

Governance Framework for the Water-Energy-Food Nexus: Evaluating Cross-Sectoral Policy Alignment in Rural Semi-Arid Regions of Katsina State, Northern Nigeria

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Abstract

Case Studies

The Water-Energy-Food (WEF) nexus approach recognises that water, energy, and food systems are interdependent and that sectoral policymaking, pursued in isolation, generates trade-offs that undermine sustainability in resource-constrained settings. This study develops and empirically applies a governance framework for evaluating cross-sectoral policy alignment in the semi-arid northern belt of Katsina State, Nigeria. Anchored on Hoff's WEF nexus model, Ostrom's Institutional Analysis and Development (IAD) framework, and polycentric governance theory, the study employed a concurrent mixed-methods design across nine rural communities drawn from nine northern local government areas bordering the Republic of Niger. Structured questionnaires (n = 354) and twenty-seven key informant interviews were analysed using descriptive statistics (SPSS) and thematic analysis (NVivo). Findings show a generally weak Cross-Sectoral Policy Alignment Index (composite mean = 0.40 of a possible 1.00), with Energy-Food alignment weakest (0.324) and Water-Food alignment comparatively stronger (0.513). Qualitative data reveal that informal, community-level coordination mechanisms function reasonably well but are not formally linked to Local Government or State-level planning, producing a governance gap between grassroots polycentricity and centralised sectoral administration. The study proposes a four-tier nexus governance framework and recommends the institutionalisation of joint water-energy-food desks at the Local Government level and a State-level inter-ministerial coordination unit. The framework offers a replicable tool for evaluating and strengthening nexus governance in comparable Sahelian settings.

Keywords: Water-Energy-Food Nexus, Polycentric Governance, Institutional Analysis and Development, Cross-Sectoral Policy Alignment, Katsina State, Semi-Arid Nigeria.

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1. Introduction

Water, energy, and food security are fundamentally interdependent: irrigation and rural water supply require energy for pumping and treatment, energy production and processing depend on water, and food production requires both water and energy inputs (Hoff, 2011; Bazilian et al., 2011). In semi-arid and Sahelian regions of West Africa, where rainfall is erratic,

groundwater is the dominant water source, and grid electricity access is minimal, these interdependencies are especially acute. Yet governance systems in most West African states, including Nigeria, remain organised along sectoral lines, with separate ministries, budgets, and planning cycles for water resources, power, and agriculture (Adeyemo & Mohammed, 2019). This sectoral fragmentation is widely implicated



in policy incoherence, duplicated investment, and missed synergies between resource sectors (Weitz et al., 2017; Rasul & Sharma, 2016).

Katsina State, located in Nigeria's Sudano-Sahelian zone, exemplifies these dynamics. Its northern local government areas (LGAs), which border the Republic of Niger, experience the state's harshest climatic conditions, including declining rainfall, advancing desertification, and heavy reliance on diesel-powered boreholes and irrigation pumps in the absence of reliable grid electricity (Ibrahim & Aliyu, 2020). Rural households in this zone must simultaneously navigate water scarcity, energy poverty, and food insecurity, yet the institutions responsible for each of these domains rarely coordinate. This creates a governance gap in which decisions made in one sector, such as siting a new borehole scheme without corresponding energy provision, can undermine outcomes in another.

This study addresses that gap by developing and empirically testing a governance framework for evaluating cross-sectoral policy alignment in the WEF nexus. Specifically, the study: (i) develops a conceptual framework integrating the WEF nexus model with Ostrom's Institutional Analysis and Development (IAD) framework and polycentric governance theory; (ii) empirically evaluates the degree of policy and institutional alignment across the water, energy, and food sectors in nine rural communities of northern Katsina State; and (iii) proposes governance mechanisms for strengthening cross-sectoral coordination from the community to the state level. The study contributes a replicable, empirically grounded governance-evaluation tool for nexus research in data-scarce rural Sahelian contexts.

