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ORIGINAL PAPER

Operationalizing the WEFE nexus through participatory strategic planning in the Jordan Valley

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Abstract
The Jordan Valley faces acute challenges of desertification, water scarcity, ecosystem degradation and socio-economic vulnerability, all exacerbated by climate change and geopolitical fragmentation. Addressing these interlinked pressures requires moving beyond sectoral interventions towards integrated and context-sensitive strategies. This paper presents a phased methodology for operationalizing the Water–Energy–Food–Ecosystem (WEFE) nexus for strategic planning in the Jordan Valley, developed through the PRIMA-funded EcoFuture project. Building on an initial diagnostic phase, the approach integrates participatory Multi-Criteria Decision Analysis (MCDA) with a strategic design process to move from system mapping to alternatives prioritization and strategic design for implementation. During a transnational living lab, Jordanian and Palestinian stakeholders assessed a portfolio of WEFE-aligned measures using a multi-criteria framework reflecting WEFE objectives, as well as socio-cultural, economic and feasibility objectives. The use of two decision algorithms—the Weighted Sum Method and the non-compensatory Minimax method—revealed convergent priorities and highlighted how alternative decision rationales may complement each other for better-informed planning. The resulting prioritized set of interventions constitutes the Agricultural Transformation Strategy (ATS), a WEFE-aligned portfolio that favours nature-based, regenerative, circular, and resource-conscious agricultural practices. Preliminary strategic design outputs—governance actions, implementation pathways, and systemic enablers—demonstrate how the assessment findings can be translated into actionable planning steps tailored to the distinct conditions of Jordan and Palestine. An illustrative bundling exercise further shows how synergistic packages of interventions can enhance feasibility and WEFE synergies. The phased approach provides a replicable blueprint for nexus-informed strategic planning in fragile, resource-scarce regions facing complex sustainability challenges.

Keywords WEFE nexus · Strategic planning · Multi-criteria decision analysis · Strategic design · Nature-based solutions · Case study

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1 Introduction

The Jordan Valley (JV) is a region of critical ecological, agricultural, and geopolitical importance. Its location at the intersection of Jordan, Palestine, and Israel makes it a key transboundary corridor, not only for its role in regional cooperation but also for its potential to support food, water and energy security in an increasingly climate-stressed landscape. The JV's ecosystems, ranging from freshwater wetlands to drylands, support diverse flora and fauna and provide essential services to rural livelihoods (Kool 2016).

However, desertification and climate-induced extremes, such as droughts and flash floods, are accelerating land degradation. Unsustainable land-use practices, irrigation inefficiencies and increasing soil salinity threaten long-term agricultural productivity. These challenges disproportionately affect vulnerable populations, particularly smallholder farmers and displaced communities, who already face limited access to reliable water, sanitation and energy services (Nikolaidis et al. 2025). The situation is further aggravated by demographic growth and geopolitical tensions, making the JV one of the most fragile regions in the Mediterranean region.

Addressing these complex challenges requires adopting integrative approaches that synergistically act upon problems of different sectors (Brazilian et al., 2011). The Water-Energy-Food-Ecosystem (WEFE) nexus has emerged as a promising framework for recognizing interdependencies between these sectors and promoting integrated resource management (Yupanqui et al. 2025; Carmona-Moreno et al., 2021). However, despite its conceptual appeal, the operationalization of the WEFE nexus (translating nexus thinking into actionable strategies) remains limited (Rhouma et al. 2024). Existing nexus studies tend to remain diagnostic, focusing on mapping interlinkages or assessing single interventions, with far fewer offering procedures for systematically moving from diagnosis to prioritization, governance design and implementation.

This paper contributes to closing this gap by presenting a blueprint for operationalizing the WEFE nexus as a strategic planning approach, grounded in the case of the Jordan Valley. The work draws on the PRIMA-funded EcoFuture project, which seeks to co-develop a climate adaptation strategy for the JV. During the first phase of the project, a comprehensive mapping of baseline WEFE conditions, causal interrelations, community capacities and policy gaps was undertaken with stakeholders from the three territories (Nikolaidis et al. 2025). Building on this foundation, the present paper presents a structured, phased procedure for moving from mapping to planning; this way contributing to current efforts to operationalize the WEFE nexus framework in practice.

A key challenge in sustainability planning is the persistent disconnect between analytical evaluation and actionable implementation (Cvitanovic et al. 2015; Turnhout et al. 2020). Structured assessment methods, such as MCDA, provide transparent and evidence-based tools for comparing alternatives, while implementation-oriented approaches emphasize context-specific design, feasibility, and institutional alignment. By bringing these two rationales together, this paper develops a phased methodology that combines (i) participatory MCDA for selecting a top-ranked portfolio of WEFE measures, and (ii) a participatory strategic design phase that elaborates governance actions, implementation pathways, enabling conditions and strategic bundles of measures. Together, these phases constitute an operational process that helps bridge the gap between evaluation and implementation (Stirling 2006; Weitz et al. 2017) and supports the design of an actionable, WEFE-aligned strategic plan for the JV.

The remainder of the paper is structured as follows. Section 2 presents the phased procedure for operationalizing the WEFE nexus and details the methodological steps applied. Section 3 reports the results of the participatory MCDA and illustrates how these outcomes inform the strategic design phase. Section 4 discusses implications for nexus research and policy, and Sect. 5 concludes with recommendations for future WEFE nexus planning efforts.

