexus governance in the studied countries is characterized by good structural alignment but limited functional integration. Addressing this gap requires moving beyond policy formulation toward more coordinated and implementation-focused governance approaches.

From a policy perspective, several priorities emerge. These include strengthening institutional capacity, improving regulatory frameworks for energy markets, enhancing cross-sectoral coordination particularly through dedicated nexus governance mechanisms and promoting sustainable agricultural practices. In particular, the standardization of PPAs, reform of FIT mechanisms, and development of integrated planning frameworks are essential for accelerating energy transition while minimizing trade-offs with water and food systems.

Promoting integrated WEF nexus governance offers a pathway to improve resource efficiency, reduce systemic vulnerabilities, and support climate adaptation in Sub-Saharan Africa. Future research should focus on operationalizing these frameworks in practice, including the development of implementation strategies, financing mechanisms, and stakeholder engagement models that can translate policy coherence into tangible outcomes.

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