2. Literature Review

2.1 The Water-Energy-Food Nexus Concept

The WEF nexus framework emerged prominently from the 2011 Bonn Conference, which argued that water, energy, and food security should be pursued jointly rather than as independent policy objectives (Hoff, 2011). Bazilian et al. (2011) formalised this as an integrated modelling challenge in which decisions in one sector produce measurable

externalities in the others. Subsequent literature has emphasised that the nexus is as much a governance and institutional challenge as a technical or biophysical one (Leck et al., 2015; Cairns & Krzywoszynska, 2016), since resource interdependencies are ultimately mediated by the institutions, rules, and actors that govern access and allocation.

2.2 Governance Challenges in Nexus Resource Management

A recurring finding across the nexus literature is that sectoral institutions rarely possess the mandate, incentive, or information to internalise cross-sectoral effects (Allouche et al., 2015; Al-Saidi & Elagib, 2017). Scott et al. (2011) describe this as an institutional blind spot in which water and energy agencies optimise independently, generating inefficiencies at their interface. In sub-Saharan Africa, these challenges are compounded by weak inter-agency data-sharing, limited fiscal decentralisation, and donor-driven, sector-specific project financing that reinforces rather than dissolves administrative silos (Weitz et al., 2017; FAO, 2014). Wichelns (2017), while cautioning against treating the nexus as a panacea, nonetheless concedes that improved cross-sectoral coordination yields measurable efficiency gains where baseline fragmentation is high, as is characteristic of rural Sahelian administration.

2.3 Ostrom's Institutional Analysis and Development Framework

Ostrom's IAD framework (Ostrom, 1990, 2005) analyses collective action problems through an action arena shaped by biophysical conditions, community attributes, and rules-in-use, which together produce patterns of interaction and outcomes. The framework is particularly suited to nexus governance because it foregrounds the rules that govern access, allocation, monitoring, and sanctioning across resource domains, rather than treating institutions as a fixed backdrop. Mohammed and Uba (2018) applied Ostrom-derived principles to groundwater governance in northern Nigeria and found that community-level rule systems, though informal, were often

more coherent than the formal administrative structures layered above them.

2.4 Polycentric Governance Theory

Ostrom (2010) subsequently argued that complex, multi-scalar environmental problems are best addressed through polycentric systems: multiple, semi-autonomous decision-making centres operating at different levels, which can adapt to local conditions while remaining loosely coordinated through shared norms or higher-level rules. Andrews-Speed et al. (2015) apply a polycentric lens to resource-nexus governance directly, arguing that no single ministry or agency can internalise the full complexity of water-energy-food interactions, and that nexus governance instead requires deliberate linkage mechanisms across otherwise independent centres of authority. This study adopts polycentricity as the structural lens through which the fragmented, multi-level governance landscape of Katsina State is analysed.

2.5 WEF Nexus Governance in Nigeria: A Gap in the Literature

While the global nexus literature is well developed (Endo et al., 2017; Biggs et al., 2015), empirical governance studies specific to semi-arid Nigeria remain scarce and tend to examine water, energy, or agricultural policy separately (Nabegu, 2010; World Bank, 2017). Few studies have empirically measured the degree of cross-sectoral policy alignment at the community level, and fewer still have done so using a combined IAD-polycentric governance lens. This study addresses that gap directly.

3. Conceptual Framework

The study's conceptual framework, presented in Figure 1, integrates three theoretical strands into a single analytical structure. At its core sits the WEF nexus triangle (Hoff, 2011), representing

the direct interdependencies between water, energy, and food outcomes at the household and community level: irrigation and domestic supply depend on energy for pumping, energy access depends on water for cooling and, indirectly, on food-crop residues used as biomass fuel, and food production depends on both water and energy inputs. Trade-offs and synergies at this core are the proximate outcomes that rural households experience directly.

