



Bridging policy silos: governance challenges and opportunities in the WEFE nexus of non-EU PRIMA partner countries – a systematic literature review

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Abstract

The Water-Energy-Food-Ecosystem (WEFE) Nexus has evolved from a resource efficiency paradigm within water, energy, and food (WEF) systems toward a broader governance framework that recognizes ecosystems as essential to resource security and sustainability. While this conceptual expansion has strengthened the Nexus' analytical scope, a research gap remains regarding how governance mechanisms translate WEFE principles into actionable policy, particularly in non-European Union (EU) countries participating in the Partnership for Research and Innovation in the Mediterranean Area (PRIMA), where institutional fragmentation and policy silos persist. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach, this systematic literature review examines how the WEFE Nexus has been integrated into governance processes, focusing on policy coherence, coordination, and complementarity. Boolean string searches combining terms on the Nexus, governance, and the Mediterranean region were applied across Scopus and Google Scholar. Publications were selected from open-access and hybrid-access databases, supplemented by inter-library loans for sources unavailable through the host university. Eighty records published between 2011 and 2025 were retained for detailed analysis. The review finds increasing policy and research alignment with WEFE principles across the Mediterranean area. Several countries, notably Morocco, Israel, Jordan, and Tunisia, are advancing integrated and participatory approaches that enhance policy coherence, promote circular economy models, and strengthen cross-sectoral collaboration. These emerging governance innovations demonstrate that the WEFE Nexus is transitioning from 'nexus thinking' to 'nexus doing' that supports sustainable resource management, regional resilience, and cross-sectoral policy integration.

Keywords Water-energy-food-ecosystem, WEFE nexus · Mediterranean · Sustainability · Policy integration · Governance

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1 Introduction

Water, energy, food, and ecosystems (WEFE) are deeply entwined, with shifts in one domain inevitably echoing across the others. As pressures mount on their future availability and resilience, an integrated nexus approach (i.e., integrated policy approach) becomes not just relevant, but essential. In recognition of this reality, the WEFE Nexus has emerged as a critical framework for addressing interdependencies and tradeoffs among key resource systems essential for sustainable development. The concept underscores the need for integrated, yet adaptive governance to manage trade-offs and synergies between resources (Adamovic et al. 2019; Brouwer 2022; Brouwer et al. 2018; Carmona-Moreno et al. 2021; Dargin et al. 2019; P. A. Salam, Sangam, Pandey and Anal 2017; Scott et al. 2015). While the original Water-Energy-Food (WEF) framework focused on enhancing resource efficiency and security, it was later expanded to include ecosystems (Bouraoui and Grizzetti 2021). The WEFE Nexus aligns with the Sustainable Development Goals (SDGs), offering a conjoint strategy that promotes cross-sectoral collaboration, efficient resource management, and resilience-building strategies (Hejnowicz et al. 2022; Lalawmpuii and Rai 2023).

Despite its conceptual strength, the implementation of the WEFE Nexus remains hindered by governance challenges (Lazaro et al. 2022). Fragmented institutional structures, policy silos, and the complexity of multi-level governance impede the operationalization of integrated approaches (Kurian et al. 2018). Illustrative of the governance tensions that may arise, the “Water legislation: Cost of non-Europe report” of the European Parliamentary Research Service highlights that, for instance, water protection objectives often conflict, occasionally incoherently, with energy and agricultural policies, underscoring the need for stronger coherence and cross-sectoral coordination (Zandstra 2015). Addressing these governance barriers requires examining policy interactions, including coherence, coordination, and complementarity, to ensure effective WEFE governance.¹

¹ The European Union (EU) policy framework follows the principles of coherence, coordination, and complementarity to ensure effective governance and policy implementation across its member states. For instance, the so-called European Semester is a yearly exercise to coordinate economic, fiscal, employment and social policy within the EU. EU policies must be internally consistent and align with overarching goals, such as sustainable development, economic growth, and social inclusion. The complementarity principle ensures that EU actions complement policies of member states rather than replacing them. The relevant EU legislation is the Treaty on European Union (TEU, Art. 5) and the Treaty on the Functioning of the European Union (TFEU, Art. 121, 153, 167, 208). While the linkage between the WEFE Nexus and the European Semester may initially appear tenuous, the EU’s 2025 Water Resilience Strategy explicitly ties water governance to macro-fiscal and cohesion policies, encouraging Member States to mobilize

Ramirez et al. (2022) illustrated how single-sector solutions can cause unintended consequences and trade-offs. For example, reducing non-revenue water² improved urban supply but depleted aquifers used in agriculture. Without coherence, trade-offs (e.g., food versus energy land use) are mismanaged and risks externalized, undermining sustainability (Scott et al. 2015). Recent discussions also highlight the importance of legal and regulatory integration to strengthen *policy coherence* and support cross-sectoral governance (Olawuyi 2020).

Additionally, polycentric, adaptive governance has gained recognition as a way to improve *policy coordination* across fragmented institutional settings, particularly in addressing WEFE governance challenges at multiple scales (e.g., cities and regions) (Behnassi et al. 2024; Srigiri and Dombrowsky 2022). Ramos et al. (2022) stress that governance reforms alone are insufficient without building cross-sectoral capacity at the individual, organizational, and institutional levels. Institutional capacity (e.g., leadership, knowledge, and funding) positively correlates with collaborative governance (Kurian et al. 2018). During the 1st Regional Roundtable on WEFE Nexus in the Mediterranean, it was pointed out that several Mediterranean countries have made progress in the past decade through, e.g., the establishment of inter-ministerial coordination bodies, thus breaking up policy-silos and moving towards better policy coherence and coordination (GWP-Med, WES, and EU, 2023).

Policy complementarity describes the degree to which policies, e.g., across WEFE sectors are mutually reinforcing rather than redundant or conflicting. Khacheba et al. (2018) offer a practical strategy to improve *policy complementarity* in Algeria. They suggest using renewable energy to power desalination or wastewater treatment, use this water for irrigation in agriculture, and introduce water pricing reforms to reduce resource overexploitation.

Overall, the role of nexus governance models has been increasingly discussed in the literature, particularly in enhancing cross-sectoral policy coherence (Urbinnati et al. 2020), coordination, and complementarity (Appolloni et al. 2025). Additionally, climate change adaptation strategies within the WEFE Nexus have gained attention, particularly in regions with high vulnerability to resource scarcity (Khacheba et al. 2018; Lalawmpuii and Rai 2023).

The literature on the WEFE Nexus has primarily focused on the EU and other well-integrated governance systems, where policy frameworks facilitate cross-sectoral collaboration (Arabi et al. 2023). Yet, while EU governance

structural funds and integrate water resilience objectives into national planning frameworks (EC 2025).

² Water lost or unaccounted for within the distribution system, never reaching the customer.

structures provide valuable insights, direct transposition of these models ought to be avoided due to contextual differences (Herrera-Franco et al. 2023). Meanwhile, governance of the WEFE Nexus in non-EU PRIMA partner countries, i.e., Algeria, Egypt, Israel, Jordan, Lebanon, Morocco, Tunisia, and Türkiye, remains fragmented, constrained by institutional silos, weak cross-sectoral coordination, and uneven capacity to implement context-specific policies (El Zein et al. 2024; Ramos et al. 2022), limiting WEFE Nexus effectiveness (Ijlil et al. 2025).

This study addresses the gap between the conceptual advancement of the WEFE Nexus and its limited operationalization in governance systems across non-EU PRIMA partner countries. While the EU has developed integrated frameworks promoting policy coherence, coordination, and complementarity, comparable governance mechanisms remain fragmented in many Mediterranean non-EU contexts.

Accordingly, this review examines the emergence of the WEFE Nexus within governance processes in non-EU PRIMA countries by (i) identifying key barriers to nexus adoption, (ii) assessing the extent of policy coherence, coordination, and complementarity, and (iii) deriving actionable recommendations to strengthen WEFE governance.

The review focuses on non-EU PRIMA partner countries due to their shared challenges in WEFE management and the strategic importance of advancing sustainable governance models in the Mediterranean region (Golfam et al. 2021). The EU's governance approach of WEFE resources serves as a reference point (Bouraoui and Grizzetti 2021). By comparing governance approaches in the EU with those in non-EU PRIMA countries, the study identifies best practices and context-specific adaptations for effective WEFE governance.

Following the introduction, Sect. 2 outlines the SLR methodology. Section 3 presents the conceptual foundations of the WEFE Nexus, while Sect. 4 synthesizes key findings on governance challenges and policy innovations in non-EU PRIMA countries. Section 5 concludes with actionable recommendations to strengthen integrated resource governance in the Mediterranean region.

2 Methodology

A SLR follows a transparent, replicable, and methodologically rigorous process that minimizes selection bias and enhances the reliability of findings. By employing predefined search strategies, inclusion and exclusion criteria, and a standardized reporting protocol, such as the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, an SLR ensures comprehensive

coverage and comparability across studies (Page et al. 2021). In line with PRISMA, the flowchart (Fig. 1) and the checklist (see Annex 1) are reported.

The search yielded 1,979 records after deleting duplicates. Eighty publications were retained (Fig. 1), which include journal articles, conference papers, book chapters, and policy reports, all written in English and published between 2011 and 2025. The start year was chosen deliberately, as the WEFE Nexus gained international prominence following the 2011 Bonn Conference on The Water, Energy and Food Security Nexus – Solutions for the Green Economy, which marked the formal consolidation of the Nexus as both a research paradigm and a policy framework (see also Sect. 3.4). The end year reflects the most recent records available at the time of the review.

In the first stage, publications were screened based on their titles and abstracts using the web-based SLR tool Rayyan, which facilitates real-time collaboration, blind screening, duplicate detection, tagging, and structured inclusion or exclusion decisions. In the second stage, full-text screening was conducted, and articles that did not address the research questions were excluded. In the third stage, the retained references served as the analytical foundation for developing the review's core arguments and recommendations.

Records were included or excluded following the PRISMA guidelines to ensure conceptual and regional relevance. The inclusion criteria required identified publications to reference at least two of the resource dimensions and at least one key element from the other two search strings. Publications addressing the WEF and WEFE nexuses in the region of interest, but focusing solely on technical aspects or methodological frameworks, were excluded. Conversely, articles that explored policy challenges, opportunities, or sectoral fragmentation within the context of the WEF or WEFE Nexus were included if referencing at least one non-EU PRIMA country.

Publications were excluded for four main reasons: (1) use of the term “nexus” with a different meaning; (2) a primary focus on technical or economic aspects of WEFE resources without governance implications; (3) emphasis on management or engineering solutions rather than policy integration; and (4) other context-related reasons, such as a focus on countries outside the non-EU PRIMA region. Due to these comprehensive inclusion and exclusion criteria, the risk of bias of individual studies is perceived as negligible.