2 Methodology

This section presents the methodological framework for strategic planning in the WEFE nexus, which has been developed and applied in the context of the Jordan Valley. A structured, participatory methodology was developed and applied to identify, assess and design the implementation of WEFE nexus measures suitable for the JV, as presented in Fig. 1. The process combined evidence-based assessment with stakeholder knowledge to support the co-design of a coherent, implementable strategic plan. The initial phase of the framework established a foundation of shared understanding with local stakeholders and identified regional priorities (Nikolaidis et al. 2025). Building on this knowledge, the second phase, presented in this paper, integrates multi-criteria assessment and strategic design as complementary approaches to operationalize the WEFE nexus into a coherent strategic plan for the JV.

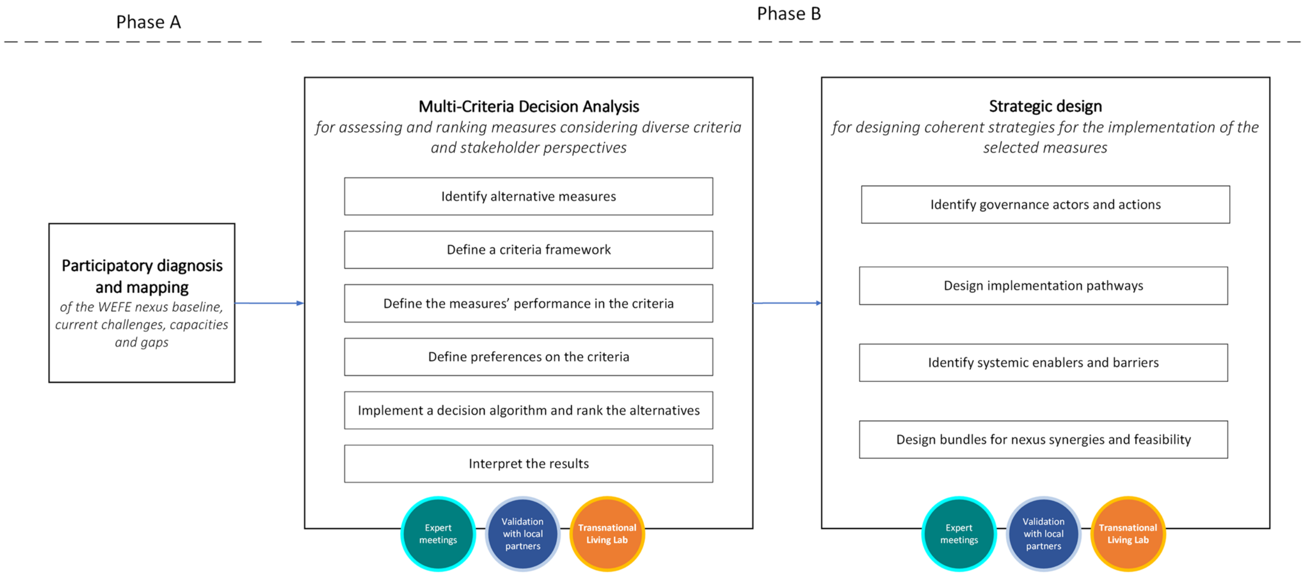

Fig. 1 A phased procedure for operationalizing the WEFE nexus in strategic planning. After an initial diagnostic phase (Nikolaidis et al. 2025), the procedure moves to multi-criteria assessment of WEFE measures and strategic co-design for their implementation

2.1 Insights from the WEFE nexus mapping phase

The first phase of the EcoFuture[1] project generated a shared evidence base on the baseline conditions, vulnerabilities and interdependencies of the WEFE nexus in the Jordan Valley. The assessment combined hydrological, water allocation and energy modelling simulations with structured stakeholder engagement procedures, including participatory systems mapping and community capacity assessment during national and transnational living labs across Jordan and Palestine (Nikolaidis et al. 2025).

The mapping confirmed several systemic pressures that shape the planning context. Water scarcity emerged as the most acute constraint, with both territories exhibiting substantial deficits in drinking and irrigation water, high network leakage (≈50%), and rising groundwater salinity driven by over-extraction and reduced recharge. Climate change is projected to exacerbate these stresses through declining rainfall, higher temperatures, and more frequent extreme events. Energy systems currently satisfy local demand, yet both countries face fast-growing electricity needs and limited diversification options, particularly in Palestine where dependence on Israeli imports is high. The mapping nevertheless identified significant untapped potential for renewable energy production in the JV. Food production remains central to the region's economy but is undermined by soil degradation, extremely low soil organic carbon, progressively increasing salinity and outdated irrigation practices. These factors result in low productivity and increased reliance on food imports. Ecosystems are under pressure from pollution, overuse of natural resources, loss of biodiversity and climate-driven shifts in hydrology. Declining inflows into the Jordan River and the Dead Sea illustrate the scale of ecological disruption.

2.2 Assessing measures with participatory MCDA

Problems that arise across the WEFE nexus, as well as their solutions, essentially span different sectors, affect diverse social groups, and touch on many dimensions of sustainability. In the JV, this complexity is further intensified by the region's transboundary character, long-standing conflicts among the three riparian countries, and ongoing war conditions. As such, the prioritization of alternative WEFE measures for the JV presents a highly complex, multidimensional decision-making challenge.