Surrounding this core is Ostrom's IAD action arena, which specifies the four elements that determine how nexus outcomes are produced: the prevailing rules-in-use governing access and allocation across sectors; the biophysical and material conditions (rainfall, aquifer depth, grid proximity); the attributes of the actors involved (farmers, herders, women water-fetchers, and local officials); and the resulting patterns of interaction, whether cooperative or conflictual. The IAD layer explains why identical biophysical conditions can produce different nexus outcomes across communities, depending on the institutional arrangements in place.

The outermost layer situates these action arenas within a four-tier polycentric governance structure spanning community, Local Government, State, and Federal levels (Ostrom, 2010). Each level constitutes a semi-autonomous decision-making centre with its own rules and mandates; the framework's central proposition is that nexus governance quality depends not on the strength of any single level but on the degree of linkage between them. Finally, the framework incorporates external drivers, including climate variability, population growth, and national policy, which condition the entire system, together with a feedback loop through which resource outcomes reshape institutions over time. This framework directly informs the study's empirical instrument, the Cross-Sectoral Policy Alignment Index (CPAI), which operationalises the degree of rule and mandate alignment between sector pairs at each level.

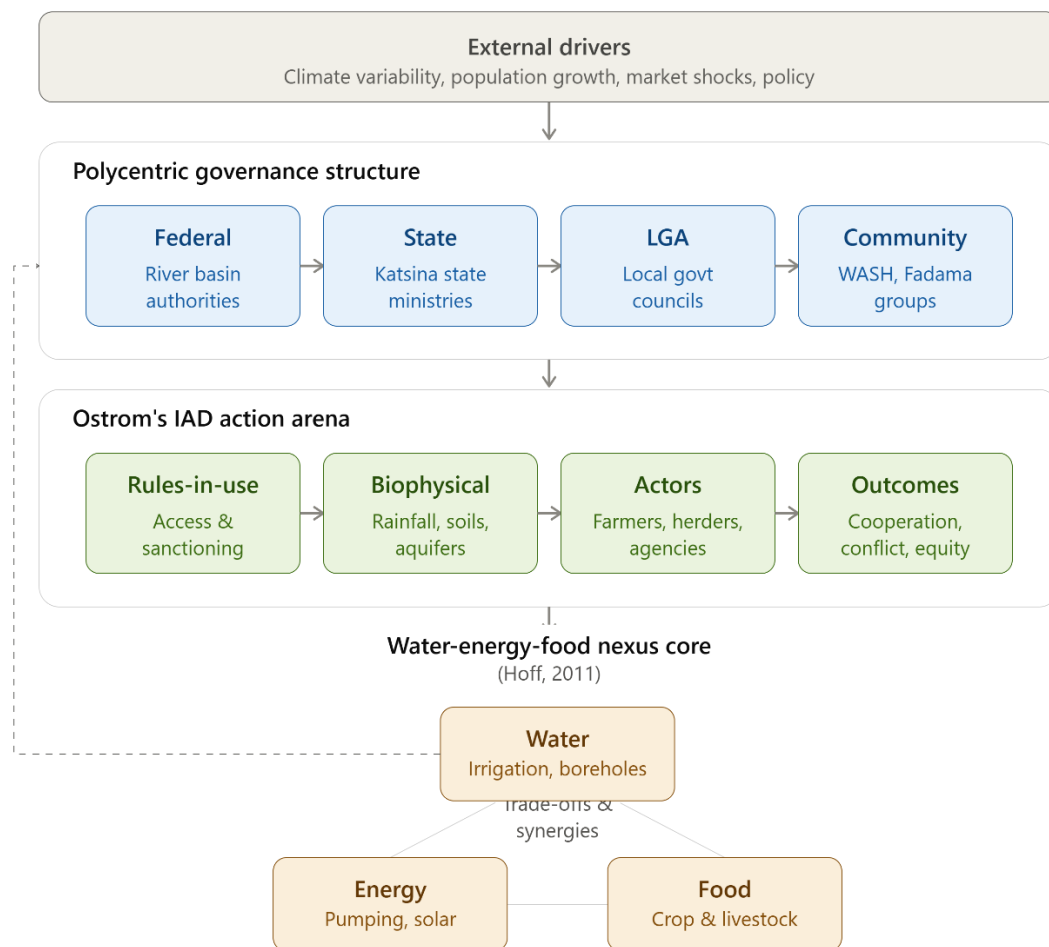


Figure 1. Conceptual framework integrating the WEF Nexus model, Ostrom's IAD framework, and polycentric governance theory (adapted from Hoff, 2011; Ostrom, 1990, 2010).

4. Study Area

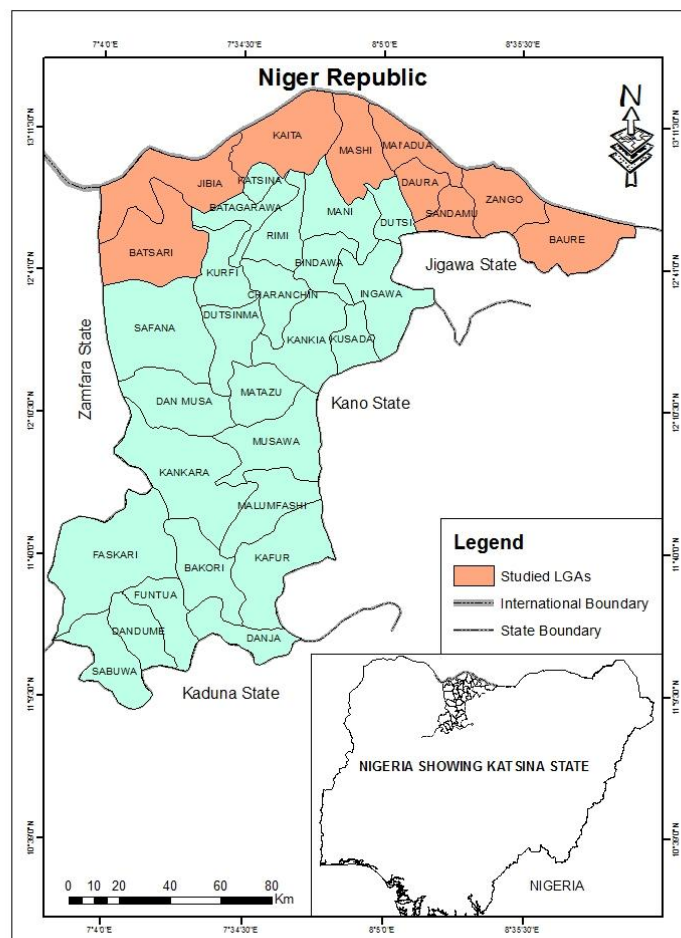
Katsina State lies in Nigeria's north-western Sudano-Sahelian agro-ecological zone, characterised by a single rainy season (June-September), mean annual rainfall generally below 700 mm, and a long dry season during which surface water sources are largely unavailable. The state's northern LGAs form a belt directly bordering the Republic of Niger and experience the most pronounced aridity, seasonal windborne dust, and land degradation within the state (Ibrahim & Aliyu, 2020). The rural economy in this belt combines rain-fed and irrigated (fadama) farming, agro-pastoralism,

and, in border communities, cross-border trade.

Nine rural communities were purposively selected to represent this northern belt, one from each of nine northern LGAs: Jibia, Kaita, Batsari, Baure, Mai'Adua, Daura, Sandamu, Zango, and Mashi. These LGAs were selected because they share the semi-arid, border-adjacent characteristics that make cross-sectoral WEF nexus tensions most acute, and because they collectively capture variation in livelihood systems, ranging from irrigation-dependent border towns to predominantly rain-fed interior communities.