In total, 1,899 records were excluded at the title- and abstract-screening stage, while full-text screening led to the removal of additional papers that did not address governance dimensions of the WEFE Nexus. Where necessary, books were disaggregated into individual chapters for accuracy. The final dataset retained 80 publications for in-depth

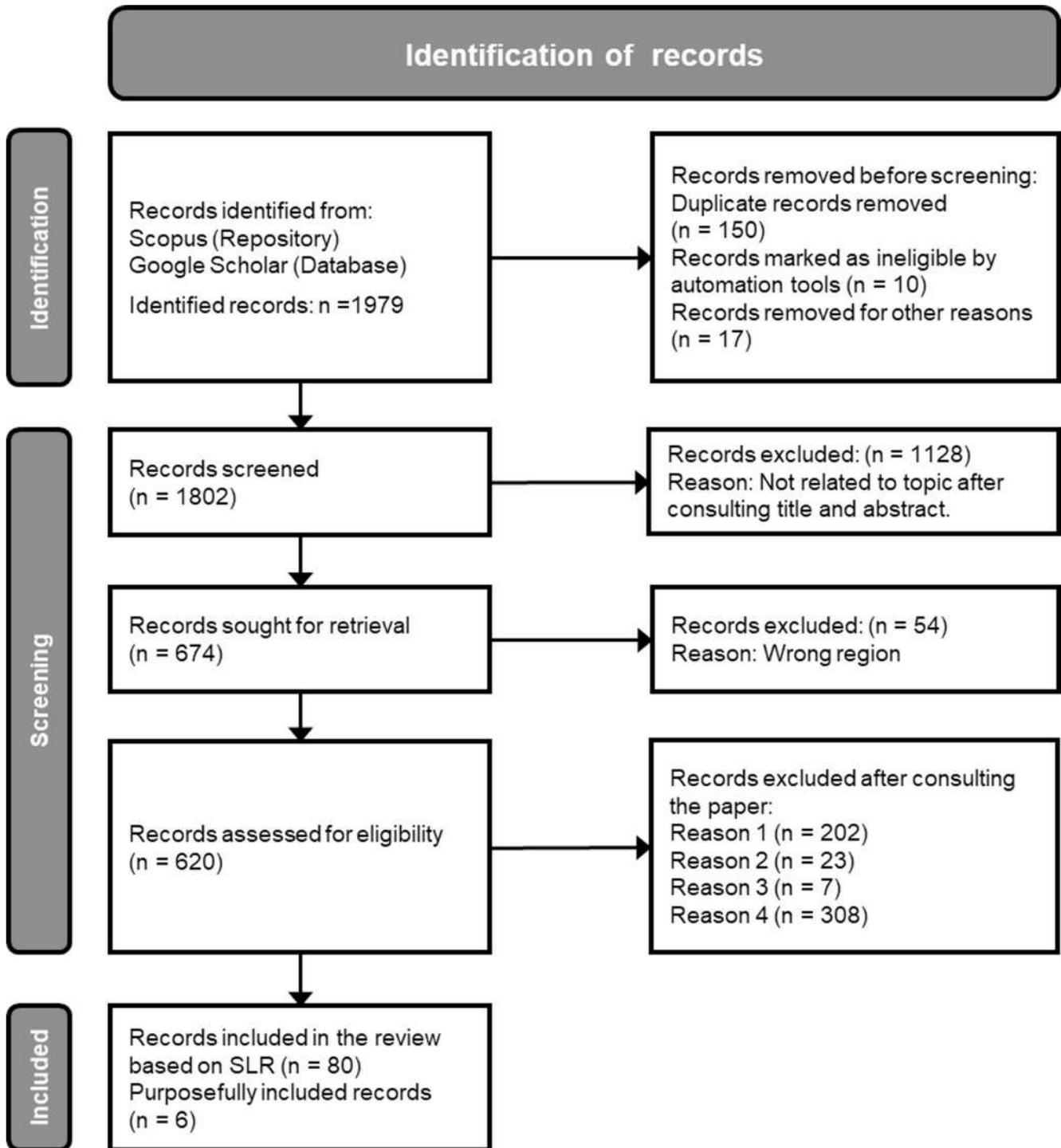


Fig. 1 PRISMA flowchart of the SLR. Source: Page et al. (2021: 372:n71), respectively PRISMA flow diagram online. Reason 1=Used the term ‘nexus’ but with a different meaning; Reason 2=Focus on

technical & economic aspects of WEF resources; Reason 3=Focus on management solutions of WEF resources; Reason 4=Other reasons

analysis, supplemented by nine key policy references to provide conceptual and regulatory context.

In addition to the 80 references identified as part of the SLR, the reference addressing the PRISMA methodology, i.e., Page et al. (2021), nine other references were included to

bring additional policy background information to the study. These are the following references (in alphabetical order): Appolloni et al. (2025), EC (2019), EC (2025), Del Borghi et al. (2020), Gawlik et al. (2022), Hoff (2011), İşleyen (2014), Mackie (2020), and Zandstra (2015). To distinguish

3.1 Evolution and conceptualization of the WEFE nexus

The WEFE Nexus has evolved from earlier integrated resource management paradigms, most notably the Integrated Water Resources Management (IWRM), the Water-Energy-Food (WEF) Nexus, and systems-thinking frameworks that emerged in response to sustainability challenges in the late 20th century (Lazaro et al. 2022; Pandey and Shrestha 2017; Rbaibi and SahibEddine 2024; Wichelns 2017; Zhang et al. 2019). Pandey and Shrestha (2017) argue that the nexus emerged as a pragmatic governance paradigm in response to the limitations of IWRM, particularly its inability to adequately address broader environmental interdependencies and cross-sectoral interactions.

The concept gained further prominence when concerns over resource scarcity entered global economic and policy debates, notably during the World Economic Forum in 2011 (Mohtar and Lawford 2016). Its subsequent conceptual consolidation was strongly influenced by the 2011 Bonn Conference on “The Water, Energy and Food Security Nexus - Solutions for the Green Economy” (Hoff 2011). Since then, the WEFE Nexus has increasingly been adopted as a framework for addressing interdependencies and trade-offs

among key resource sectors while simultaneously fostering synergies and sustainable development outcomes (Carmona-Moreno et al. 2019; Zhang et al. 2018).

A defining feature of the WEFE Nexus is its explicit integration of ecosystem services into the traditional WEF triad (Fig. 3), reflecting the recognition that water, energy, and food security cannot be sustained in the absence of healthy and resilient ecosystems (Carmona-Moreno et al. 2021). In this sense, the nexus approach places particular emphasis on inter-sectoral governance, system integration, and dynamic interactions across spatial and institutional scales. It further promotes a transition from linear to circular resource flows, highlighting feedback loops, resilience, and resource productivity as central elements of sustainable resource governance (Arabi et al. 2023; Yillia 2016).

More recent scholarship underscores the relevance of WEFE Nexus governance for supporting sustainable and equitable economic development, especially in resource-constrained and climate-vulnerable regions such as the Mediterranean (Markantonis et al. 2019). Within this context, the 2030 Agenda for Sustainable Development positions the nexus approach as both a governance and analytical framework for managing interdependencies among the SDGs, thereby guiding integrated planning and coordination across



Fig. 3 Flowchart of the evolution of the WEFE Nexus framework

national and local policy levels (Riccaboni et al. 2022; Spinzola and Cavalli 2022).

3.2 Theoretical underpinnings and key principles

The WEF Nexus is conceptually grounded in socio-ecological systems theory, complexity science, resilience thinking, and integrative environmental governance. The rationale for adopting a nexus perspective arises from converging global pressures, including growing demand for natural resources, climate variability, environmental degradation, and the persistent shortcomings of siloed sectoral governance systems (Al-Saidi and Elagib 2017; Bhaduri et al. 2015; Diriöz 2021; Mohtar and Lawford 2016). Within this body of literature, the nexus is framed not merely as an analytical construct but as a response to governance failures in managing interconnected resource systems.

Building on this foundation, Weitz et al. (2017) argue that coherence within the WEF Nexus should not be understood solely as institutional integration. Rather, they conceptualize coherence as a dynamic learning process shaped by evolving stakeholder perceptions, power relations, and policy frames. This perspective complements socio-ecological systems thinking by foregrounding the cognitive, political, and institutional dimensions that mediate how nexus principles are translated into policy practice. Together, these insights underscore the centrality of institutional transformation, systems thinking, adaptive coordination, and stakeholder inclusion as core elements of the nexus paradigm.

Beyond socio-ecological and resilience-oriented frameworks, the Resource Nexus approach proposed by Brouwer et al. (2024) and echoed by Rhouma et al. (2024) contribute a structured typology that distinguishes between key environmental resources (i.e., water, soil, material, and climate) and derived or composite resources (i.e., sea, food, waste, energy, and land). This distinction enables a more precise structuring of interdependencies, offering a parsimonious yet comprehensive basis for cross-sectoral analysis. By differentiating between primary and derived resources, the framework also helps policymakers identify intervention points where trade-offs and synergies are most pronounced. To operationalize this logic, Brouwer et al. (2024: 54) propose a morphological box (see Annex 2) for the Resource Nexus, mapping typological dimensions such as environmental resources, governance rationales, stakeholder constellations, spatial-temporal scales, and enabling conditions.

Taken together, these theoretical perspectives position the WEF Nexus as a paradigm shift away from linear, sector-specific management toward integrated and multidimensional policy frameworks that explicitly address trade-offs, feedbacks, and synergies across resource systems. This shift is further reinforced by the recognition that environmental

sustainability and resilient food systems depend on managing interlinked risks dynamically and in alignment with economic, ecological, and social objectives (Bhaduri et al. 2015; Daher et al. 2022; Drobinski et al. 2024; Lalawmpui and Rai 2023). By way of synthesis, the reviewed literature converges on several key theoretical principles that underpin the WEF Nexus:

- *Systemic interconnectivity*: Acknowledging complex, dynamic interdependencies among WEF resources (Lalawmpui and Rai 2023).
- *Policy coherence*: Ensuring that policies across sectors and governance levels reinforce rather than contradict one another (Bazzana et al. 2023; Brouwer et al. 2024).
- *Resilience and security*: Enhancing the capacity of systems to absorb and adapt to shocks while maintaining essential resource functions (Daher et al. 2022; Lalawmpui and Rai 2023).
- *Participatory and inclusive governance*: Empowering stakeholders to co-design context-specific and socially legitimate solutions (Almulla et al. 2022; Malamataris et al. 2025; Nikolaidis et al. 2025).
- *Context-sensitive integration*: Emphasizing the importance of scale, geography, and institutional diversity in shaping effective governance responses (Al-Saidi and Hefny 2018; El Majdoubi and El Ayadi 2025; Lazaro et al. 2022).

3.3 Governance models and institutional frameworks

Governance within the WEF Nexus requires a shift from traditional, siloed management approaches toward adaptive, flexible, and integrative frameworks. Drawing on Brouwer et al. (2024), nexus governance must also address challenges of conceptual overstretch and operational fragmentation, which arise when broad analytical ambitions are not matched by institutional capacity or clear governance arrangements. Scholars such as Brouwer et al. (2024) and Lazaro et al. (2022) therefore argue for greater clarity in defining nexus boundaries and for governance designs that explicitly support stakeholder inclusion across multiple temporal and spatial scales. Complementary work emphasizes the need for institutional transformation that acknowledges power asymmetries, incentive structures, and the transaction costs associated with coordination, particularly in contexts where policy fragmentation may also reflect democratic pluralism rather than governance failure per se (Weitz et al. 2017).

Despite these complexities, the literature consistently highlights that WEF governance benefits from policy coherence, coordination across sectors, and complementarity

between national and sub-national actions, while supporting multi-level stakeholder participation (Boas et al. 2016; Diriöz 2021; Mackie 2020). From this perspective, governance effectiveness hinges on the alignment of policy objectives and instruments rather than on institutional centralization alone. For instance, Del Borghi et al. (2020) stress the importance of vertical integration across governance levels alongside horizontal integration across sectors, while Simpson and Jewitt (2019) underscore the need for coordination across spatial and administrative scales to manage cross-sectoral interdependencies effectively.

Transboundary governance adds a further layer of complexity to WEFE implementation, given frequent mismatches between biophysical systems and administrative boundaries, divergent national interests, and uneven institutional capacities (Zarei 2020). In river basins such as the Blue Nile, effective transboundary governance is critical for managing shared water resources and mitigating cross-sectoral trade-offs (Basheer et al. 2018). The literature identifies several enabling conditions for transboundary WEFE governance, including trust-building through institutionalized dialogue, treaty-based cooperation, shared monitoring systems, and polycentric or decentralized governance arrangements (Leck et al. 2015; Spinazzola and Cavalli 2022; Zarei 2020). At the regional level, GWP-Med et al. (2023) highlight the Union for the Mediterranean (UfM) Nexus Task Force as a coordination platform that supports policy dialogue, technical exchange, and capacity building across WEFE sectors and countries. In addition, inter-regional cooperation in water and energy infrastructure planning, including renewable-energy-powered desalination, has been identified as a potential mechanism for bridging sectoral divides (Quagliarotti 2023).

