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Collaboration and Governance in the WEF Nexus: A Systematic Review of Lessons from Emerging Economies

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Abstract - *The Water–Energy–Food (WEF) nexus offers a holistic framework for managing interconnected resource systems. Governance is central to translating nexus principles into equitable and durable outcomes, yet it remains underexplored, particularly in emerging economy contexts. Existing scholarship is heavily skewed toward resource-interaction mapping, techno-economic optimization, and sectoral modelling, with limited integration of socio-political realities such as institutional fragmentation, power asymmetries, and financing volatility. This study applies the PRISMA 2020 framework to systematically review 91 Scopus-indexed articles on WEF nexus governance. Four dominant governance models are identified: Public–Private Partnerships, Community-led or Co-management, Inter-agency Coordination, and Hybrid or Multi-level Governance. Each demonstrates distinct sectoral alignments, stakeholder configurations, and trade-offs, from the innovation potential and equity risks of Public–Private Partnerships to the inclusivity and capacity limitations in community-led approaches. Findings reveal persistent gaps in governance durability, energy–agriculture integration, and the role of digital mechanisms. The review calls for longitudinal, comparative, and mixed-method studies to advance theory and inform adaptive and inclusive governance frameworks that can withstand the socio-environmental uncertainties of countries with emerging economies.*

Keywords - *Water–Energy–Food nexus, governance, stakeholder participation, adaptive governance, resilience*

I. INTRODUCTION

The Water–Energy–Food (WEF) nexus has emerged as a critical framework for addressing interconnected challenges of resource security, environmental sustainability, and socio-economic development, particularly in emerging economies where scarcity and institutional constraints heighten intersectoral trade-offs [1], [2]. By recognizing the mutual dependencies between these sectors, the nexus approach promotes integrated governance strategies that can enhance efficiency, build resilience, and support the achievement of Sustainable Development Goals (SDGs 2, 6, and 7) [3], [4].

However, much of the existing WEF nexus literature remains disproportionately focused on resource-interaction mapping [5], techno-economic optimization, and sectoral modelling [4], [6]. With limited systematic evaluation of governance structures and institutional arrangements, particularly in Global South contexts [2], [7]. As a result, the socio-political realities of emerging economies, which are characterized by fragmented institutions, asymmetrical stakeholder power, and volatile financing, are often underrepresented in nexus scholarship [5]. This gap is problematic because governance quality frequently determines whether nexus policies translate into durable, equitable, and context-sensitive outcomes.

Addressing this shortcoming, this paper conducts a systematic review of WEF nexus governance models, focusing on Public–Private Partnerships, community-led arrangements, inter-agency coordination, and hybrid systems. Guided by the PRISMA 2020 framework, we synthesise evidence from 91 peer-reviewed studies to analyse sectoral alignments, stakeholder configurations, and trade-offs in implementation. By centring governance in the analysis and explicitly contextualising findings for emerging economies, this review offers targeted lessons for designing adaptive, inclusive, and durable nexus governance frameworks capable of withstanding the socio-environmental uncertainties these economies face.

II. LITERATURE REVIEW

A. Conceptual Foundations of the WEF Nexus

The Water–Energy–Food (WEF) nexus framework provides an integrated perspective for managing the interdependencies between essential resource systems. Initially developed to promote cross-sector planning for sustainability and climate resilience [8], the framework

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emphasizes balancing trade-offs and harnessing synergies. Early approaches focused on technical integration, but more recent studies highlight the importance of governance, institutional arrangements, and stakeholder participation in shaping outcomes [8], [9].

B. Governance Theories in Complex Resource Systems

In recent years, scholarship on resource governance has increasingly focused on the complex interplay between ecological systems, institutional structures, and stakeholder dynamics. The water–energy–food (WEF) nexus exemplifies such complexity, as it spans multiple sectors and jurisdictions while requiring coordinated responses to environmental change and socio-economic pressures. In this context, polycentric governance theory [10] offers valuable insights by emphasizing the role of multiple, semi-autonomous decision-making centers that coordinate through negotiated arrangements. Complementing this perspective, collaborative governance theory [11] underscores trust-building, joint decision-making, and shared accountability as essential for resolving cross-sectoral challenges. Together, these frameworks explain why hybrid and multi-level governance models often prove more adaptive and effective than centralized approaches in WEF management.