Table 1: Sampled communities across the selected Local Government Areas and their livelihood.

LGA	Community (Study Site)	Predominant Livelihood
Jibia	Jibia Town (Kaikai ward)	Cross-border trade; irrigated onion/vegetable farming
Kaita	Yandaki	Rain-fed millet/sorghum; livestock rearing
Batsari	Batsari Central	Rain-fed cereals; charcoal & fuelwood trade
Baure	Yardaje	Groundnut & cowpea farming; agro-pastoralism
Mai'Adua	Mai'Adua Town	Cross-border trade; livestock
Daura	Zango-Daura	Mixed farming; small-scale trading
Sandamu	Yankara	Rain-fed farming; livestock
Zango	Zango Kudu	Agro-pastoralism; seasonal migration
Mashi	Mashi	Farming; small scale trading

**Figure 2. Map of the study area showing the nine sampled LGAs of Katsina State**

5. Methodology

5.1 Research Design

The study adopted a concurrent mixed-methods design, combining a structured household questionnaire survey with key informant interviews (KIIs), to allow triangulation between quantitative measures of policy alignment and qualitative accounts of institutional practice (Weitz et al., 2017). This design was chosen because cross-sectoral governance alignment has both a measurable, perception-based dimension, captured through the survey, and a procedural, relational dimension best understood through interviews with officials and community leaders.

5.2 Population and Sampling

The target population comprised household heads or their adult representatives in the nine selected communities, together with officials and community leaders with direct responsibility for water, energy, or agricultural matters. A multi-stage sampling procedure was applied. First, nine northern LGAs were purposively selected on the basis of their shared semi-arid, border-adjacent characteristics. Second, one rural community was randomly selected within each LGA from a list of eligible settlements meeting minimum population and accessibility criteria. Third, households within each community were selected using systematic random sampling with a random start, at approximately every fifth household along a transect walk, until the community quota was reached.

The overall sample size was determined using the Yamane (1967) formula for a finite population at a 95% confidence level and 5% margin of error, yielding a minimum requirement of 341 respondents; a total of 360 questionnaires were administered, of which 354 were returned complete and valid, giving a response rate of 98.3% and approximately 39 respondents per community. In addition, three key informants were purposively selected in each community, comprising a Local Government water, agricultural extension, or energy desk officer, a traditional or community leader, and a representative of a community water-user, farmers', or women's cooperative group, yielding

27 KIIs in total.

5.3 Research Instruments

The structured questionnaire captured respondent demographics, household access to water, energy, and food-production resources, and a set of Likert-scale items measuring perceived policy and institutional alignment across three sector-pairs: Water-Energy, Water-Food, and Energy-Food. Items were adapted from prior nexus governance instruments (Weitz et al., 2017; Rasul & Sharma, 2016) and piloted in a non-sampled community for clarity and cultural appropriateness prior to full administration. The KII guide, administered in Hausa with translation, explored institutional mandates, inter-agency coordination practices, and perceived barriers to cross-sectoral cooperation.

5.4 Data Analysis

Quantitative data were analysed using SPSS (version 26) through descriptive statistics and the construction of a Cross-Sectoral Policy Alignment Index (CPAI). The CPAI was computed by averaging normalised Likert responses (rescaled to a 0-1 range) across the alignment items for each sector-pair, aggregated first at the community level and then as a state-wide composite. Qualitative interview data were transcribed, translated, and analysed thematically in NVivo (release 1.7) following an inductive coding approach, with themes cross-checked against the quantitative CPAI patterns to support triangulation.

6. Results

6.1 Respondent Characteristics

Table 2 summarises the demographic and resource-access characteristics of the 354 valid respondents. Slightly more than half of respondents were male (55.4%), and the majority (65.8%) were between 31 and 60 years of age. Rain-fed and irrigated farming together accounted for the primary livelihood of 63.3% of respondents. Notably, only 16.4% of households

reported access to grid electricity, while more than half relied on boreholes or hand pumps as their primary water source, underscoring the

practical centrality of the water-energy linkage in daily household life.