Beyond national and transboundary governance arrangements, the literature increasingly points to the role of experimental and participatory planning frameworks in operationalizing the WEFE Nexus at local and regional levels. Case studies such as those implemented in the Jordan Valley (Nikolaidis et al. 2025) and the Doroodzan dam irrigation network (Mirzaei et al. 2023) demonstrate how methodological tools including causal loop diagrams, agent-based models, and multi-criteria decision analysis can support context-specific policy design and foster local stakeholder engagement. Riccaboni et al. (2022) similarly emphasize the importance of place-based and cross-scalar implementation strategies tailored to local governance conditions, an approach that is particularly relevant in heterogeneous institutional landscapes.

In this context, participatory tools such as the Miradi Open Standards framework as applied in initiatives like the PRIMA-funded FrontAg Nexus project, illustrate how structured situation models and policy action plans can be

used to assess WEFE-related opportunities and risks and to promote cross-sectoral policy dialogue and stakeholder engagement at the local and regional level.

3.4 Policy frameworks and strategic alignment

The WEFE Nexus aligns closely with global policy frameworks such as the 2030 Agenda for Sustainable Development and its SDGs, particularly SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), and SDG 7 (Affordable and Clean Energy). Despite this strong normative alignment, the literature consistently indicates that the implementation of integrated and coherent resource governance strategies remains uneven and, in many cases, largely symbolic (Mackie 2020). This gap reflects persistent challenges in translating high-level policy commitments into operational governance mechanisms.

Within this context, the EU's framework for external action, as articulated through its Policy Coherence for Development (PCD) strategy (EC, 2019), offers a reference model that explicitly promotes coherence, coordination, and complementarity across sectors and governance levels. These principles provide an institutional foundation for integrated approaches such as the WEFE Nexus and support intersectoral, cross-scalar, and transboundary governance aligned with the SDGs. However, the literature cautions that the presence of such frameworks does not automatically ensure effective implementation, particularly beyond the EU context.

Accordingly, several studies highlight a persistent governance gap between policy ambition and practical implementation tools. Naidoo et al. (2021) for example, propose the Theory of Change as a flexible analytical and planning instrument to identify barriers, align interventions, and support coordinated action across governance levels. In Mediterranean and African contexts, the nexus approach has increasingly evolved into a strategic platform that extends beyond environmental management to encompass social justice, resilience, and livelihood security, thereby broadening its relevance for sustainable development policy (Drobinski et al. 2024).

From a legal perspective, Olawuyi (2020) underscores the challenges associated with integrating water, energy, and food sectors within fragmented legal and regulatory systems. While many nexus-oriented strategies formally acknowledge interlinkages among sectors and policy domains, relatively few have been codified through binding legislative mechanisms capable of ensuring durability, accountability, and enforcement. Nevertheless, the nexus lens is increasingly recognized as a useful framework for advancing the integrated governance of natural resources, ecosystems, agri-food systems, public health, and the SDGs,

particularly when supported by coherent legal mandates and institutional arrangements.

3.5 Towards an operational nexus paradigm

Operationalizing the WEFE Nexus entails translating integrated and systems-oriented thinking into concrete institutional processes, legal mandates, and funding mechanisms. The reviewed literature suggests that this transition requires coordinated progress across several interrelated domains:

- *Refining integration models*: By moving from conceptual clarity (M. Al-Saidi and Elagib 2017) to operational typologies and participatory strategic frameworks (Nikolaidis et al. 2025), integrative models of the WEFE Nexus can be refined.
- *Building trust and policy synergies*: Institutional trust and policy synergies are fostered through regional co-operation frameworks, shared nexus data platforms, and cross-sectoral capacity-building initiatives (Al-Zubari 2021; Bazzana et al. 2023). Including civil society actors in governance processes further enhances transparency and legitimacy, thereby strengthening public trust and policy acceptance (Khacheba et al. 2018).
- *Leveraging funding mechanisms*: The literature highlights the importance of mobilizing appropriate financial instruments to scale nexus-compatible investments. Public authorities may therefore consider engaging in Public-Private Partnerships and promoting blended finance mechanisms to support integrated WEFE initiatives, particularly in infrastructure-intensive sectors (Behnassi et al. 2024; Drouiche et al. 2022; GWP-Med et al. 2023).
- *Strengthening the science-policy interface*: Effective operationalization depends on robust science-policy interfaces that connect modeling tools, decision-support systems, and participatory platforms (Albrecht et al. 2018; Brouwer et al. 2024; Naidoo et al. 2021; Riccaboni et al. 2022). Initiatives such as the WEFE4Med Community of Practice illustrate how structured knowledge exchange can support policy learning and coordination (GWP-Med et al. 2023). In addition, accessible and comprehensible integrated resource indicators can help bridge science-policy gaps and inform decision-making, while data sharing across institutions supports adaptive governance processes (Kurian et al. 2018).
- *Embedding legal coherence*: Translating nexus principles into practice further requires embedding legal coherence across policy domains and governance levels. This includes aligning WEFE-related legislation while explicitly addressing coordination and complementarity among sectoral policies (Olawuyi 2020).

- *Emphasizing actionable, locally adapted governance strategies*: Several authors argue for focusing on a minimal yet essential set of interrelated resources, such as water, energy, and food, to enhance measurability, policy relevance, and implementation feasibility, particularly in contexts with limited administrative capacity (Brouwer et al. 2024).

Taken together, the WEFE Nexus emerges from the SLR as a strategic governance framework capable of supporting integrated planning, enhancing institutional coherence, and fostering systemic resilience. Its relevance is particularly pronounced in fragile and resource-constrained regions facing compound challenges, including climate stress, environmental degradation, and food system vulnerabilities.

4 Towards better governance in the WEFE nexus

Building upon the conceptual foundations in Sect. 3, this chapter examines practical governance challenges and pathways for implementing the WEFE Nexus in non-EU PRIMA countries. Reflecting a synthesis-oriented style informed by Behnassi et al. (2024), it integrates policy perspectives, draws on regional best practices and case studies to inform actionable strategies for advancing the WEFE Nexus.

Figure 4 provides a conceptual synthesis of the relationships among principles, governance frameworks, strategies, and barriers discussed in Sects. 3 and 4. It illustrates how WEFE implementation is shaped by guiding principles and governance arrangements that enable strategic action, while structural barriers both constrain and emerge from governance processes. In this way, the figure bridges the conceptual foundations of the WEFE Nexus with the governance challenges and country-level experiences analyzed in the subsequent section.

4.1 Barriers to integrated WEFE governance

Despite mounting climate and resource pressures as well as conceptual appeal, WEFE Nexus implementation in Algeria, Egypt, Israel, Jordan, Lebanon, Morocco, Tunisia, and Türkiye is hindered by persistent governance bottlenecks that reflect a legacy of insufficient cross-sectoral integration (A. P. Salam, Shrestha, Pandey and Anal 2017; Sarkodie and Owusu 2020). Counter-intuitively, Raviv et al. (2024) even show that climate change-induced uncertainty, particularly from extreme events, poses a barrier rather than incentive to integrated WEFE governance.

Pandey and Shrestha (2017) claim that nexus debates remain elite-driven and globally framed, lacking

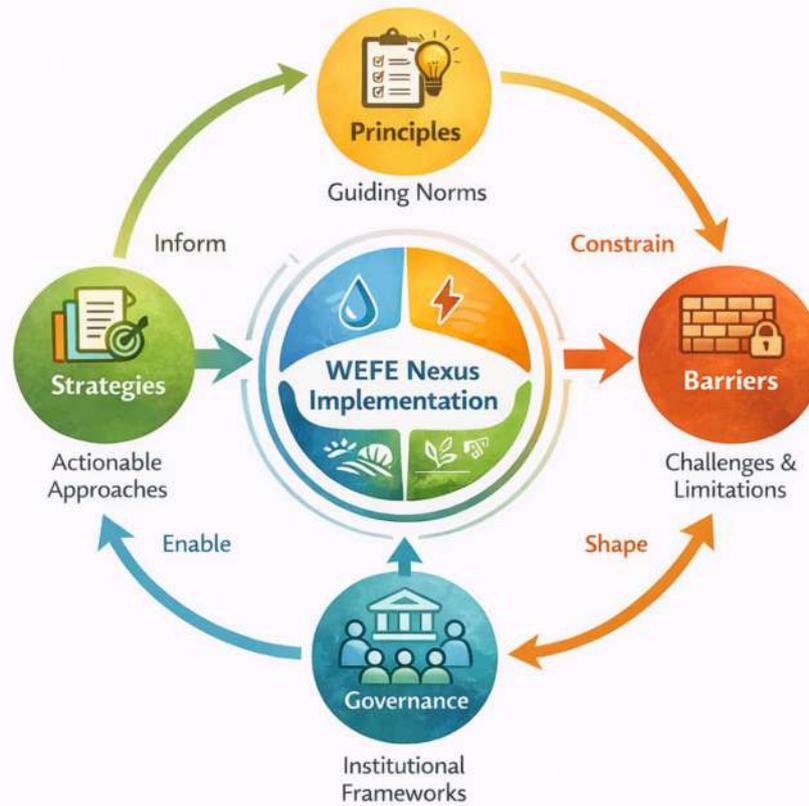


Fig. 4 Interactions on the way to the WEF E Nexus implementation

institutional translation into national policy. Thus, it may not surprise that fragmented policy regimes and siloed institutional arrangements persist across most non-EU PRIMA countries. Horizontal and vertical governance misalignments impede policy implementation. Cross-sectoral coordination remains largely ad hoc, constrained by weak or unclear mandates, insufficient funding, and a lack of institutional incentives for collaboration (Lalawmpuii and Rai 2023; Leck et al. 2015; Lucca et al. 2023; van Gevelt 2020). Consequently, public agencies of water, agriculture, energy, and environment often pursue conflicting objectives, while national development strategies rarely acknowledge interdependencies across sectors (Urbinatti et al. 2020; Zhang et al. 2019). The result is poor alignment and trade-off blind policymaking. These structural deficits are exacerbated by the limited adoption of integrated assessment models, e.g., the Climate, Land, Energy, and Water Systems (CLEWs) framework (Ramos et al. 2022), and weak science-policy interfaces (Herrera-Franco et al. 2023; Lawford 2019; Liu et al. 2018).

Scott et al. (2015) explain how siloed sectoral policies and weak feedback between environmental outcomes and

governance structures inhibit systemic WEF integration. Their case on the electricity-for-water policy in Jordan shows how coordination failure can create negative trade-offs, like unsustainable extraction of groundwater due to subsidized pumping.

Yet, policy coherence across WEF E sectors should be understood as an evolving learning process and norm alignment, rather than a fixed governance outcome (Weitz et al. 2017). Coherence emerges through negotiation and shifting perceptions, suggesting the importance of building institutional trust, shared values, and respect. Taguta et al. (2022) further highlight that despite the proliferation of WEF(E) nexus tools, their practical application remains limited due to inaccessibility, lack of geospatial capabilities, and insufficient adaptability to local and regional contexts, factors that constrain their integration into planning systems and hinder evidence-based policy coherence.

While decentralization or devolution is widely promoted, its implementation is uneven. In several cases, local authorities lack legal clarity and fiscal autonomy to support integrated planning (Ijlil et al. 2025; Kurian 2017). Limited technical capacity further undermines the uptake of adaptive

planning mechanisms and thus policy complementarity (Liu et al. 2017).