Stakeholder participation within nexus governance, however, is not uniformly distributed or equally influential.

The capacity of governance systems to anticipate, absorb, and adapt to shocks is increasingly seen as a determinant of long-term sustainability in nexus contexts. Adaptive governance [12] stresses the value of flexibility, iterative learning, and inclusive engagement to navigate uncertainty and change. Closely aligned, social–ecological resilience theory [13] conceptualizes governance as an evolving process that must retain the capacity to respond effectively to both predictable and unforeseen disturbances. Integrating these perspectives into WEF governance research supports a transition from static, linear planning toward dynamic, feedback-informed strategies that enhance system resilience.

III. METHODOLOGY

This study employed a systematic literature review (SLR) to identify, evaluate, and synthesize peer-reviewed research relevant to governance frameworks within complex resource systems, with a particular focus on the water–energy–food (WEF) nexus. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021) to ensure methodological rigor, transparency, and replicability.

Articles were screened using predefined criteria to ensure thematic relevance, methodological rigor, and accessibility. Inclusion was restricted to peer-reviewed journal articles indexed in Scopus with an explicit focus on governance within the water–energy–food (WEF) nexus or comparable multi-resource governance contexts, offering empirical, conceptual, or theoretical contributions that address governance structures, stakeholder participation, or policy mechanisms. Exclusion was based on five main criteria: (1) not focused on WEF nexus governance or collaboration, where the WEF nexus was absent or only tangentially addressed including studies of other nexuses with minimal collaboration or governance analysis; (2) developed country–only context, involving cases in high-income settings without clear applicability to emerging markets; (3) technical or optimization studies without governance dimension, where research centered on modelling, metrics, or tool development lacked governance analysis; (4) conceptual or theoretical discussions without empirical emerging market application, consisting of broad reviews or frameworks without operationalized governance in an emerging market context; and (5) unrelated sector or thematic scope, covering studies outside WEF nexus relevance such as tourism ESG or historical contexts. The whole PRISMA process is visualized in Fig.1.

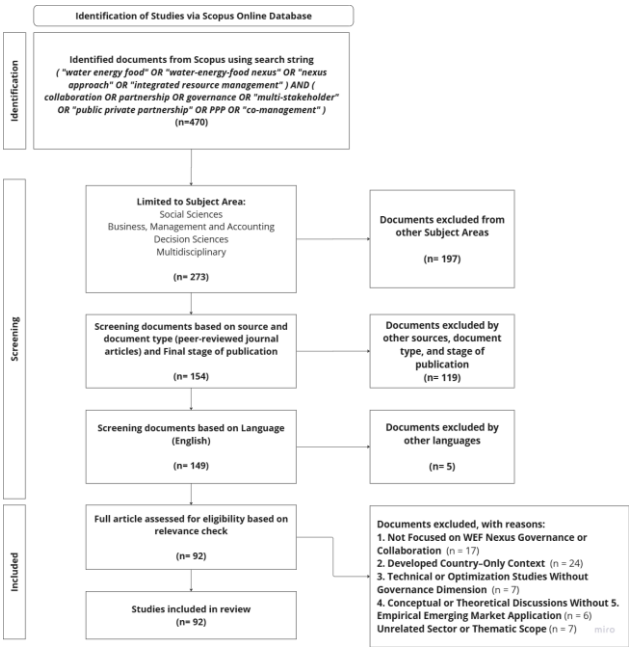

Fig. 1. Literature search PRISMA and screening process

A structured template was used for data extraction, capturing bibliographic details, research aims, governance frameworks, methodological approaches, and principal findings. Thematic organization facilitated cross-study comparison and identification of recurring theoretical patterns. Narrative synthesis was then conducted to address the three research questions. For RQ1, the synthesis examined how governance frameworks such as polycentric governance, collaborative governance, and stakeholder theory

explain institutional arrangements and actor interactions. For RQ2, it explored the relevance of power-dependence theory, adaptive governance, and resilience theory in understanding mechanisms that strengthen or weaken governance outcomes. For RQ3, the analysis integrated insights across frameworks to assess how governance in complex resource systems can be improved through multi-actor coordination, adaptive capacity, and equitable stakeholder engagement. This approach ensured that theoretical insights were systematically connected to the study's objectives, providing a comprehensive understanding of governance dynamics in multi-resource contexts.