Table 2. Demographic and resource-access characteristics of survey respondents (n = 354).

Characteristic	Category	Frequency (n=354)	Percent (%)
Sex	Male	196	55.4
	Female	158	44.6
Age (years)	18-30	89	25.1
	31-45	141	39.8
	46-60	92	26.0
	Above 60	32	9.1
Primary livelihood	Farming (rain-fed)	148	41.8
	Irrigated farming	76	21.5
	Livestock/agro-pastoralism	64	18.1
	Trading / other	66	18.6
Household water source	Borehole / hand pump	189	53.4
	Open well / surface source	121	34.2
	Piped scheme	44	12.4
Access to grid electricity	Yes	58	16.4
	No (off-grid / solar / none)	296	83.6

6.2 Cross-Sectoral Policy Alignment Index

Table 3 presents the CPAI results disaggregated by community and sector-pair. The state-wide composite CPAI was 0.400, indicating an overall weak-to-moderate degree of perceived cross-sectoral alignment. Alignment was consistently weakest between the Energy and Food sectors (mean 0.324), reflecting the near-total absence of coordinated planning between rural electrification and agricultural programming.

Water-Food alignment was comparatively the strongest sector-pair (mean 0.513), plausibly because irrigation scheduling and water-user associations already mediate some water-food coordination informally. Mai'Adua and Daura, both larger border towns with more active community organisations, recorded the highest composite CPAI scores (0.49 and 0.47 respectively), while Zango and Batsari recorded the lowest (0.31 and 0.33).

Table 3. Cross-Sectoral Policy Alignment Index (CPAI) by community and sector-pair (scale: 0 = no alignment, 1 = full alignment).

Community (LGA)	Water-Energy Alignment	Water-Food Alignment	Energy-Food Alignment	Composite CPAI (0-1)
Jibia	0.41	0.58	0.36	0.45
Kaita	0.33	0.49	0.29	0.37
Batsari	0.29	0.44	0.27	0.33
Baure	0.38	0.52	0.34	0.41
Mai'Adua	0.47	0.61	0.40	0.49
Daura	0.44	0.57	0.39	0.47
Sandamu	0.31	0.46	0.28	0.35
Zango	0.27	0.42	0.24	0.31
Mashi	0.39	0.53	0.35	0.42
State-wide mean	0.365	0.513	0.324	0.400

6.3 Qualitative Findings

Thematic analysis of the 27 key informant interviews identified three dominant themes. First, informants across all nine communities described robust informal coordination at the community level, typically organised through traditional leadership structures or water-user and farmers' associations, but consistently noted that these arrangements had no formal channel for input into Local Government or State-level planning. Second, Local Government officials in water, agriculture, and energy desks reported holding no joint planning meetings with counterpart desks, attributing this to separate reporting lines, budgets, and supervising ministries at the State level. Third, women key informants specifically highlighted a gendered dimension of nexus misalignment: the time and physical burden of water and fuelwood collection falls disproportionately on women and girls, yet women's cooperative groups were rarely consulted in water or energy infrastructure siting decisions, despite being consulted more often in food-production programming.

7. Discussion

Read through the conceptual framework

developed in this study, the findings suggest that the IAD action arena in northern Katsina State's rural communities is characterised by functioning, community-level rules-in-use, but by rules-in-use that are poorly linked across the water, energy, and food domains, and almost entirely disconnected from higher-level polycentric decision centres. This pattern is consistent with Mohammed and Uba's (2018) observation that informal groundwater governance in northern Nigeria is often more internally coherent than the formal structures above it, and it extends that finding by showing that the coherence does not currently extend across sectors, only within them.