Outdated legal frameworks continue to prioritize sectoral mandates, hindering integrated planning. In Tunisia and Lebanon, sectoral legislation often conflicts or overlaps, contributing to governance gridlocks (El Zein et al. 2024; Yillia 2016). Legal provisions for public participation remain weak or absent, limiting inclusive policymaking. As long as stakeholder engagement remains superficial, despite growing recognition of the value of co-produced knowledge, valuable policy feedback is going unexploited. As recent findings show, resilience in resource governance is also undermined by systemic political constraints, including clientelism and centralized decision-making (Daher et al. 2022).

Nevertheless, Brouwer et al. (2024) caution against the tendency of some nexus frameworks to overreach in scope without adequate definitional clarity or stakeholder engagement. Their meta-review identifies five primary categories of challenges: conceptual, operational, cross-scalar, governance, and contextual. Each of which is mirrored in the governance obstacles encountered in non-EU PRIMA countries. These are echoed by Rhouma et al. (2024), who highlight additional gaps such as the integration of health considerations, a lack of standardized tools and models, weak science-policy interfaces, and minimal attention to subnational governance levels.

4.2 What lessons May non-EU PRIMA countries learn from the eu's WEFE governance approach?

The EU's 3 C principles of governance³ remain relevant touchstones for WEFE governance. The EU has institutionalized a range of integrative mechanisms that non-EU PRIMA countries may want to consider in their national contexts.

Coordination: Institutional architecture features formal mechanisms such as inter-Directorate General (i.e., EU administrative units divided into policy areas) coordination groups, the Secretariat General's oversight, and data-sharing platforms such as Eurostat Agriculture Database, Eurostat Environment Data, Agri-Food Data Portal, or the Statistics for the European Green Deal (Johnson et al. 2019; Mackie 2020; Purwanto et al. 2021).

³ The relevant EU legislation for the 3 C-principles concept are: Article 5 of the Treaty on European Union (TEU) – Establishes subsidiarity and proportionality, ensuring that EU action is necessary and does not overstep national competencies. Article 121 of the Treaty on the Functioning of the European Union (TFEU) – sets out economic policy coordination through the European Semester. Article 153 TFEU – Provides for EU action to complement national social policies. Article 167 TFEU – Ensures complementarity in cultural policies.

Complementarity: Through subsidiarity and shared competencies, EU governance aligns local adaptation with regional strategies. The EU Better Regulation Toolbox is part of a broader toolkit that illustrates how regulatory instruments can enhance complementarity by identifying external policy spillovers early. This also applies to policy complementarity to achieve the SDGs (i.e., Tool #34). Applying a WEFE Nexus perspective is perceived as creating synergies and managing trade-offs concerning the SDGs (Spinazzola and Cavalli 2022). Science-policy interfaces embedded in research frameworks like PRIMA and Horizon Europe foster policy innovation while respecting national sovereignty. The EU experience demonstrates how institutional layering and cross-scalar trust-building can foster nexus-oriented governance (Adamovic et al. 2019; Behnassi et al. 2024).

Coherence: Promoting policy coherence is inherently political. Mackie (2020) argues that policy coherence cannot be achieved through isolated reforms but must be supported by a systemic approach comprising political commitment, institutional coordination mechanisms, and analytical capacity. This perspective aligns with the EU's experience in mainstreaming coherence through a dedicated regulatory framework. For instance, the EU's Green Deal, the Common Agricultural Policy (CAP), and water directives embed nexus logic by promoting ex-ante impact assessments and cross-sectoral consultation. Policy coherence is further supported by mainstreaming sustainability across trade, development, and climate portfolios (Brouwer et al. 2024; EC, 2019).

The EU has increasingly adopted the 3 C policy principles to ensure sustainable resource management while balancing economic and environmental priorities. Although there is no formal EU strategy on WEFE governance, the EU **coordinates** WEFE-related policies through the following communications, directives, initiatives, and strategies (list not complete):

- Water Framework Directive (2000/60/EC), which ensures sustainable water management, aligning with agriculture and energy policies.
- Renewable Energy Directive (2018/2001/EU), which encourages sustainable energy production while considering water and food security.
- CAP (2021/2115/EU), which aligns agricultural practices with environmental sustainability.
- The European Green Deal (2019/640/EC communication), which aims to make the EU climate-neutral by 2050, encompasses initiatives across various sectors including energy, agriculture, and biodiversity.
- Farm to Fork Strategy (2020/381/EC communication) (part of the Green Deal), which seeks to create a fair,

healthy, and environmentally friendly food systems that respect water and energy limits.

- EU Circular Economy Action Plan (2020/98/EC communication) (part of the Green Deal), which promotes sustainable resource use across the WEF sectors by focusing on product design, sustainable consumption, and waste prevention, thereby ensuring that policies across these sectors are coherent and mutually reinforcing.
- EU Biodiversity Strategy for 2030 (2020/380/EC communication), which aims to protect and restore biodiversity across the EU, setting targets.
- Forging a Climate-Resilient Europe (COM(2021)/C 445/19) frames climate adaptation as a systemic priority and explicitly calls for integration with sectors such as agriculture, water, ecosystems, and infrastructure to ensure coherent implementation across climate, environmental, and socio-economic policies.
- Fit for 55 Package (2021/550/EC communication), which aligns EU energy and climate policies with SDGs.
- Nature Restoration Regulation (2024/1991), which legally binds nature restoration obligations to reinforce ecosystem components of WEF resources.
- Competitive Compass 2025 (COM(2025) 30 final) as a foundation for growth in the EU, which includes a 'competitiveness coordination tool' and links to the water resilience goals.
- Vision for Agriculture and Food (COM(2025) 75 final), representing a roadmap to shape 'an attractive farming and agri-food sector for future generations'. The Vision explicitly frames research, innovation, knowledge, and skills as cross-cutting drivers and calls for coordinated (blended) funding instruments across sectoral policies to reinforce synergies between agriculture, water, climate, and ecosystem dimensions.
- Water Resilience Strategy 2025 (COM(2025) 280 final), which embeds cross-sectoral objectives and governance actions.
- European Ocean Pact (COM(2025) 281 final), which promotes cross-sectoral governance by integrating marine ecosystem protection with climate adaptation, food systems, blue energy, and maritime spatial planning, thus reinforcing the WEF Nexus at the ocean-land interface.

The EU *complements* national efforts by providing guidelines, funding, and legal frameworks while allowing EU member states to implement measures suited to their specific needs. Key policy tools ensuring complementarity are:

- The EU Adaptation Strategy, which helps member states integrate climate resilience into water and agricultural management.

- The CAP eco-schemes, which financially support farmers in adopting sustainable practices that benefit water and energy efficiency.

For instance, Orimoloye (2022) cited Portugal's WEF Index⁴ and the Netherlands' Green Deal approach as policy instruments that foster policy complementarity. Similarly, the WEF Nexus Gateway Atlas (Gawlik et al. 2022), developed by the European Commission's Joint Research Centre (JRC), served as a policy-support tool to visualize inter-sectoral trade-offs and synergies across the Mediterranean region, helping decision-makers identify nexus interactions and prioritize integrated governance strategies (GWP-Med et al. 2023). However, the link to the WEF Nexus Gateway Atlas is no longer active.

The EU Water Initiative is an example showcasing the support for sustainable water management strategies in partner countries while ensuring *coherence* with EU climate and energy policies. The WEF Nexus approach requires ensuring coherence between policies affecting water, energy, food, and ecosystems.

By applying the 3 C principles, the EU enhances the effectiveness of the WEF Nexus approach. Coordination ensures joint efforts between institutions and sectors, complementarity allows member states flexibility in implementation, and coherence prevents conflicting policies.

For EU partner countries, the twinning instrument is available to assist them in administrative and policy reforms along the *Aquis Communautaire*. Twinning cooperation projects usually last for up to three years. Through peer-to-peer exchange, the instrument acquaints civil servants in partner countries with implementing more effective and efficient public policies, thus building ecosystems, creating opportunities, and shaping reform processes, which translate policy priorities into action. Nevertheless, the twinning instrument has also been implemented within the European Neighborhood Policy Program as a response to the Arab uprisings that started in 2010. In Egypt and Tunisia, twinning was used for project-based institution-building cooperation between relevant public bodies of EU member states and their national counterparts to foster their technical, administrative, and judicial capacities to implement the European Neighborhood Policy objectives (İşleyen 2014).

Nevertheless, there are clear limits to directly transferring or replicating the EU's WEF governance approach in non-EU PRIMA partner countries. Our analysis reveals that the enabling conditions underpinning EU frameworks, such as a consolidated legal *acquis*, mature inter-ministerial coordination, multi-level governance, and comprehensive

⁴ A national-level composite WEF Nexus Index is available for the years 2019-23. This is informational for governments aiming at coherent and coordinated WEF Nexus governance.

Table 2 Governance pathways and WEF nexus implementation patterns in non-EU PRIMA partner countries

Country	Entry point for WEF governance	Key governance instruments / initiatives	Dominant WEF dimensions	Scale of implementation	Illustrative references
Algeria	Policy complementarity in water-energy-food	Renewable-energy-powered desalination and wastewater reuse; irrigation reuse; water pricing reforms.	Water-Energy-Food	National / transboundary	Khacheba et al. (2018) Drouiche et al. (2022)
Egypt	Decentralized WEF integration	Rabia community off-grid WEF solutions; Eastern Nile Basin cooperation.	Water-Energy-Food	Local / transboundary	El Zein et al. (2024) Mohammad Al-Saidi and Hefny (2018)
Israel	Strategic long-term planning	National Water Master Plan (2012–2050); Energy 2050 Plan.	Water-Energy-Food-Ecosystems	National	Appolloni et al. (2025) Orimoloye (2022)
Jordan	Climate- and energy-driven integration	Green Growth National Action Plan; participatory planning in the Jordan Valley.	Water-Energy	National / regional	Scott et al. (2015) Nikolaidis et al. (2025)
Lebanon	Adaptive, decentralized governance	Local planning initiatives; donor-supported resilience strategies.	Water-Energy	Local	Daher et al. (2022)
Morocco	Participatory and circular governance	Saïss groundwater management; circular irrigation; renewable integration.	Water-Energy-Food-Ecosystems	Sub-national / national	Ijlil et al. (2025) Arabi et al. (2023) Rbaïbi and SahibEd-dine (2024)
Tunisia	Integrated national planning	Water 2050; Water Code reform; WEF-CAP White Paper.	Water-Energy-Food-Ecosystems	National	Appolloni et al. (2025) GWP-Med et al. (2023)
Türkiye	Climate-water-food integration	Water Security Policy; Climate Change Mitigation and Adaptation Strategy; basin-level governance.	Water-Energy-Food	National / transboundary	Appolloni et al. (2025) Zarei (2020)

WEF water-energy-food, *CAP* common agricultural policy

data systems, are not uniformly present. In many non-EU contexts, institutional fragmentation, fiscal constraints, and uneven administrative capacity hinder the adoption of similarly structured instruments. As a result, ‘one-size-fits-all’ replication risks producing scale and fit mismatches when local governance realities, resource endowments, and political economies are not considered. The findings, therefore, point to the need for adaptive translation rather than mechanical transfer: identifying context-specific entry points, building polycentric coordination instead of centralized authority, sequencing legal and fiscal reforms with capacity development, and combining technological innovation with ecosystem-based measures. These insights underscore that effective WEF governance in the Mediterranean requires gradual, tailored adaptation to each country’s institutional maturity and environmental challenges rather than direct policy emulation.