MCDA was selected as the most appropriate method to support decision-making in this context. MCDA is a family of appraisal techniques that enable the structured comparison of alternatives across multiple, often conflicting, criteria, while explicitly incorporating the preferences of different stakeholders. It is widely used for strategic planning and sustainability assessment processes and increasingly applied in WEFE nexus studies. It is especially suitable for participatory processes, as it allows transparency, stakeholder interaction, and can be adapted to diverse data types and decision contexts.

A central component of the MCDA process was the Transnational Living Lab (TLL) workshop, held on 28–30 April 2025 at the Dead Sea in Jordan. The workshop brought together over 40 stakeholders from Jordan and Palestine (including policymakers, farmers, researchers, technical

[1] www.ecofuture-prima.eu.

experts, and civil society representatives) to collaboratively assess and prioritize WEFE-aligned interventions for reducing vulnerability to desertification and climate change in the Jordan Valley.

As part of the MCDA process, participants reviewed and refined the list of measures and assessment criteria, assigned weights to the criteria based on their preferences, and validated or adjusted the performance assessments of each measure. Through this iterative engagement, stakeholders were able to visualize the implications of their preferences, deliberate on trade-offs and propose refinements to ensure robustness and contextual fit. The TLL not only advanced the technical prioritization of measures, but also played a key role in strengthening transboundary collaboration and laying the groundwork for future implementation and institutional adoption.

The different steps of the MCDA process are outlined in detail in Sect. 2.2.1 to 2.2.6.

2.2.1 Identify alternative measures

This phase began by building on the outputs of Phase A of the EcoFuture strategic planning framework, where key WEFE-related challenges in the Jordan Valley were identified. These challenges were linked to their underlying drivers, forming the basis for identifying viable points of intervention (Pellegrini et al. 2023). The resulting challenge-driver pairs were then mapped to a broad portfolio of Nature-Based Solutions (NBS), as well as circular resource strategies, low-impact technologies, and demand-side management tools (Nikolaidis et al. 2025).

The mapping process drew on established methodologies for designing context-sensitive solution portfolios, including classification by type, targeted challenges, ecosystem services delivered, and alignment with the Sustainable Development Goals (Vanino et al. 2024). The proposed solutions were also informed by pilot demonstrations in both Palestinian and Jordanian sites. These pilots offered tangible evidence of the relevance and effectiveness of key measures to address WEFE challenges in their respective contexts, particularly those focused on water use efficiency, rainwater harvesting, decentralized treated wastewater reuse, and soil regeneration through agro-ecological practices.

To complement the core technical measures, a suite of horizontal actions, such as training, capacity building, education, and further R&D, was also integrated. These cross-cutting measures were derived from consultations during national and transnational Living Labs and address institutional and knowledge barriers identified as critical by stakeholders. Including them helped ensure coherence with broader regional strategies and international environmental commitments.

The initial list of measures was refined through structured consultation with Jordanian and Palestinian partners to ensure contextual relevance, institutional feasibility, and alignment with national planning priorities. It was then validated during the Transnational Living Lab, where stakeholders reviewed the portfolio, confirmed its relevance, and made final adjustments. The resulting set of measures represents a shared, participatory outcome that provides the foundation for the subsequent assessment and design phases.

2.2.2 Define a criteria framework

A multi-criteria framework was developed to assess the proposed measures across key dimensions of sustainable development and WEFE nexus management in the JV.

The definition of criteria was informed by three complementary sources. First, insights from the scientific literature on MCDA, WEFE nexus planning, and NBS provided methodological foundation and examples of indicator use. Second, the selection drew directly on regional knowledge and stakeholder input generated during phase A of the strategic planning process, particularly in relation to key socio-ecological challenges and policy priorities in the Jordan Valley. Third, institutional frameworks such as the UN Sustainable Development Goals (SDGs) (UN, 2015) and the IUCN Global Standard for NBS (IUCN 2020) were consulted for consistency with internationally recognized sustainability benchmarks.

The resulting framework linked the project's overarching goals to concrete objectives and measurable sub-criteria, enabling a structured and transparent evaluation of each measure. The criteria were grouped into four categories:

- Key challenges & environmental sustainability: Assesses how each measure addresses the region's most pressing water-energy-food (WEF) challenges together with ecosystem and environmental sustainability, recognising that these dimensions are tightly interconnected.
- Social equity, community empowerment, and well-being: Captures the inclusiveness and fairness of resource management, with emphasis on benefit distribution, community engagement, and improvements to public health and local capacities.
- Economic benefits and affordability: Evaluates whether the measures generate economic opportunities, such as income and job creation, and whether they are financially accessible to affected stakeholders and communities.
- Implementation feasibility and operational sustainability: Assesses whether each measure is practical, technically mature, culturally and institutionally compatible, and manageable within the socio-economic conditions of the region.

Criteria were specified for each category, and the framework was validated by the project partners. This framework serves as an operational bridge between the project's strategic vision and the evaluation of specific measures. The criteria hierarchy is visualized in a three-level decision tree (Fig. 2) and the full description of the criteria may be found as supplementary material (S2).

2.2.3 Define the measures' performance in the criteria

Each measure was evaluated across all criteria using a qualitative scale from −3 to +3, where −3 indicates highly negative performance, 0 represents neutral or no significant impact, and +3 indicates highly positive performance. The scoring scale for each criterion is described in detail in the supplementary material (S3). The initial scoring was conducted by the coordinating expert team drawing on the full body of empirical and analytical work produced within the EcoFuture project[2], including: hydrological, water-distribution and energy modelling (D3.1–D3.3), ecosystem services modelling (D3.4), socio-ecological system mapping (D2.1), baseline WEFE resource mapping (D1.1–D1.3), NBS bundle analysis (D1.4), governance and gap analyses (D5.1–D5.2), pilot projects in Jordan and Palestine, and stakeholder exchanges during national and transnational living labs. These project-wide analyses and knowledge exchanges provided baseline information on irrigation efficiency, soil degradation, energy reliability, wastewater reuse potential and socio-economic constraints and opportunities in the Jordan Valley (Nikolaidis et al. 2025).