IV. FINDINGS AND DISCUSSION

A. Collaboration Models in WEF Nexus Implementation

The 91 included studies revealed four primary collaboration models in the implementation of the WEF nexus in emerging markets: Public–Private Partnerships (PPP), Community-led or Co-management models, Inter-agency/Government Coordination, and Hybrid or Multi-level Governance arrangements. These models differ in their institutional configurations, lead actors, and integration mechanisms, but all aim to address interdependence among water, energy, and food systems. Table I presents the frequency of each collaboration model identified in the reviewed literature.

Public–Private Partnership (PPP) models were most frequently observed in Southeast Asia and Sub-Saharan Africa, particularly in infrastructure-intensive interventions such as large-scale irrigation schemes and renewable energy mini-grids, where private investment complemented public sector funding [14]. Community-led or co-management approaches were more prevalent in South Asia and parts of Latin America, especially in contexts where smallholder farmers and local water user associations played central roles in resource governance [15][16]. Inter-agency or government coordination models were widely reported in the Middle East and North Africa (MENA) and Central Asia, often driven by ministries of water, energy, and agriculture aligning sectoral policies to improve cross-sectoral outcomes [17][18]. Hybrid or multi-level governance models appeared across multiple regions but were particularly notable in East Africa and Southeast Asia, where vertical integration linked national strategies with local-level implementation through adaptive governance frameworks [19][17].

TABLE I
FREQUENCY OF COLLABORATION MODELS IN WEF NEXUS IMPLEMENTATION

Collaboration Model	Frequency	Percentage
Public–Private Partnerships (PPP)	28	30.80%
Community-led/Co-management	21	23.10%
Inter-agency/Government Coordination	19	20.90%
Hybrid/Multi-level Governance	23	25.30%
Total	**91**	**100%**

A PPP example is documented by Lebel (2020) [17], describing a rural electrification project in Lower Mekong Basin that integrated hydropower development with agricultural productivity programs, financed through a combination of public and private investment. In the community-led category, Cansino-Loeza et al (2021)[20] examined Mexico's watershed committees that jointly manage irrigation water and reforestation programs to enhance food and energy sustainability. For inter-agency coordination, Stein et al (2018) [21] analyzed Ethiopia's coordinated policy reform between the Ministries of Water Resources, Agriculture, and Energy, aimed at optimizing resource allocation in the Nile basin. In the hybrid governance category, Bhanye et al. (2024) [22] highlighted Africa's decentralized WEF governance model, which links county-level climate adaptation plans with national energy and agriculture policy frameworks

B. Sector and Stakeholder Involvement

WEF nexus initiatives is divided between single-sector and multi-sector approaches. Single-sector projects, often concentrated in water management or energy access, typically emerge in contexts where urgent infrastructure deficits require targeted intervention [23]. Multi-sector initiatives are more common in integrated development programs, with the Water–Agriculture combination dominating, particularly in irrigation modernization and watershed restoration programs [4], [24][9]. Energy–Water linkages frequently involve renewable energy systems for pumping, treatment, or desalination [25] while Energy–Agriculture projects—though less common—are gaining traction in climate-smart agriculture schemes that utilize solar-powered cold storage and processing facilities [26].

Across governance arrangements, five recurring stakeholder categories emerged: government agencies, private sector actors, civil society organizations, academic/research institutions, and international donors. Government agencies were the most consistently involved, appearing in more than 80% of

the reviewed cases, often providing regulatory frameworks and coordination [27]. Private sector involvement was concentrated in PPP-driven projects, offering investment and technological solutions [28]. Civil society engagement was strongest in community-led or hybrid arrangements, where grassroots organizations, cooperatives, and NGOs played central roles in local implementation and monitoring [29]. Academic institutions contributed to technical design and capacity building, while international donors supported financing, policy alignment, and cross-regional knowledge sharing [30].