4.3 Accelerating transformation: lessons from high-performing non-EU PRIMA countries

Several non-EU PRIMA countries have experimented with integrative governance approaches that demonstrate the operational viability of the WEF Nexus. Although

heterogeneous in scope and scale, these initiatives offer valuable insights for integrating the WEF Nexus into national and transboundary resource governance. Table 2 synthesizes governance entry points and implementation patterns of illustrative examples highlighted in Sect. 4.3.

Integrated and adaptive planning as entry point: National climate, water, and energy strategies serve as coordination nodes for embedding nexus logic in several non-EU PRIMA countries. Participatory groundwater management in Morocco’s Saïss region has improved vertical integration by linking community needs with regional planning (Ijlil et al. 2025). In Jordan, integrated assessments inform adaptive water-energy infrastructure, with a growing emphasis on renewables. This is visible in Jordan’s Green Growth National Action Plan (2021–2025) (Albatayneh et al. 2022; Appolloni et al. 2025; Scott et al. 2015). In Lebanon, interactive and decentralized planning approaches are gaining traction in response to complex shocks and institutional constraints (Daher et al. 2022). The Tunisian Water 2050 (Eau 2050) program, initiated in 2019, couples a system-wide diagnosis and hydro-economic modelling with a national strategy and an explicit portfolio of projects. The Water 2050 program prioritizes demand management and pricing, rehabilitation and digital monitoring of urban and irrigation networks,

non-conventional supply through desalination and wastewater reuse, irrigation efficiency, and ecosystem protection. As such, Water 2050 illustrates how integrated planning in a non-EU PRIMA context can be translated into sequenced policy-backed management measures and investment pipelines. While Israel has not enacted legislation explicitly dedicated to the WEF Nexus, the interconnectedness of these sectors is recognized in various strategic documents. Two of the most relevant documents are Israel's Long-Term Master Plan for the National Water Sector (2012–2050) and the Energy 2050 Plan. The Long-Term Master Plan outlines Israel's vision, goals, and objectives for sustainable water management. It underscores the importance of aligning water management with energy, food, and ecosystems. By promoting sustainable energy practices, the Energy 2050 Plan indirectly supports the conservation of water resources and the protection of ecosystems, reflecting an integrated approach to resource management. One could conclude that this governance evidence illustrates Israel's commitment to integrated resource management, addressing the interdependencies and trade-offs between water, energy, food, and ecosystems to promote sustainable development (Appolloni et al. 2025).

Legal and regulatory reform: Tunisia and Morocco have revised key legal instruments to reflect integrated land-water-energy governance. For instance, the Tunisian Water 2050 program calls for revising the Water Code and clarifying roles across sectoral ministries and public agencies. These reforms support legal complementarity across scales. In Egypt, the Rabia case illustrates how off-grid WEF integration can enhance climate resilience, gender equity, and livelihood diversification through decentralized, context-specific solutions (El Zein et al. 2024). Türkiye's Water Security Policy, the National Adaptation Strategy and Action Plan on Water Management (2023–2030), and the 2024–2030 Climate Change Mitigation and Adaptation Strategy integrate climate change adaptation with food security policies, water management in agriculture, protection of soils and biodiversity, and improve interagency cooperation in Türkiye (Appolloni et al. 2025). Yet, Zarei (2020) highlights that Türkiye's advancement in renewable energy infrastructure, while beneficial for domestic energy security, may pose challenges for food and water systems in downstream countries unless accompanied by negotiated legal frameworks that ensure equitable cross-border benefit-sharing. This underscores the need for regulatory reforms that align national development with transboundary resource governance.

Technological and circular economy solutions: Morocco stands out in advancing water circularity, drip irrigation, and renewable energy integration into agricultural systems, aiming at mitigating and adapting to climate change (Arabi

et al. 2023; El Youssfi et al. 2020). The country's transition towards circular economy principles further illustrates the synergy between nexus logic and sustainable production models. The integration of non-conventional water resources (e.g., through desalination or wastewater reuse) is part of the Tunisian Water 2050 program, thus emphasizing circular economy principles. Furthermore, the Water 2050 process links non-conventional water resources, network rehabilitation, and irrigation efficiency with investments in ecosystem protection and restoration, including watersheds, oases, forests, and wetlands. These measures indicate a shift toward ecosystem-aware nexus implementation.

Recent evidence by Rbaibi and SahibEddine (2024) complements this view by highlighting Morocco's evolving governance landscape in the shift from water-centered IWRM to cross-sectoral WEF Nexus strategies. They identify key enablers such as overcoming ministerial silos, promoting equitable access to land and water, and deploying agroecological innovations like integrated soil fertility management and micro-irrigation. While Taguta et al. (2022) emphasize the benefits of co-designed, user-friendly tools tailored to different governance scales, particularly GIS-enabled and scenario-based models appear beneficial for local planners to enhance vertical policy coherence across administrative levels. M. Al-Saidi and Elagib (2017) and Rbaibi and SahibEddine (2024) call for early-warning systems (possibly AI-enabled) to anticipate water risks and support intersectoral synergies, marking a strategic path toward more adaptive and integrated WEF governance in countries such as Egypt, Sudan, Ethiopia, or Morocco.

Transboundary initiatives: Regional coordination platforms such as the Union for the Mediterranean (UfM) Nexus Task Force and GWP-Med have begun to institutionalize multi-stakeholder engagement across borders, promoting polycentric approaches that align national and basin-level strategies (GWP-Med et al. 2023). Nevertheless, transboundary resource initiatives demonstrate both the challenges and the promise of collaborative WEF governance. The EcoPeace Middle East Water-Renewable Energy Exchange between Jordan, Israel, and Palestine illustrates how cross-border cooperation can leverage comparative advantages in natural resources, namely solar energy in Jordan and desalinated water in Israel, to promote mutual water and energy security while fostering regional stability (Quagliarotti 2023). Similarly, efforts toward joint planning and infrastructure investment in the Eastern Nile Basin (Egypt, Sudan, and Ethiopia) reflect the potential for shared hydropower, irrigation, and agricultural benefits when dialogue mechanisms support equitable resource allocation (M. Al-Saidi and Elagib 2017). In contrast, the absence of coordinated governance in the Tigris-Euphrates Basin (Türkiye, Iraq, and Iran) has resulted in trade-offs and environmental

degradation, underscoring the costs of fragmented management (Zarei 2020). In North Africa, the Northern Sahara Aquifer System (NSAS/NWSAS), shared by Algeria, Libya, and Tunisia, offers another promising model. Facilitated by the *Observatoire du Sahara et du Sahel* (OSS), the aquifer's joint monitoring framework, data-sharing protocols, and dialogue structures have strengthened coordination on groundwater abstraction, irrigation, and ecosystem protection. These mechanisms illustrate how transboundary governance can operationalize WEF Nexus principles by integrating hydrological interdependence, institutional cooperation, and shared accountability, ultimately reinforcing regional resource security and adaptive capacity in the face of climate stress.

Stakeholder-driven innovations, Public Private Partnerships, and blended finance: Participatory scenario modeling, causal loop diagrams, and Learning & Action Alliances have been piloted to support decision-making in Tunisia, Lebanon, and Jordan. These tools promote shared mental models and illuminate feedback dynamics, enhancing both trust and policy effectiveness (Hoolohan et al. 2018; Malamataris et al. 2025). Furthermore, the White Paper on the Water-Energy-Food Nexus: Unexplored Potentials for Tunisia advocates for establishing a committee under the National Environmental Protection Agency (ANPE) to enhance policy coherence across sectors and address nexus-related challenges (Appolloni et al. 2025). The Tunisian White Paper was developed under the project WEF-CAP (Technology Transfer and Capitalisation of the Water-Energy-Food Nexus, 2021–2023) as part of the European Neighbourhood Instrument (ENI) Cross-Border Cooperation (CBC) Mediterranean (ENI CBS Med) Program, which supports integrated Nexus governance in Jordan, Egypt, and Tunisia. Lazaro et al. (2022) reinforce the need for flexible governance innovations tailored to local realities and thus call for a 'learning-by-doing' and 'context-specific' approach, which could be facilitated by stakeholder participation. Such stakeholder participation could be organized in private-public partnerships, which might be beneficial for mobilizing blended finance for achieving cross-sector investments and thus job creation within the WEF Nexus (GWP-Med et al. 2023). Procedural innovations like green budgeting and inter-departmental assessments, as proposed by Weitz et al. (2017), could institutionalize complementarity by translating nexus principles into concrete policy routines.

These examples reinforce the finding that robust governance emerges from locally adapted, systems-aware approaches. Countries that combine stakeholder inclusion, socio-political dynamics, domestic development priorities, scenario modeling, and legal reforms are better positioned to transform nexus thinking into practice (Hejnowicz et al.

2022; Pandey and Shrestha 2017). The morphological box proposed by Brouwer et al. (2024) could be such a structured but flexible pathway for translating nexus logic into context-sensitive strategies, an approach well-suited to the institutional heterogeneity across the PRIMA region. In the following, actionable strategies for policymakers are summarized:

- *Legal integration:* Institutionalize national responsibilities towards the WEF Nexus through legal and constitutional reforms (Al-Muqdad et al. 2021; Purwanto et al. 2021), thus creating legal mandates that require ministries to consider cross-sectoral impacts (i.e., trade-offs and synergies) when drafting policies. Furthermore, align WEF Nexus legislation under a unified sustainability framework, ideally the Agenda 2030 (Dombrowsky 2022). This would foster the 3Cs within the WEF Nexus.
- *Institutional reform:* Establish cross-scalar WEF Nexus governance bodies with clear mandates and sufficient resources (Lalawmpui and Rai 2023), thus avoiding mistakes made when introducing inter-ministerial and parliamentary committees without effective influence on Agenda 2030 policy making (Spinazzola and Cavalli 2022). For instance, Kurian et al. (2018) suggest observatories, Al-Muqdad et al. (2021) propose Technical Committees for Natural Resources (TCNR'), Daher et al. (2022) speak of WEF(E) systems-thinking platforms to facilitate a cross-ministerial dialogue and thus improve governance coherence. GWP-Med et al. (2023) highlight the role of the UfM Nexus Task Force and the PRIMA WEF4MED Community of Practice as regional and transboundary cooperation and governance innovations.
- *Stakeholder engagement:* Institutionalize participatory planning, using, for instance, serious games, citizen panels, online visualization tools, and other digital platforms (Dombrowsky 2022; Hoolohan et al. 2018; Ramirez et al. 2022). Mohtar and Lawford (2016) and Rhouma et al. (2024) emphasize the importance of community-building through Communities of Practice (e.g., in PRIMA-funded initiatives). Community of Practices could support cross-sectoral collaboration and co-develop adaptable, context-sensitive solutions at the national and regional level (GWP-Med et al. 2023; Mohtar and Lawford 2016). Ramos et al. (2022) and Rhouma et al. (2024) further stress the need to embed nexus concepts into vocational and university curricula and institutional planning to accelerate diffusion.
- *Context-specific and place-based nexus customization:* Because WEF Nexus challenges are deeply context-specific and place-based, Bizikova et al. (2013) and Al-Muqdad

et al. (2021) argue against one-size-fits-all frameworks. Customized nexus approaches should be based on political, socio-economic, spatially explicit, and ecological realities, which calls for integrating stakeholders in nexus customization. Ramirez et al. (2022) emphasize the importance of scenario testing and stakeholder co-design to identify context-sensitive WEFE nexus solutions.