To ensure contextual accuracy and local relevance, the initial scoring was then reviewed, challenged, and revised by national expert groups in Jordan and Palestine, bringing in operational knowledge from national research institutions, as well as water and agricultural authorities. This two-step process strengthened the robustness and transparency of the performance assessment. The final performance matrix of the alternative measures is available as supplementary material (S4).

2.2.4 Define preferences on the criteria

A two-step process was applied to determine the relative importance (weights) of the assessment criteria. First, a pilot assessment was conducted internally by the project's consortium using equal weights across criteria categories and several scenario-based variations, each emphasizing one category at a time. This sensitivity analysis helped to explore how different weighting assumptions influenced the prioritization results and was subsequently used in the TLL as a demonstration tool to highlight the significance of the weighting step.

During the TLL held in Jordan, stakeholders from Jordan and Palestine were invited to express their preferences

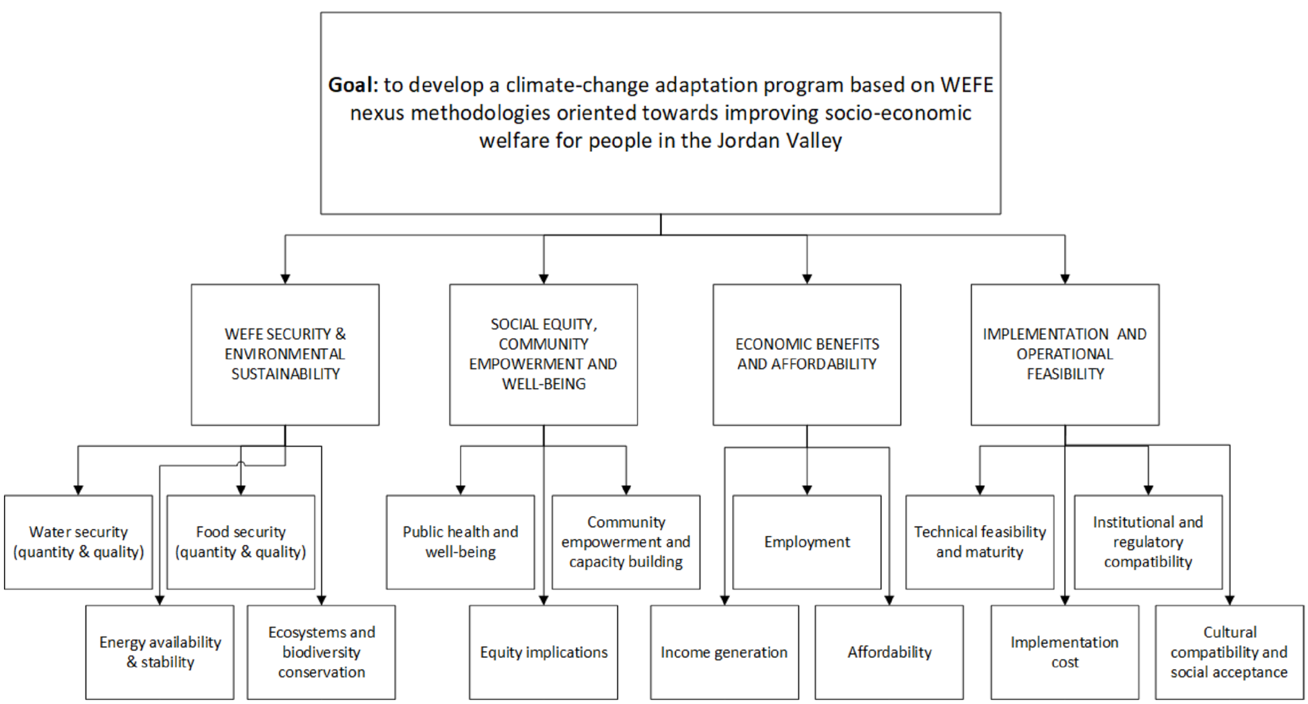

Fig. 2 Hierarchical decision tree. Level 1: Goal of the assessment; Level 2: Criteria categories; Level 3: Criteria. A detailed description of all criteria is provided in the Supplementary material (S2)

[2] https://ecofuture-prima.eu/knowledge-hub.

regarding the importance of each criterion. The Simos method (Figueira and Roy 2002) was used to facilitate this process. This method relies on a simple and intuitive card-based technique: each criterion is printed on a separate card, and stakeholders are asked to rank these cards from least to most important. Equal rankings are allowed by grouping cards of similar importance into subsets (pre-orders), while additional blank cards may be inserted to indicate larger perceived differences between ranks. The resulting pre-order structure is then used to calculate a unique weight vector for the criteria, first in non-normalized form and subsequently normalized so that weights sum to one.

The method is widely recognized in multi-criteria decision analysis for its transparency and ease of use, particularly in participatory settings involving a large and diverse group of stakeholders. Its intuitive, non-technical format makes it well suited for eliciting preferences from participants without requiring technical or mathematical expertise. This participatory weighting process ensured that the resulting prioritization reflected local knowledge and the values of those directly affected by the interventions.