The frequency distribution of stakeholder participation patterns suggests that sector–stakeholder alignments are not random but influenced by governance model type and geographic context. Water–Agriculture linkages were most often facilitated by government–civil society partnerships, particularly in Sub-Saharan Africa and South Asia [19][31]. Energy–Water initiatives showed stronger ties between governments and private companies, especially in the Middle East and North Africa where desalination and solar-powered pumping dominate [32]. Hybrid governance models exhibited the most diverse engagement profiles, integrating all five stakeholder types in multi-sector programs that balance infrastructure development with environmental and social objectives [33]. Table II summarizes these participation patterns, providing a comparative view of stakeholder involvement across sectors.

The distribution in Table II reveals that government involvement remains the backbone of WEF nexus governance, regardless of sectoral scope, reflecting the state's central role in policy alignment and regulatory authority [27][31]. Private sector engagement, while strong in energy-related initiatives, is less pronounced in agriculture-focused programs, partly due to lower immediate returns on investment and higher perceived risk [14]Civil society's active presence in Water–Agriculture and multi-sector projects highlights the importance of community ownership in achieving long-term sustainability outcomes [29]. The high participation rates of academic institutions and international donors in multi-sector programs suggest that knowledge exchange and financing are critical enablers for cross-sector integration [30]. These patterns indicate that successful nexus initiatives often hinge on bridging the technical, financial, and social capacities of diverse stakeholders, with sector–stakeholder alignments shaping both the design and durability of interventions.

TABLE II
STAKEHOLDER PARTICIPATION PATTERNS ACROSS SECTORS IN WEF NEXUS INITIATIVES

Sectoral Focus	Government	Private Sector	Civil Society	Academia	International Donors
Water (single)	High	Low	Medium	Medium	Medium
Energy (single)	High	High	Low	Medium	Medium
Water–Agriculture	High	Medium	High	Medium	Medium
Energy–Water	High	High	Low	Medium	Medium
Energy–Agriculture	Medium	Medium	Medium	Medium	Low
Multi-sector (3+)	High	Medium	High	High	High

C. Outcomes and Challenges

Across the reviewed cases, collaborative governance models generated notable gains while facing persistent constraints. Positive outcomes included improved resource efficiency through integrated planning and optimized allocation of water, energy, and agricultural inputs, particularly in multi-sector partnerships [17] [18]. Resilience gains emerged where adaptive management and cross-sector linkages supported timely responses to climate variability and market disruptions[34]. Community-led and hybrid arrangements enhanced equity by improving access for marginalized groups through participatory decision-making and capacity-building [35], while inter-agency cooperation strengthened governance capacity via policy alignment and institutional learning [36]. Some initiatives also demonstrated innovation in technology deployment, financing, and stakeholder engagement, particularly with active private-sector involvement [37].

However, recurrent challenges constrained impact and scalability. Funding limitations affected both public and community-led models, often resulting in underinvestment in infrastructure or maintenance. Institutional fragmentation and overlapping mandates

hindered implementation in multi-agency contexts [38], while power asymmetries between national authorities, private investors, and local communities undermined trust and equitable benefit-sharing [15]. Technical capacity gaps, especially in rural or resource-limited areas, reduced the quality of system design, operation, and monitoring [20].

TABLE III
OUTCOME–CHALLENGE MATRIX BY COLLABORATION MODEL TYPE

Collaboration Model Type	Key Positive Outcomes	Main Challenges (by Category)
A. Public–Private Partnership (PPP)	Resource efficiency; technological innovation; diversified financing.	Institutional misalignment; profit-driven priorities; skills gaps; unequal benefits.
B. Community-led / Co-management	Equity and inclusion; strong local governance; cultural fit.	Weak policy support; funding volatility; limited monitoring tools; power imbalances.
C. Inter-agency / Government Coordination	Governance capacity; policy alignment; resilience.	Bureaucratic inertia; budget limits; weak data systems; low public engagement.
D. Hybrid / Multi-level Governance	Cross-sector synergies; adaptive governance; innovation.	Coordination complexity; fragmented funding; integration challenges; conflicting priorities.