- *Circular economy integration and climate-resilient financing*: Scale up nature-based, climate-smart solutions and circular economy innovations through appropriate governance, particularly in water reuse and desalination to economize on groundwater and renewable energy, to valorize agro-waste, to protect ecosystems, thus advancing resource use efficiency and local resilience (Arabi et al. 2023). Mobilize climate funds and blended finance to support decentralized WEFE infrastructure, prioritizing rural and peri-urban areas (Behnassi et al. 2024; Carmo-na-Moreno et al. 2021). Private public partnerships are an option (GWP-Med et al. 2023).
- *Integrated, transboundary cooperation*: Although not operational yet, Quagliarotti (2023) mentions the EcoPeace Mid-East Water-Renewable Energy Exchange as a vision for integrated and transboundary water-energy cooperation among Jordan, Israel, and Palestine, based on comparative advantages in natural resources and technological capacity. The idea is that Jordan would export solar-generated electricity to Israel and Palestine, while Israel exports desalinated water to Jordan and Palestine. Apart from improving regional energy and water security, it would also contribute to regional political stability. Moreover, the agreement brokered by EcoPeace reflects transboundary policy coordination and complementarity in the WEFE Nexus. M. Al-Saidi and Elagib (2017) also underscore the potential of transboundary WEF(E) policy coordination in the Eastern Nile Basin (Egypt, Sudan, Ethiopia) with regional trade, joint infrastructure investment, and technical knowledge exchange (e.g., irrigation, hydropower, biofuel systems) as coordination enablers. Zarei (2020) underscores that the absence of cross-border coordination on the Tigris-Euphrates basin, particularly among Türkiye, Iraq, and Iran, undermines WEFE security by prioritizing national infrastructure projects over basin-wide sustainability. Fragmented governance has led to trade-offs such as declining agricultural output in Iraq and intensified dust storms in Iran, demonstrating how a lack of policy coherence across borders compromises human and environmental security. Such transboundary trade-offs could be reduced by adopting “hydro-diplomacy” mechanisms, including joint early-warning systems.
- *Science-policy interfaces and PRIMA consortia*: Riccaboni et al. (2022) and GWP-Med et al. (2023) highlight that PRIMA and the WEFE4Med Community of Practice serve as regional platforms promoting integrated WEFE governance through multi-stakeholder engagement and science-policy interfaces in the Mediterranean region, i.e., between EU and non-EU PRIMA countries. The Partnership, i.e., PRIMA, exemplifies how multi-stakeholder consortium creation and a shared nexus approach can foster cross-sectoral coordination, accelerate knowledge transfer, technological innovation, and policy innovation among non-EU PRIMA countries by encouraging co-governance and transnational collaboration. To name a few, Mohtar and Lawford (2016) and Lazaro et al. (2022) have advocated stronger science-policy interfaces to mature the nexus approach into real governance approaches. For instance, most EU governments make use of topical scientific advisory boards for regular expert opinion reports and consultations. Such interfaces could also be useful in making trade-offs of sectoral policy siloes explicit (Simpson and Jewitt 2019). Other science-policy interfaces are decision-support systems, for instance, serious games. For instance, SIM4Nexus⁵ explores interlinkages among water, energy, food, land, and climate (WEFLC) and supports decision-making via a serious game platform to help users (e.g., policymakers, planners) visualize trade-offs and synergies under different scenarios (Simpson and Jewitt 2019). Sorek, Peeters, and Yuval (2024) tested a decision-support system powered by data analytics and predictive modeling to inform cross-scalar policy measures in Israel, e.g., taxing excess use of water and energy in certain administrative units (e.g., municipalities, districts).
- *Data and modeling tools*: Develop open-access, interoperable data platforms, integrated modeling, and dynamic scenario tools to inform nexus trade-offs and synergies (Albrecht et al. 2018; Lawford 2019; Liu et al. 2017). Sarkodie and Owusu (2020) and Simpson and Jewitt (2019) call for transdisciplinary modeling and simulation games like SIM4Nexus, respectively, that incorporate not only biophysical and economic dimensions but also social dynamics, emphasizing that the effectiveness of nexus policies is contingent on localized planning, governance alignment, and trade-off analysis. Macroeconomic modeling approaches, like the GTAP-AW and

⁵ SIM4NEXUS is an EU Horizon 2020 project (2016–2020). By integrating scientific models with stakeholder engagement, it translates nexus thinking into actionable strategies tailored to specific regions and governance contexts. While the serious game is still online available, this example shows the importance of conserving expertise beyond the duration of a project’s lifetime.

RICE-MED models⁶, offer robust evidence for climate-resilient WEFE strategies in countries like Egypt and Morocco. These models simulate second-order impacts, such as how reduced agricultural output lowers desalinated water demand, and show that investing in irrigated agriculture and alternative water sources (AWS) can significantly reduce exposure to food insecurity (Raviv et al. 2024). Such approaches support long-term integrated planning under uncertainty. Purwanto et al. (2021) and Orimoloye (2022) mention the absence of suitable nexus data infrastructure as a prerequisite for, e.g., lifecycle assessments or virtual water accounting to support nexus decision-making and operationalization. Such infrastructure could facilitate adaptive, integrative, and flexible decision-making at all governance levels (Bizikova et al. 2013; Dombrowsky 2022).

The diverse approaches to WEFE Nexus governance across non-EU PRIMA countries reflect underlying differences in institutional maturity, legal and regulatory frameworks, financing capacities, and political contexts. Countries such as Israel, Jordan, Morocco, and Tunisia have advanced relatively comprehensive and coordinated strategies, anchored in formal planning processes and legal reform, often supported by multilateral partnerships and technical assistance from organizations such as the EU, the World Bank, the Food and Agriculture Organization (FAO), and regional platforms like GWP-Med, the OSS, and the UfM. Other countries, such as Lebanon or Egypt, demonstrate more localized or experimental applications shaped by contextual constraints but increasingly benefit from externally facilitated knowledge transfer and capacity-building initiatives. In some cases, sectoral priorities, such as water reuse in Tunisia, renewable energy integration in Jordan, or ecosystem restoration in Morocco, have served as pragmatic entry points for cross-sectoral action even in the absence of overarching nexus frameworks. These variations underscore that advancing cross-sectoral WEFE governance is neither linear nor uniform, but evolves through differentiated institutional pathways. Multilateral and regional collaboration thus play a crucial role in reducing asymmetries in capacity and financing, enabling countries to adapt WEFE principles to their specific governance landscapes, development

trajectories, and adaptive capacities while fostering shared learning across the Mediterranean.

By combining these comparative and diverging insights, transdisciplinary approaches, and grounded governance strategies, this section highlighted how non-EU PRIMA countries can move from aspirational conceptual frameworks to transformative action. The pathway to effective WEFE governance lies in embedding systems thinking into legal, institutional, and socio-political processes, what Purwanto et al. (2021) and Behnassi et al. (2024) aptly term the shift from ‘nexus thinking’ or ‘nexus logic’ to ‘nexus doing’.

5 Conclusion and policy recommendations

This SLR demonstrates that, while the WEFE Nexus constitutes a compelling framework for integrated resource governance, its practical implementation in non-EU PRIMA partner countries remains partial and uneven. A persistent gap emerges between the conceptual maturity of the nexus and the realities of governance practice, shaped by entrenched institutional silos, fragmented legal frameworks, and limited cross-sectoral coordination. These structural constraints continue to impede the translation of nexus principles into robust policy outcomes.

The findings confirm that policy integration across WEFE sectors is both essential and difficult to achieve. In many of the reviewed countries, institutional arrangements still privilege sectoral autonomy over synergy, resulting in trade-offs rather than co-benefits. Although recent reforms in countries such as Morocco, Jordan, and Tunisia point to emerging pathways toward more integrated governance, these initiatives remain nascent and often lack the legal anchoring, institutional continuity, and financial resources required for systemic transformation.

The review further suggests that effective WEFE governance cannot rely exclusively on top-down coordination. Instead, it appears to depend on adaptive, participatory, and context-sensitive governance arrangements that account for political economy dynamics, spatial variability, and local priorities. While the growing integration of ecosystem services, climate adaptation, and circular economy principles into WEFE-related strategies is promising, such approaches remain largely experimental across much of the region.

A central insight of the review is that stakeholder engagement continues to be insufficiently institutionalized. Strengthening policy coherence and responsiveness may therefore require greater emphasis on co-production of knowledge, inclusive decision-making platforms, and sustained capacity building across governance levels. Without

⁶ The Global Trade Analysis – Alternative Water (GTAP-AW) is a Computable General Equilibrium (CGE) model that integrates alternative water sources (like desalinated and treated wastewater) and distinguishes between irrigated and rainfed agriculture within global trade and economic simulations. The Regional Integrated Model of Climate and the Economy – Mediterranean (RICE-MED) is customized for the Mediterranean region, to assess climate change impacts and uncertainties (especially extreme events) on economic growth and agricultural output.

these elements, nexus-oriented strategies risk reproducing the very governance deficits they are intended to address.

Taken together, the findings indicate that the WEFE Nexus functions more effectively as a meta-framework than as a prescriptive model. Its value lies in enabling cross-sectoral learning, iterative governance, and the creation of enabling conditions rather than in offering standardized policy templates. Lessons drawn from EU experiences with coordination, complementarity, and coherence may provide useful orientation; however, their application in non-EU PRIMA contexts requires careful adaptation to local institutional and political realities.

Against this background, several strategic policy recommendations emerge:

- Legal and regulatory frameworks should be harmonized to explicitly mandate intersectoral coordination and to incentivize collaborative decision-making across WEFE domain.
- Institutional arrangements should evolve toward poly-centric configurations that enhance flexibility, feedback mechanisms, and accountability across governance levels.
- Participatory governance structures, including communities of practice, strategic foresight platforms, and learning alliances, should be institutionalized rather than treated as ad hoc or project-based mechanisms.
- Science-policy interfaces require strengthening through accessible data infrastructures, transparent decision-support tools, and regularized expert advisory processes that facilitate evidence-informed policymaking.
- Financing models should shift from fragmented funding streams toward blended and climate-resilient investment approaches that enable decentralized, nexus-compatible infrastructure and technologies.

In conclusion, moving from “nexus thinking” to “nexus doing” entails more than incremental institutional adjustment. It requires a recalibration of governance logics, from siloed efficiency toward systemic resilience, from isolated interventions toward integrative strategies, and from technocratic planning toward inclusive governance. When approached as an evolving governance framework rather than a fixed blueprint, the WEFE Nexus may offer Mediterranean countries a viable pathway for navigating increasing resource interdependencies, climate stress, and socio-economic transformation.

Future research may benefit from more fine-grained comparative analyses of nexus implementation at subnational levels, particularly in politically volatile or ecologically fragile contexts. Expanding the empirical evidence on the effectiveness of integrated governance tools and platforms

would further strengthen the foundation for policy learning and informed adaptation across the region.

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Declarations

Competing interests There are no relevant financial or non-financial competing interests to report.