2.2.5 Implement a decision algorithm and rank the alternatives

To assess and rank the alternatives, two decision algorithms were applied: the Weighted Sum Method (WSM) and the reference point 'minimax' method (Vanderpooten and Vincke 1989). Each reflects a distinct decision logic, offering a complementary perspective on sustainability priorities.

- WSM is fully compensatory, where a low score in one criterion can be offset by a high scores in another. It favors cumulative performance and reflects a utilitarian logic.
- Minimax favors solutions with more balanced performance, penalizing large weaknesses in individual criteria. It embodies an egalitarian logic.

WSM was selected as the method used in the TLL due to its simplicity, transparency, and widespread use in participatory planning. It aggregates weighted performance scores across all criteria for each alternative, providing an intuitively straightforward ranking. Despite its compensatory nature, its clarity and ease of interpretation made it particularly suitable for stakeholder engagement during the TLL, where transparency and procedural legitimacy were essential.

To complement WSM and address its limitations, the reference point method was also applied. To apply this method, a minimax algorithm based on the L∞ metric minimized the distance from the reference point (most often the ideal choice) thus ranking alternatives by their performance on their weakest (most critical) criterion. This Rawlsian approach has been used in environmental decision-making where fairness, risk-aversion, or safeguards against poor outcomes are a priority, especially in contexts where failing to meet minimum thresholds in any one area may jeopardize overall sustainability.

By applying both decision rules, the analysis exposes how underlying decision rationales influence prioritization outcomes. This dual-method approach adds a meta-layer of transparency to the process and enables more robust and risk-informed planning.

2.2.6 Perform sensitivity analysis

To assess the sensitivity of the ranking to the choice of criteria weights, we performed a sensitivity analysis around the baseline weight vector. Specifically, each of the 14 criteria weights was perturbed uniformly within ±25% of its baseline value, using the equation:

$$w_i^{(k)} = w_i^{baseline} \cdot \ (0.75 + 0.5 \cdot \ RAND())$$

The perturbed weights were then normalized so that all weight sets sum to one. This procedure generated 50 random weight scenarios, representing local but non-trivial deviations from the baseline preferences. This form of local sensitivity analysis is appropriate because the baseline weights were directly elicited from stakeholders during the transnational living lab in Jordan, and therefore represent a well-justified reference point from which to explore plausible variations in decision-maker preferences.

A sensitivity analysis was also performed for the Minimax method using 50 perturbed weight sets generated within ±25% of the baseline stakeholder-defined weights (with normalization).

2.3 Strategic design for implementation

While the participatory MCDA provides a transparent and evidence-based prioritization of WEFE measures, it does not by itself constitute a strategy. MCDA answers the question "*What are the most promising measures?*", but not "*How can they be implemented*, *by whom and under what conditions?*". For this reason, the assessment phase needs to be followed by a strategic design phase, in which the prioritized measures will be translated into actionable, context-sensitive planning steps. This phase has been methodologically designed within the EcoFuture project and will be carried out separately for Jordan and Palestine to account for the differences in local conditions with the engagement of stakeholders.

The objective of this phase is to transform the top-ranked portfolio of measures into a coherent, implementable strategy by:

(i) Identifying governance actions needed to enable implementation,
(ii) Developing implementation pathways for selected measures,
(iii) Specifying systemic enablers (institutional, financial, organizational), and.
(iv) Synthesizing measures into bundles that enhance WEFE synergies and reduce trade-offs.

These steps ensure that the strategy does not remain a list of isolated, technical interventions but evolves into a systemic and feasible implementation plan.

2.3.1 Governance actions for operationalizing the prioritized measures

This step identifies the governance reforms required to adopt and support the prioritized portfolio of measures. These may include cross-ministerial coordination mechanisms, updates to water and agricultural regulations, financial incentives for farmers, new monitoring responsibilities, and enhanced data-sharing arrangements. Governance design is essential for embedding WEFE integration into institutional structures and avoiding sectoral fragmentation. The stakeholders will articulate priority governance actions and assess their feasibility and alignment with existing national frameworks.

2.3.2 Implementation pathways for each measure

Implementation pathways specify how each selected measure can realistically progress from concept to action. Pathways will be developed for the top ranked interventions identified through MCDA. Each pathway will map sequence of actions (short-, medium-, long-term), responsible actors, required resources and financing mechanisms, enabling regulations, social acceptance and capacity considerations, as well as risks and mitigation strategies. This step translates prioritized measures into practical roadmaps tailored to the governance and socio-economic conditions of the Jordan Valley.

2.3.3 Identification of systemic enablers and barriers

Systemic enablers create the conditions for long-term and scalable implementation of the measures. Drawing on insights from all the previous steps, the stakeholders will identify enabling conditions and barriers across institutional, economic, organizational and knowledge domains. This step ensures that interventions are not implemented in isolation but are embedded in a supportive environment, and that potential barriers are explicitly addressed in the strategy.

2.3.4 Strategic bundling of measures

The rationale of combining multiple interventions is increasingly recognized as a means to address cross-sectoral goals and enhance systemic impact (Rogge and Reichardt 2016; Raymond et al. 2017). In this paper, we adopt the concept of ‘bundling’, as a heuristic for grouping complementary WEFE measures into synergistic implementation strategies (Raymond et al. 2017; Somarakis et al. 2019; Dumitru and Wendling 2021). Bundling is the final step of the strategic design phase and plays an integrative role. Even though the MCDA process has evaluated measures individually, implementation often requires coherent packages of interventions that address multiple needs simultaneously.