To structure these findings, challenges can be grouped into four thematic categories (institutional, financial, technical, and socio-political) and mapped against governance models. Table III presents this Outcome–Challenge Matrix, enabling direct comparison of benefits and constraints across collaboration types. The comparative analysis indicates that Public–Private Partnership (PPP) models often deliver strong efficiency and infrastructure innovation through private-sector agility and financing [39], [40], but profit-driven priorities can misalign with environmental or equity goals, widening access gaps (Hoff, 2018). Community-led or co-management models excel in inclusivity, trust, and local knowledge integration (Boakye-Danquah et al., 2021) yet face chronic funding instability and limited technical expertise (Sullivan et al., 2020). Inter-agency coordination fosters durable governance frameworks and policy coherence in cross-boundary systems [28], though bureaucratic inertia and weak citizen engagement may limit adaptability [41]. Hybrid or multi-level arrangements enhance resilience and adaptability through cross-scale integration [42], but incur high coordination costs, fragmented funding, and potential conflicts between local autonomy and national priorities (Galaitsi et al., 2023). Overall, scalability and sustainability are maximized when governance models are tailored to local institutional maturity, resource capacity, and power dynamics, with hybrid approaches showing the greatest flexibility under enabling policy environments.

D. Patterns and Trade-offs Across Governance Approaches

The synthesis of collaboration models, sectoral alignments, and governance outcomes presented in Table III reveals distinct patterns in how approaches are matched to context, as well as trade-offs in their implementation. Governance model type often aligns closely with the dominant sectors and stakeholder configurations. Public–Private Partnerships (PPP) are frequently linked to energy-related initiatives, particularly Energy–Water projects in the Middle East and North Africa and Southeast Asia, where private firms supply capital-intensive infrastructure in partnership with government agencies[43][17]. By contrast, Community-led and Co-management models are concentrated in Water–Agriculture initiatives in Sub-Saharan Africa and Latin America, where civil society organizations and local cooperatives collaborate with government extension services to manage irrigation systems and restore watersheds [44]. Hybrid governance arrangements—blending state-led structures with bottom-up participation—emerge more often in multi-sector programs, often supported by international donors and academic institutions to bridge local action and national policy priorities [42].

Patterns in governance outcomes also point to recurring trade-offs. PPP arrangements often deliver technological innovation and operational efficiency yet risk inequitable benefit distribution and weaker environmental safeguards when commercial incentives dominate [39]. Community-led models foster trust and local ownership, contributing to sustainability over time, but suffer from unstable funding and limited policy integration [45][46]. Inter-agency coordination can enhance policy coherence and institutional learning, though it is vulnerable to bureaucratic inertia and siloed mandates, particularly in transboundary settings [28]. Hybrid models offer adaptability and inclusivity but tend to require higher transaction and coordination costs [47].

Regional variations further shape these patterns and trade-offs, underscoring that institutional maturity, resource endowments, and socio-political contexts influence the appropriateness of each governance type. In East Africa, hybrid governance linked to climate adaptation strategies has proven more effective than

single-sector approaches because of its ability to integrate livelihoods and resilience-building in policy frameworks [18]. In parts of South Asia, community-led approaches align with long-standing traditions of collective resource management, while in MENA contexts, inter-agency coordination is more prevalent under centralized government structures [22]. These contrasts reinforce the need for context-sensitive design over a universal "best practice" model.

E. Implications for Policy and Practice

The patterns and trade-offs observed across governance approaches highlight several priorities for policy and practice in emerging economies. In these contexts, resource constraints, institutional fragmentation, and rapidly shifting socio-economic conditions necessitate adaptive governance models that combine sectoral flexibility with clear institutional mandates (such as hybrid multi-stakeholder platforms) capable of sustaining cross-sector collaboration under uncertainty [30]. Stakeholder engagement strategies should be aligned with dominant sectoral priorities, ensuring that lead actors, whether from government, private sector, or civil society, are paired with partners that can fill technical, financial, and socio-political capacity gaps.

For emerging economies, enabling conditions are particularly critical. Supportive legal and regulatory frameworks should clarify mandates, reduce institutional overlap, and strengthen accountability mechanisms [41]. Diversified financing arrangements, including blended public–private instruments, can reduce dependence on volatile donor funding. Targeted capacity-building initiatives must extend beyond technical training to include negotiation, facilitation, and conflict-resolution skills essential for collaborative governance in politically and socially diverse environments.