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References

- Adamovic M, Al-Zubari W, Amani A, Amezttoy Aramendi I, Bacigalupi C, Barchiesi S, Zaragoza G (2019) Position paper on water, energy, food and ecosystem (WEFE) nexus and sustainable development goals (SDGs). Publications Office of the European Union, Luxembourg

- Al-Muqdad SWH, Khalaifawi A, Abdulrahman B, Kittana FA, Alwadi KZ, Abdulkhaleq MH, Al Dahmani R (2021) Exploring the challenges and opportunities in the water, energy, food nexus for arid region. *J Sustainable Dev Energy Water Environ Syst* 9(4):1–30. <https://doi.org/10.13044/j.sdewes.d8.0355>
- Al-Saidi M, Elagib NA (2017) Towards Understanding the integrative approach of the water, energy and food nexus. *Sci Total Environ* 574:1131–1139. <https://doi.org/10.1016/j.scitotenv.2016.09.046>
- Al-Saidi M, Hefny A (2018) Institutional arrangements for beneficial regional Cooperation on water, energy and food priority issues in the Eastern Nile basin. *J Hydrol* 562:821–831. <https://doi.org/10.1016/j.jhydrol.2018.05.009>
- Al-Zubari WK (2021) WEF nexus regional studies: the water-energy-food nexus in the Arab region: governance and role of institutions. Manamah, Bahrain
- Albatayneh A, Hindiyeh M, AlAmawi R (2022) Potential of renewable energy in water-energy-food nexus in Jordan. *Energy Nexus* 7. <https://doi.org/10.1016/j.nexus.2022.100140>
- Albrecht TR, Crootof A, Scott CA (2018) The water-energy-food nexus: A systematic review of methods for nexus assessment. *Environ Res Lett* 13(4). <https://doi.org/10.1088/1748-9326/aaa9c6>
- Almulla Y, Ramirez C, Joyce B, Huber-Lee A, Fuso-Nerini F (2022) From participatory process to robust decision-making: an agriculture-water-energy nexus analysis for the Souss-Massa basin in Morocco. *Energy Sustain Dev* 70:314–338. <https://doi.org/10.1016/j.esd.2022.08.009>
- Appoloni E, Cerasola VA, Pennisi G, Biru W, Buchenrieder G, Uyar TS, Yavuz Yİ (2025) FrontAg nexus D1.1: systematic literature review (SLR) of frontier agriculture systems and empirical evidence in the Mediterranean region (Revised version). University of the Bundeswehr Munich (UniBw M), Neubiberg. FrontAg Nexus (ID2422)
- Arabi M, El Ouadi I, Amhamdi H, Didi A, El Haji M, El Jarroudi M, Lahmass I (2023) Understanding the climate–water–energy–food nexus and the transition towards a circular economy: the case of Morocco. *E3S Web Conferences* 364. <https://doi.org/10.1051/e3sconf/202336401006>
- Basheer M, Wheeler KG, Ribbe L, Majdalawi M, Abdo G, Zagona EA (2018) Quantifying and evaluating the impacts of Cooperation in transboundary river basins on the water-energy-food nexus: the blue Nile basin. *Sci Total Environ* 630:1309–1323. <https://doi.org/10.1016/j.scitotenv.2018.02.249>
- Bazzana D, Comincioli N, El Khoury C, Nardi F, Vergalli S (2023) WEF nexus policy review of four Mediterranean countries. *Land* 12(2). <https://doi.org/10.3390/land12020473>
- Behnassi M, Lamonaca E, Papadopoulou MP, Berchoux T, La Jeunesse AG, Queralt Bassa I, A (2024) 5. Governance, policies and research options for the WEF nexus. In: Drobinski P, Rivera-Ferre MG, Abdel Monem M, Driouech F, Cramer W, Guiot J, Gattacceca JC, Marini K (eds) *Interlinking climate change with the Water-Energy-Food-Ecosystems (WEFE) nexus in the Mediterranean basin*. MedECC Reports. MedECC Secretariat, Marseille, France, pp 209–239
- Bhaduri A, Ringler C, Dombrowski I, Mohtar R, Scheumann W (2015) Sustainability in the water–energy–food nexus. *Water Int* 40(5–6):723–732. <https://doi.org/10.1080/02508060.2015.1096110>
- Bizikova L, Roy D, Venema HD, McCandless M, Swanson DA (2013) The water-energy-food security nexus: towards a practical planning and decision support framework for landscape investment and risk management. The International Institute for Sustainable Development (IISD), Manitoba, Canada
- Boas I, Biermann F, Kanie N (2016) Cross-sectoral strategies in global sustainability governance: towards a nexus approach. *Int Environ Agreements: Politics Law Econ* 16(3):449–464. <https://doi.org/10.1007/s10784-016-9321-1>
- Bouraoui F, Grizzetti B (2021) WEF: nexus cross-cutting issues: Water–energy–food nexus: methodologies and data. In: Carmona-Moreno C, Crestaz E, Cimmarrusti Y, Farinosi F, Biedler M, Amani A, Mishra A, Carmona-Gutierrez A (eds) *Implementing the Water–Energy–Food–Ecosystems nexus and achieving the sustainable development goals*. UNESCO, pp 29–35
- Brouwer F (2022) 1: introduction to the water-energy-food nexus. In: Brouwer F (ed) *Handbook on the water-energy-food nexus*. Elgar Publishing, Cheltenham, UK
- Brouwer F, Vamvakieridou-Lyroudia L, Alexandri E, Bremere I, Griffey M, Linderhof V (2018) The nexus concept integrating energy and resource efficiency for policy assessments: A comparative approach from three cases. *Sustainability* 10(12). <https://doi.org/10.3390/su10124860>
- Brouwer F, Caucci S, Karthe D, Kirschke S, Madani K, Mueller A, Guenther E (2024) Advancing the resource nexus concept for research and practice. *Sustain Nexus Forum* 31(1–4):41–65. <https://doi.org/10.1007/s00550-024-00533-1>
- Carmona-Moreno C, Dondeynaz C, Biedler M (eds) (2019) Position paper on water, energy, food, and ecosystem (WEFE) nexus and sustainable development goals (SDGs). Publications Office of the EU, LU
- Carmona-Moreno C, Crestaz E, Cimmarrusti Y, Farinosi F, Biedler M, Amani A, Carmona-Gutierrez A (2021) e. *Implementing the water–energy–food–ecosystems nexus and achieving the sustainable development goals*. Luxembourg: Publications Office of the European Union
- Daher B, Hamie S, Pappas K, Roth J (2022) Examining Lebanon’s resilience through a water-energy-food nexus lens. *Front Sustainable Food Syst* 6. <https://doi.org/10.3389/fsufs.2022.748343>
- Dargin J, Daher B, Mohtar RH (2019) Complexity versus simplicity in water energy food nexus (WEF) assessment tools. *Sci Total Environ* 650(Pt 1):1566–1575. <https://doi.org/10.1016/j.scitotenv.2018.09.080>
- Del Borghi A, Moreschi L, Gallo M (2020) Circular economy approach to reduce water–energy–food nexus. *Curr Opin Environ Sci Health* 13:23–28. <https://doi.org/10.1016/j.coesh.2019.10.002>
- Diriöz AO (2021) Addressing climate change through the water–energy–food nexus. Lessons learned from Turkey In D. S. Olawuyi (Ed.), *Climate Change Law and Policy in the Middle East and North Africa Region* Routledge
- Dombrowski I (2022) Implementing the 2030 agenda under resource scarcity: the case of WEF nexus governance in Azraq/Jordan. In: Breuer A, Malerba DS, Srinivasa, Balasubramanian P (eds) *Governing the interlinkages between the SDGs: Approaches, opportunities and challenges*. Routledge, London, UK, pp 124–139
- Drobinski P, Rivera-Ferre MG, Abdel Monem M, Driouech F, Cramer W, Guiot J, Marini K (2024) e. *Interlinking climate change with the water-energy-food-ecosystems (WEFE) nexus in the Mediterranean Basin*. Marseille, France: MedECC Secretariat
- Drouiche N, Villarreal OR, Ouali S, Lebouachera SEI, Soni R (2022) Role of desalination technologies and water reuse in water-energy-food nexus: an opportunity for Algeria. *Desalination Water Treat* 261:83–93. <https://doi.org/10.5004/dwt.2022.28538>
- EC. (2019) *2019 EU report on policy coherence for development*. Brussels, BE: European Commission (EC)
- EC (2025) *European Water Resilience Strategy, COM(2025) 280 final*. Brussels, BE: European Commission (EC), available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52025DC0280> (accessed: Sep. 2025)
- El Majdoubi G, El Ayadi H (2025) Unlocking potential: A holistic approach to water, energy, and food security nexus in Tangier-Tetouan-Al Hoceima, Morocco. *Case Stud Chem Environ Eng* 11. <https://doi.org/10.1016/j.csee.2025.101129>
- El Youssfi L, El Youssfi L, Doorsamy W, Aghzar A, Cherkaoui SI, Elouadi I, Ouaggajou Y (2020) Review of water energy food