The rationale for bundling may include one of the following objectives: (i) to increase feasibility and uptake by pairing mutually supportive actions, (ii) to compensate for weaknesses in individual measures (e.g., technical gaps or limited scope), (iii) to align interventions with existing funding streams or policy frameworks, (iv) to maximize cross-sectoral benefits and systemic synergies across water, energy, food and ecosystems.

Participants will co-create bundles using the top-ranked measures as building blocks. Bundles offer a practical means to shift from lists of interventions toward integrated action packages that enhance WEFE synergies and improve the likelihood of successful implementation. Graphically presenting the impact of bundles will help stakeholders visualize how certain combinations of measures mitigate the WEFE trade-offs of individual measures, serving both as a visual aid and a design tool for optimizing implementation strategies. To illustrate the use of bundling in strategic planning, we provide examples of bundles for the Jordan Valley case study in Sect. 3.3.

3 Results

This section presents the results of applying the phased methodology described in Sect. 2. First, in 3.1, we report the outcomes of the participatory MCDA conducted for the JV case study. The top-ranked portfolio of measures resulting from the MCDA constitutes what we refer to as the Agricultural Transformation Strategy (ATS) for the Jordan Valley: a coherent set of WEFE-aligned interventions that collectively articulate a shift toward nature-based, regenerative, circular and resource-conscious agricultural practices in the

JV. Then, in 3.2, we outline the preliminary outputs of the strategic design phase for operationalizing the ATS, which—although not yet implemented—has been fully specified as a methodological blueprint for the forthcoming planning cycles. Finally, Sect. 3.3 provides an illustrative example of how bundling can support cross-sectoral strategic design, demonstrating the practical use of the methodology.

3.1 MCDA results

3.1.1 Alternative measures

Table 1 presents the final list of measures that have been considered in the assessment process. This list of measures represents actions that both Jordan and Palestine can implement now and be part of a strategy to improve Resource Security, Environmental Sustainability, and Socio-Economic Prosperity, The proposed measures and initiatives have been focused exclusively on WEFE pillars; each

Table 1 List of WEFE measures and actions to address desertification in the Jordanian and Palestinian sections of the JV

Water security measures (W)	**Ecosystem sustainability measures (Ec)**
Category W1. Water loss reduction	Category Ec1: Enhancing farmland sustainability through non-productive landscape elements
W1.1 Technology-driven water loss detection & infrastructure repair	Ec1.1 Nature-inclusive agriculture (NIA) for biodiversity and ecosystem services
W1.2 Reducing water losses in agricultural ponds	Ec1.2 Integrating hedgerows and flower strips for biodiversity and habitat creation
Category W2. Efficient irrigation practices. Advancing water-saving irrigation practices	Category Ec2: Phytoremediation for water and soil restoration
W2.1 Installation of soil moisture meters and data transmitters	Ec2.1 Implement phytoremediation in contaminated sites.
W2.2 Development of a mobile application for smart irrigation management	Category Ec3: Establishment of biomass buffer strips for water and soil conservation
W2.3 Enhancing soil coverage to conserve moisture	Ec3.1 Plant riparian buffer strips
W2.4 Improving pressure uniformity in irrigation systems	Category Ec4: Fencing for biodiversity conservation and landscape connectivity
Category W3: Rainwater harvesting for sustainable irrigation	Ec4.1 Install and maintain conservation fencing
W3.1 Implementation of rainwater collection systems	Category Ec5: Terracing for erosion control and water quality protection
Category W4: Desalination of brackish groundwater for freshwater production	Ec5.1 Construct and maintain terraces
W4.1 Desalination of brackish groundwater	Category Ec6: In-stream small dams for sediment control in wadies
Category W5: Advanced wastewater treatment and reuse	Ec6.1 Design and construct small dams
W5.1 Implement secondary & tertiary wastewater treatment	Category Ec7: Establishment of constructed wetlands for wastewater treatment and pollutant removal
Energy security measures (E)	Ec7.1 Design and construction of constructed wetlands - site identification and planning
Category E1: Solar energy technologies for sustainable water and energy management	Category Ec8: Wetland restoration for ecosystem health and water quality improvement
E1.1 Integrated systems for water and energy management	Ec8.1 Wetland restoration
E1.2 Adoption of agrivoltaics for sustainable agriculture	Category Ec9: Establishment of ecological corridors for enhancing connectivity in terrestrial ecosystems
Category E2: Implementing efficient energy practices for sustainability	Ec9.1 Design and plan ecological corridors
E2.1 Sustainable energy practices in agriculture	Category Ec10: Protected areas for biodiversity conservation
Category E3: Biomass utilization for renewable energy and organic fertilizer production	Ec10.1 Design and establish new protected areas
E3.1 Biomass and organic waste collection	Ec10.2 Enhance the management of existing protected areas
E3.2 Organic fertilizer production from biomass residues	**Horizontal measures (H)**
E3.3 Biogas production	Category H1: Educational measures
Food security measures (F)	H1.1 Professional training of farmers and livestock breeders
Category F1: Agroecological practices	H1.2 Public Awareness and sensitization on water issues
F 1.1 Carbon addition for soil health and climate resilience	H1.3 Enhancing environmental programs in primary & secondary & higher education
F 1.2 Permaculture and agroforestry for sustainable land use	Category H2: Research, development and demonstration projects
	H2.1 Pilot Measures for the implementation of precision agriculture
	H2.2 Installation of monitoring stations for different purposes

WEFE pillar is further subdivided into specific categories and sub-measures, providing a detailed inventory of potential interventions.