When combined, these measures can enhance resilience, improve resource-use efficiency, and reduce equity gaps, while retaining the adaptability needed to respond to climate variability, demographic shifts, and market volatility. By embedding such approaches into policy frameworks, emerging economies can better operationalize WEF nexus governance to achieve sustainable and inclusive resource management outcomes.

F. Directions for Future Research

The synthesis across this study surfaces several underexplored dimensions of WEF nexus governance that merit targeted, methodologically diverse investigation. The durability of governance arrangements—whether Public–Private Partnerships, community-led initiatives, inter-agency coordination platforms, or hybrid models—remains poorly documented in dynamic socio-political and environmental contexts. Understanding how these arrangements evolve under shifting political regimes, economic cycles, and climate-related stressors could be advanced through longitudinal designs integrating time-series policy analysis [48] and repeated network mapping [49] to track adaptation pathways and stakeholder reconfigurations.

Sectoral integration gaps are also evident—most notably the underrepresentation of the energy–agriculture interface in Table III, despite its strategic role in rural development, climate-smart agriculture, and decentralized energy transitions. Future work could apply nexus-based scenario modelling [28], [50] and coupled agent-based simulations [51] to assess policy trade-offs, technological adoption rates, and equity implications in integrated WEF strategies.

TABLE IV
FUTURE RESEARCH GAPS, GOV. MODEL LINKAGES, AND METHODOLOGICAL OPPORTUNITIES

Research Gap / Opportunity	Govt. Model	Illustrative Methods	Potential Contribution
Governance model durability under political, economic, and environmental shifts	A–D (all)	Time-series policy analysis; Institutional ethnography; Repeated network mapping	Reveal adaptation trajectories, resilience mechanisms, and stakeholder reconfigurations
Underexplored energy–agriculture interface	B & C	Nexus-based scenario modelling; Coupled agent-based simulations	Test integrated WEF strategies, quantify trade-offs, assess rural development impacts
Limited evidence on digital governance tools	A–D (all)	Experimental and quasi-experimental field designs; RCTs in policy pilots	Measure causal effects on transparency, efficiency, and cross-sector coordination
Need for comparative, context-sensitive governance evaluation	A–D (all)	Configurational Comparative Methods; Participatory Systems Mapping	Identify governance conditions across institutional settings; integrate local knowledge into design

Research Gap / Opportunity	Govt. Model	Illustrative Methods	Potential Contribution
Integration of stakeholder engagement strategies into sector-specific priorities	C & D	Mixed-method process tracing; Stakeholder network analysis	Link governance design choices to participation outcomes and legitimacy

Emerging digital governance tools—including geospatial analytics for monitoring land–water–energy interactions), distributed ledger technologies for traceability and accountability[52], and AI-enabled decision-support systems for scenario planning [53]—offer promising mechanisms to address coordination and transparency challenges identified in Table III. Experimental and quasi-experimental designs could provide causal evidence of their effectiveness in improving cross-sector integration, transaction efficiency, and governance legitimacy.

Finally, the trade-offs and regional variations described in Section D underscore the need for comparative, context-sensitive evaluation. Mixed-method strategies that combine Configurational Comparative Methods (CCM) (Rihoux & Ragin, 2009) with Participatory Systems Mapping (PSM) (Voinov et al., 2018) can identify necessary and sufficient governance conditions while embedding local priorities into the analytical frame. Such methodological pluralism can refine theoretical models and yield operationally viable, equity-oriented governance frameworks adaptable to varying institutional maturity levels.

V. CONCLUSION

This review shows that WEF nexus governance models, including Public–Private Partnerships, community-led initiatives, inter-agency coordination, and hybrids, perform differently depending on sectoral priorities, stakeholder composition, and institutional context. PPPs deliver infrastructure and innovation but risk equity and sustainability without strong regulation. Community-led models ensure inclusivity yet face resource and capacity limits. Inter-agency coordination improves coherence but suffers from bureaucratic inertia, while hybrids offer adaptability with higher coordination costs.

Policy design should prioritize context-sensitive governance that aligns sectoral goals, mandates, and financing with long-term capacity building. Addressing gaps such as governance durability, the energy–agriculture interface, and digital tools requires longitudinal, comparative, and mixed-method research. Methodological pluralism will be essential for creating governance frameworks that are both operationally viable and adaptive to diverse socio-political and environmental conditions.

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