- nexus in africa: Morocco and South Africa as case studies. E3S Web Conferences 183. <https://doi.org/10.1051/e3sconf/202018302002>
- El Zein Z, Milad NA, Mohamed AS, Mahmoud N, Abdo N, Abdel-Ghaffar HM (2024) Sustainable development on the basis of the WEF nexus in arid coastal areas for climate change mitigation: case study of rabia community in Matrouh, Egypt. *Energy Nexus* 14. <https://doi.org/10.1016/j.nexus.2024.100299>
- Gawlik BM, Elelman R, Zamel D, Easton P, Laspidou C, Berman RA, Constantianos V (eds) (2022) *The gateway to the future of the Mediterranean – Water, energy, food and the environment*. Publications Office of the European Union, Luxembourg
- Golfam P, Ashofteh P-S, Loáiciga HA (2021) Modeling adaptation policies to increase the synergies of the water-climate-agriculture nexus under climate change. *Environ Dev* 37. <https://doi.org/10.1016/j.envdev.2021.100612>
- GWP-Med WES, EU (2023) &. *1st Regional WEF Nexus Roundtable in the Mediterranean on 'Promoting innovation, investments and upscaling of solutions'*. Rabat, Morocco: Global Water Partnership Mediterranean (GWP-Med), Water and Environment Support (WES) in the ENI Southern Neighbourhood region, European Union (EU)
- Hejnowicz AP, Thorn JPR, Giraudo ME, Sallach JB, Hartley SE, Grugel J, Emberson L (2022) Appraising the water-energy-food nexus from a sustainable development perspective: A maturing paradigm? *Earths Future* 10(12). <https://doi.org/10.1029/2021ef002622>
- Herrera-Franco G, Bollmann HA, Pasqual Lofhagen JC, Bravo-Montero L, Carrión-Mero P (2023) Approach on water-energy-food (WEF) nexus and climate change: A tool in decision-making processes. *Environ Dev* 46. <https://doi.org/10.1016/j.envdev.2023.100858>
- Hoff H (2011) *Understanding the nexus. Background paper for the Bonn 2011 nexus conference*. Stockholm: Stockholm Environment Institute (SEI)
- Hoolohan C, Larkin A, McLachlan C, Falconer R, Soutar I, Suckling J, Yu D (2018) Engaging stakeholders in research to address water-energy-food (WEF) nexus challenges. *Sustain Sci* 13(5):1415–1426. <https://doi.org/10.1007/s11625-018-0552-7>
- Ijlil S, Essahlaoui A, Essahlaoui N, Skrimizea E, Parra C, Mili EM, Van Rompaey A (2025) Building bridges to achieve SDG 6 and integrated water resources management: an assessment of stakeholder integration in the Saiss region, Morocco. *Water Int* 1–22. <https://doi.org/10.1080/02508060.2025.2458967>
- İşleyen B (2014) The European union and neoliberal governmentality: twinning in Tunisia and Egypt. *Eur J Int Relat* 21(3):672–690. <https://doi.org/10.1177/1354066114554464>
- Johnson N, Burek P, Byers E, Falchetta G, Flörke M, Fujimori S, Parkinson S (2019) Integrated solutions for the Water-Energy-Land nexus: are global models rising to the challenge? *Water* 11(11). <https://doi.org/10.3390/w11112223>
- Khacheba R, Cherfaoui M, Hartani T, Drouiche N (2018) The nexus approach to water–energy–food security: an option for adaptation to climate change in Algeria. *Desalination Water Treat* 131:30–33. <https://doi.org/10.5004/dwt.2018.22950>
- Kurian M (2017) The water-energy-food nexus. *Environ Sci Policy* 68:97–106. <https://doi.org/10.1016/j.envsci.2016.11.006>
- Kurian M, Portney KE, Rappold G, Hannibal B, Gebrechorkos SH (2018) Governance of water-energy-food nexus: A social network analysis approach to Understanding agency behaviour. In: Hülsmann S, Ardakanian R (eds) *Managing Water, soil and waste resources to achieve sustainable development goals*. Springer, Cham
- Lalawmpuii, Rai PK (2023) Role of water-energy-food nexus in environmental management and climate action. *Energy Nexus* 11. <https://doi.org/10.1016/j.nexus.2023.100230>
- Lawford RG (2019) A Design for a Data and Information Service to Address the Knowledge Needs of the Water-Energy-Food (W-E-F) Nexus and Strategies to Facilitate Its Implementation. *Front Environ Sci*, 7(May). <https://doi.org/10.3389/fenvs.2019.00056>
- Lazaro LLB, Bellezoni RA, de Oliveira JAP, Jacobi PR, Giatti LL (2022) Ten years of research on the water-energy-food nexus: an analysis of topics evolution. *Front Water* 4. <https://doi.org/10.3389/frwa.2022.859891>
- Leck H, Conway D, Bradshaw M, Rees J (2015) Tracing the Water–Energy–Food nexus: Description, theory and practice. *Geogr Compass* 9(8):445–460. <https://doi.org/10.1111/gec3.12222>
- Liu J, Yang H, Cudennec C, Gain AK, Hoff H, Lawford R, Zheng C (2017) Challenges in operationalizing the water–energy–food nexus. *Hydro Sci J* 62(11):1714–1720. <https://doi.org/10.1080/02626667.2017.1353695>
- Liu J, Hull V, Godfray HCJ, Tilman D, Gleick P, Hoff H, Li S (2018) Nexus approaches to global sustainable development. *Nat Sustain* 1(9):466–476. <https://doi.org/10.1038/s41893-018-0135-8>
- Lucca E, Jeitany E, Castelli J, Pacetti G, Bresci T, Nardi E, F., Caporali E (2023) A review of water-energy-food-ecosystems nexus research in the mediterranean: evolution, gaps and applications. *Environ Res Lett* 18(8). <https://doi.org/10.1088/1748-9326/ace375>
- Mackie J (2020) Promoting policy coherence: lessons learned in EU development Cooperation. European Centre for Development Policy Management (ECDPM), Brussels, BE
- Malamataris D, Pisinaras V, Pagano A, Baratella V, Vanino S, Bea M, Panagopoulos A (2025) Managing water-ecosystem-food nexus using participatory approaches: insights from an innovative methodological approach developed in two mediterranean areas. *Front Water* 7. <https://doi.org/10.3389/frwa.2025.1469762>
- Markantonis V, Reynaud A, Karabulut A, El Hajj R, Altinbilek D, Awad IM, Bidoglio G (2019) Can the implementation of the Water-Energy-Food nexus support economic growth in the mediterranean region? The current status and the way forward. *Front Environ Sci* 7. <https://doi.org/10.3389/fenvs.2019.00084>
- Mirzaei A, Ashktorab N, Noshad M (2023) Evaluation of the policy options to adopt a water-energy-food nexus pattern by farmers: application of optimization and agent-based models. *Front Environ Econ Manage*. <https://doi.org/10.3389/fenvs.2023.1139565>
- Mohtar RH, Lawford R (2016) Present and future of the water-energy-food nexus and the role of the community of practice. *J Environ Stud Sci* 6(1):192–199. <https://doi.org/10.1007/s13412-016-0378-5>
- Naidoo D, Nhamo L, Mpandeli S, Sobratee N, Senzanje A, Liphadzi S, Mabhaudhi T (2021) Operationalising the water-energy-food nexus through the theory of change. *Renew Sustain Energy Rev* 149:111416. <https://doi.org/10.1016/j.rser.2021.111416>
- Nikolaidis NP, Troullaki K, Lilli MA, Halasah S, Lehrer D, Rozakis S, Reznik A (2025) An integrated participatory framework for WEF nexus strategic planning: the Jordan Valley case study. *J Environ Manage* 375:124246. <https://doi.org/10.1016/j.jenvman.2025.124246>
- Olawuyi D (2020) Sustainable development and the water-energy-food nexus: legal challenges and emerging solutions. *Environ Sci Policy* 103:1–9. <https://doi.org/10.1016/j.envsci.2019.10.009>
- Orimoloye IR (2022) Water, energy and food nexus: policy relevance and challenges. *Front Sustainable Food Syst* 5. <https://doi.org/10.3389/fsufs.2021.824322>
- Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Moher D (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *bmj*(March) 372:n371
- Pandey VP, Shrestha S (2017) 2. Evolution of the nexus as a policy and development discourse. In: Salam AP, Shrestha S, Pandey VP, Anal AK (eds) *Water-energy-food nexus. Principles and*

- practices, vol 229. American Geophysical Union (AGU) and Wiley, and Hoboken, N.J., USA, Washington, D.C.
- PRIMA (2023) *Survey report: Gender dimension in PRIMA projects 2018–2022*. Retrieved from Barcelona, Spain: www.prima-med.org
- Purwanto A, Sušnik J, Suryadi FX, de Fraiture C (2021) Water-Energy-Food nexus: critical Review, practical Applications, and prospects for future research. *Sustainability* 13(4). <https://doi.org/10.3390/su13041919>
- Quagliarotti DAL (2023) The Water-Energy-Food nexus in the mediterranean region in a scenario of polycrisis. *TeMA - J Land Use Mobil Environ* 2:109–122. <https://doi.org/10.6093/1970-9870/10308>
- Ramirez C, Almulla Y, Joyce B, Huber-Lee A, Nerini FF (2022) An assessment of strategies for sustainability priority challenges in Jordan using a water–energy–food nexus approach. *Discover Sustain* 3(1). <https://doi.org/10.1007/s43621-022-00091-w>
- Ramos EP, Gardumi F, Niet T, Sridharan V, Alfstad T, Pappis I, Rogner H-H (2022) 9. Capacity development and knowledge transfer on the climate, land, water and energy nexus. In: Brower F (ed) *Handbook on the water-energy-food nexus*. Edward Elgar, Cheltenham, UK, pp 149–177
- Raviv O, Palatnik RR, Castellini M, Gusperti C, Vergalli S, Sirota J, Shechter M (2024) Synergies of CGE and IAM modelling for climate change implications on WEF nexus in the mediterranean. *Clim Risk Manage* 44. <https://doi.org/10.1016/j.crm.2024.100608>
- Rbaibi O, SahibEddine A (2024) Sustainability in integrated water resources management: systematic literature review. In: Mabrouki J, Mourade A (eds) *Technical and technological solutions towards a sustainable society and circular economy*. Springer, Cham, pp 195–202
- Rhouma A, El Jeitany J, Mohtar R, Gil JM (2024) Trends in the Water–Energy–Food nexus research. *Sustainability* 16(3):1162
- Riccaboni A, Antonelli M, Stanghellini G (2022) Partnership for research and innovation in the mediterranean area and the promotion of a nexus approach. In: Cavalli L, Vergalli S (eds) *Connecting the sustainable development goals: the WEF nexus, sustainable development goals series. Understanding the role of the WEF nexus in the 2030 agenda*. Springer, Cham, pp 13–19
- Salam PA, Sangam S, Pandey VP, Anal AK (2017) 1. The need for the nexus approach. In: Salam PA, Sangam S, Pandey VP, Anal AK (eds) *Water-energy-food nexus. Principles and practices, vol 229*. American Biophysical Union (ABU) and Wiley, and Hoboken, N.J., USA, Washington, D.C.
- Sarkodie SA, Owusu PA (2020) Bibliometric analysis of water–energy–food nexus: sustainability assessment of renewable energy. *Curr Opin Environ Sci Health* 13:29–34. <https://doi.org/10.1016/j.coesh.2019.10.008>
- Scott CA, Kurian M, Wescoat JL (2015) The water-energy-food nexus: enhancing adaptive capacity to complex global challenges. In: Kurian M, Ardakanian R (eds) *Governing the Nexus. Water, soil and waste resources considering global change*. Springer, Cham
- Simpson GB, Jewitt GPW (2019) The water-energy-food nexus in the anthropocene: moving from ‘nexus thinking’ to ‘nexus action’. *Curr Opin Environ Sustain* 40:117–123. <https://doi.org/10.1016/j.cosust.2019.10.007>
- Sorek S, Peeters A, Yuval F Policy Directed Information Technology Governing Network Welfare by Balancing the Water-Energy-Food Nexus and Human Perceptions (WEFH) Measures. In J. R. da Costa Sanches Galvão, Brito P, Neves F, de Almeida H (2024) S. d. J. M. Mourato, & C. Nobre (Eds.), *Proceedings of the 3rd International Conference on Water Energy Food and Sustainability (ICoWEFS 2023)* (pp. 661–668). Cham: Springer
- Spinazzola M, Cavalli L (2022) The 2030 agenda for sustainable development and the WEF nexus. In: Cavalli L, Vergalli S (eds) *Connecting the sustainable development goals: the WEF nexus*. Springer, Cham
- Srigiri SR, Dombrowsky I (2022) Analysing the water-energy-food nexus from a polycentric governance perspective: conceptual and methodological framework. *Front Environ Sci* 10. <https://doi.org/10.3389/fenvs.2022.725116>
- Taguta C, Senzanje A, Kiala Z, Malota M, Mabhaudhi T (2022) Water-energy-food nexus tools in theory and practice: A systematic review. *Front Water* 4. <https://doi.org/10.3389/frwa.2022.837316>
- Urbanatti AM, Benites-Lazaro LL, Carvalho CMD, Giatti LL (2020) The conceptual basis of water-energy-food nexus governance: systematic literature review using network and discourse analysis. *J Integr Environ Sci* 17(2):21–43. <https://doi.org/10.1080/1943815x.2020.1749086>
- van Gevelt T (2020) The water-energy-food nexus: bridging the science-policy divide. *Curr Opin Environ Sci Health* 13:6–10. <https://doi.org/10.1016/j.coesh.2019.09.008>
- Washington DC (2017) *Water-energy-food nexus: principles and practices*. American Geophysical Union (AGU) and Wiley, and Hoboken, New Jersey, USA
- Weitz N, Strambo C, Kemp-Benedict E, Nilsson M (2017) Closing the governance gaps in the water-energy-food nexus: insights from integrative governance. *Glob Environ Change* 45:165–173. <https://doi.org/10.1016/j.gloenvcha.2017.06.006>
- Wichelns D (2017) The water-energy-food nexus: is the increasing attention warranted, from either a research or policy perspective? *Environ Sci Policy* 69:113–123. <https://doi.org/10.1016/j.envsci.2016.12.018>
- Yillia PT (2016) Water-energy-food nexus: framing the opportunities, challenges and synergies for implementing the SDGs. *Österreichische Wasser- Und Abfallwirtschaft* 68(3–4):86–98. <https://doi.org/10.1007/s00506-016-0297-4>
- Zandstra T (2015) *Water legislation. Cost of non-Europe report (PE 536.369)*. European Parliament, European Parliamentary Research Service (EPRS), European Added Value Unit, Brussels, BE
- Zarei M (2020) The water-energy-food nexus: A holistic approach for resource security in Iran, Iraq, and Turkey. *Water-Energy Nexus* 3:81–94. <https://doi.org/10.1016/j.wen.2020.05.004>
- Zhang X, Li H-Y, Deng ZD, Ringler C, Gao Y, Hejazi MI, Leung LR (2018) Impacts of climate change, policy and water-energy-food nexus on hydropower development. *Renewable Energy* 116:827–834. <https://doi.org/10.1016/j.renene.2017.10.030>
- Zhang P, Zhang L, Chang Y, Xu M, Hao Y, Liang S, Wang C (2019) Food-energy-water (FEW) nexus for urban sustainability: A comprehensive review. *Resour Conserv Recycl* 142:215–224. <https://doi.org/10.1016/j.resconrec.2018.11.018>

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