For instance, water security measures span from technology driven water loss reduction (W1) and efficient irrigation practices (W2) to rainwater harvesting (W3), groundwater desalination (W4), and advanced wastewater treatment (W5). Ecosystem sustainability measures include actions such as integrating non-productive landscape elements (Ec1), phytoremediation (Ec2), buffer strip establishment (Ec3), conservation fencing (Ec4), and wetland restoration (Ec8) etc. Energy security is addressed through the adoption of solar technologies (E1), efficient energy practices in agriculture (E2), and biomass utilization (E3). Food security focuses on agro-ecological practices (F1), such as permaculture and soil carbon enrichment (sub-measures). Additionally, horizontal measures (H) highlight the importance of education (H1) and research and demonstration projects (H2) as cross-cutting enablers (Table 1). The complete description of the measures may be found in the supplementary material (S1).

While this compartmentalization into pillars may seem counter-intuitive to the nexus approach, it is used here to guide the identification of relevant measures, and does not imply that each measure contributes to only one pillar. In fact, most selected measures present synergistic impacts across WEFE sectors with minimal trade-offs. Measures motivated by water scarcity, treat water as an entry point rather than a standalone sector: irrigation efficiency and rainwater harvesting directly affect food production and energy demand, while wastewater reuse contributes to ecosystem restoration and nutrient cycling. Similarly, ecosystem-oriented measures support long-term water regulation and soil health; food security measures positively affect ecosystem sustainability and water security while often reducing energy demand; and energy security measures are designed to be compatible with, and complementary to, soil, water, and ecosystem health interventions.

3.1.2 Criteria weights

The calculated weights assigned to the criteria by different stakeholder groups are presented in Table 2. While slight variations can be observed among groups (e.g., between Jordanian and Palestinian participants or between policymakers and farmers), overall the weights were found to be sufficiently convergent to justify the use of an average weight set for the multi-criteria analysis.

Table 2 The relative importance assigned to the criteria by different stakeholder groups derived with the Simos method

	1.1 Water security (quantity & quality)	1.2 Energy availability & stability	1.3 Food security (quantity & quality)	1.4 Ecosystems and biodiversity conservation	2.1 Public health and wellbeing	2.2 Equity implications	2.3 Community empowerment and capacity building	3.1 Income generation	3.2 Employment	3.3 Affordability	4.1 Technical feasibility and maturity	4.2 Implementation cost	4.3 Institutional and regulatory compatibility	4.4 Cultural compatibility and social acceptance
All merged	11.00%	9.32%	9.42%	6.97%	7.27%	5.65%	6.34%	7.44%	6.74%	6.45%	5.73%	6.49%	5.04%	6.12%
Jordan	10.96%	8.97%	8.86%	6.40%	7.53%	5.78%	7.01%	7.03%	6.75%	6.40%	5.37%	7.23%	5.18%	6.53%
Palestine	11.09%	10.07%	10.60%	8.17%	6.74%	5.37%	4.93%	8.29%	6.73%	6.57%	6.49%	4.92%	4.77%	5.27%
Farmers	11.30%	9.97%	8.06%	5.87%	6.31%	6.72%	7.43%	7.33%	6.24%	5.90%	5.35%	6.95%	5.26%	7.33%
Scientists -Policymakers	10.78%	8.16%	9.91%	7.15%	8.19%	5.45%	6.58%	6.23%	7.01%	6.27%	5.25%	7.22%	5.57%	6.23%
Policymakers	10.98%	9.82%	9.89%	7.51%	7.16%	5.14%	5.49%	8.44%	6.85%	6.94%	6.34%	5.64%	4.50%	5.30%

3.1.3 Ranking of alternatives

A comparison of the top 15 measures under each method is presented in Table 3. The ranking of the complete list of measures with the two methods is presented in the supplementary material (S5-S6). For the purposes of comparison, only "vertical" measures are included in the ranking, while "horizontal" measures (generic support actions such as training and awareness) are excluded, as these are considered beneficial across all scenarios and are intended to be adopted regardless of score. The averaged weights representing the whole group of stakeholders have been used for these rankings.

By comparing the results from the two methods, several insights emerge. First, WSM provides a complete ranking, while Minimax yields clusters of equally ranked alternatives (due to identical distance value from the reference point), reflecting its egalitarian logic that prioritizes minimizing the worst shortfall across all criteria.

The table reveals a substantial degree of convergence between the two methods. All of the ten highest-ranked WSM measures appear within the top 15 of the Minimax results. This indicates a shared core of prioritized measures, regardless of the decision logic applied. Among these, "W3.1: Implementation of Rainwater Collection Systems" ranks first in both methods, confirming its high performance across WEFE and sustainability dimensions and its strong contextual fit for the JV.

These ten top-ranked interventions emphasize the urgent need for sustainable water management, such as the implementation of rainwater collection systems (W3.1), which can significantly enhance water availability, particularly in drought-prone areas. Complementary strategies, including technology-driven water loss detection (W1.1) and smart irrigation applications (W2.2), bring innovation into resource management, increasing efficiency and reducing waste.