The particularly weak Energy-Food alignment score corroborates the broader nexus literature's identification of energy as the most institutionally neglected node in African rural nexus governance (Rasul & Sharma, 2016; IRENA, 2015): where water and food institutions have at least some historical basis for local coordination through irrigation and extension systems, rural electrification in this context remains almost entirely exogenous, delivered through centralised, donor- or federally-driven programming with minimal community or agricultural input. This is

consistent with Andrews-Speed et al.'s (2015) polycentric governance argument that nexus outcomes deteriorate specifically at the interfaces between decision centres that lack deliberate linkage mechanisms, rather than within any single centre.

The gendered finding also merits attention within the IAD framework's actors-and-attributes component: because women disproportionately bear the practical costs of water-energy misalignment yet are institutionally marginalised from water and

energy decision-making, the current governance arrangement is likely to reproduce, rather than resolve, this asymmetry unless deliberately addressed in future institutional design.

8. Policy Recommendations

Building on the conceptual framework and the empirical findings, the study proposes a set of governance actions targeted at each polycentric level, summarised in Table 4.

Table 4. Recommended governance actions by polycentric level.

Governance Level	Key Constraint Identified	Recommended Action
Community	Strong informal coordination but no formal linkage upward	Formally recognise community WEF committees and grant them a consultative seat in LGA planning
Local Government (LGA)	Extension and water desks operate in isolation from energy planning	Establish joint LGA WEF desks combining water, agricultural extension, and rural electrification officers
State	Separate sectoral ministries with no shared budget line or data platform	Create an inter-ministerial WEF Nexus Coordination Unit under the Katsina State Planning Commission
Federal / Basin	River basin and rural electrification programmes designed without nexus screening	Mandate a nexus impact screening tool for federally funded water and energy infrastructure in semi-arid states

In addition to the level-specific actions in Table 4, three cross-cutting measures are recommended: (i) the development of a shared, GIS-based WEF data platform accessible to water, energy, and agriculture desks at the LGA and State levels, to replace the current absence of shared information; (ii) mandatory representation of women's cooperative groups in the siting and design of water and energy infrastructure, addressing the gendered marginalisation identified in the qualitative findings; and (iii) periodic re-administration of the CPAI as a monitoring tool to track whether

governance reforms produce measurable improvements in cross-sectoral alignment over time.

9. Conclusion

This study set out to develop and empirically apply a governance framework for evaluating cross-sectoral policy alignment in the water-energy-food nexus of rural, semi-arid northern Katsina State. By integrating the WEF nexus model with Ostrom's IAD framework and

polycentric governance theory, and by applying this framework across nine rural communities using a mixed-methods design, the study finds that cross-sectoral policy alignment remains weak overall (composite CPAI = 0.40), with the Energy-Food interface the most institutionally neglected. The central governance problem is not an absence of functioning institutions, since community-level coordination is often robust, but the absence of formal linkage between community-level polycentric arrangements and the sectoral ministries and agencies operating above them. Institutionalising joint local-government WEF desks, a State-level coordination unit, and nexus-sensitive screening of federally funded infrastructure would directly address this linkage gap. The framework and CPAI tool developed here offer a replicable approach for evaluating and monitoring nexus governance in comparable Sahelian and semi-arid rural settings across West Africa.

Ethical Considerations

Informed consent was obtained from all respondents prior to participation, anonymity and confidentiality were assured, and participation was entirely voluntary with the right to withdraw at any stage. Ethical clearance and community entry permissions were obtained from the relevant Local Government authorities prior to fieldwork.

Limitations

As with most cross-sectional nexus governance studies, the CPAI reflects respondent perceptions rather than direct audit of institutional documents, and the purposive selection of nine communities, while capturing meaningful variation, does not permit statistical generalisation to all of Katsina State's northern LGAs. These limitations are addressed through triangulation with key informant accounts and should be considered when interpreting the findings.

Declarations

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Conflict of Interest: The author(s) declare no conflict of interest.

Data Availability: Data supporting the findings of this study are available from the corresponding author upon reasonable request.

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