Equally critical is the transition toward nature-inclusive agricultural practices (Ec1.1) and land-use systems that restore and protect biodiversity. Approaches such as terracing (Ec5.1) and permaculture and agroforestry (F1.2) not only sustain yields but also improve habitat quality and soil health. These measures are key to reversing environmental degradation while supporting rural livelihoods. Soil health is another recurring theme, with interventions like carbon addition (F1.1) directly contributing to long-term land productivity and climate resilience. Furthermore, the integration of organic waste management strategies, such as fertilizer production from biomass residues (E3.2), reflects a shift toward circular and regenerative agricultural systems.

Finally, the inclusion of measures to protect and enhance ecosystems, such as the improved management of protected areas (Ec10.2), underscores the interconnectedness of land, water, and biodiversity. These actions are vital for maintaining ecological functions and ensuring sustainable resource availability for future generations. Together, these interventions present a comprehensive framework for transforming

Table 3 Comparative view of rankings with the two methods (first fifteen measures). Common measures in both top 15 lists are presented with bold

WSM ranking		Minimax ranking	
W3.1 Implementation of rainwater collection systems	1	W3.1 Implementation of rainwater collection systems	1
Ec1.1 Nature-inclusive agriculture (NIA) for biodiversity and ecosystem services	2	E1.2 Adoption of agrivoltaics for sustainable agriculture	2
W1.1 Technology-driven water loss detection & infrastructure repair	3	E3.2 Organic fertilizer production from biomass residues	2
W2.2 Development of a mobile application for smart irrigation management	4	Ec10.1 Design and establish new protected areas	2
Ec5.1 Construct and maintain terraces	5	W1.1 Technology-driven water loss detection & infrastructure repair	5
W2.4 Improving pressure uniformity in irrigation systems	6	W1.2 Reducing water losses in agricultural ponds	5
E3.2 Organic Fertilizer production from biomass residues	7	W2.1 Installation of soil moisture meters and data transmitters	5
F1.1 Carbon Addition for soil health and climate resilience	8	W2.2 Development of a mobile application for smart irrigation management	5
F1.2 Permaculture and agroforestry for sustainable land use	9	W2.4 Improving pressure uniformity in irrigation systems	5
Ec10.2 Enhance the management of existing protected areas	10	E1.1 Integrated systems for water and energy management	5
Ec1.2. Integrating hedgerows and flower strips for biodiversity and habitat creation	11	F1.1 Carbon addition for soil health and climate resilience	5
E3.1 Biomass and organic waste collection	12	F1.2 Permaculture and agroforestry for sustainable land use	5
W5.1 Implement secondary wastewater treatment to remove organic matter & tertiary treatment to further improve water quality to ensure safe reuse in irrigation	13	Ec1.1 Nature-Inclusive Agriculture (NIA) for Biodiversity and Ecosystem Services	5
W2.3 Enhancing soil coverage to conserve moisture	14	Ec5.1 Construct and maintain terraces	5
Ec3.1 Plant riparian buffer strips	15	Ec10.2 Enhance the management of existing protected areas	5

environmental stewardship in both rural and peri-urban landscapes. Their successful implementation will require cross-sector collaboration, investment in capacity-building, and adaptive governance to ensure that the benefits are widely shared and sustained over time.

Despite overall convergence, notable variations in ranking remain, due to the different decision logic of the two methods. WSM rewards strong cumulative performance, allowing high scores in some criteria to compensate for weaknesses in others. This benefits ambitious or transformative measures with uneven performance profiles. Minimax, by contrast, penalizes even moderate weaknesses in highly weighted criteria, favouring measures with balanced performance in the most critical areas (e.g., water, food, energy security, and income generation). This divergence offers important strategic insights.

For example, "Ec1.1: Nature-Inclusive Agriculture (NIA) for Biodiversity and Ecosystem Services" ranks 2nd under WSM but 5th (tie with other ten measures) under minimax. Its high WSM score is driven by strong positive impacts in biodiversity, well-being, community empowerment and affordability, which compensate for a lower score in technical maturity and moderate score in water and food security. In contrast, minimax penalizes heavily its moderate score on water security, which is a highly weighted criterion, lowering its overall ranking.

Conversely, "E1.2: Adoption of Agrivoltaics for Sustainable Agriculture", is ranked 2nd with the Minimax but 24th with the WSM. While Ec1.1 scores higher overall, it scores moderately on Income generation, which is a highly weighted criterion, and this cannot be overlooked by the minimax algorithm. On the contrary, E1.2 performs more reliably across highly weighted criteria; hence, its higher rank under Minimax; even if it doesn't achieve excellent scores for any criterion.

Other measures that exhibit this divergence include "W5.1 Implement secondary & tertiary wastewater treatment", "E3.1 Biomass and Organic Waste Collection" and "Ec3.1 Plant riparian Buffer Strips", all of which perform well in several categories but are penalized by minimax for their moderate impact on either water, energy or food security, which are all highly weighted criteria. Conversely, some measures are elevated in the Minimax ranking due to their balanced performance across criteria, particularly the highly weighted ones, even if they do not achieve outstanding scores in any single criterion. These include "Ec10.1 Design and Establish New Protected Areas", "E1.1: Integrated Systems for Water and Energy Management", "W1.2: Reducing Losses in Agricultural Ponds" and "W2.1: Installation of Soil Moisture Meters and Data Transmitters". These are considered more balanced options, with no major weaknesses, and may be especially suitable for early or risk-averse implementation phases.

3.1.4 Sensitivity analysis of the weights

For each weight scenario, the WSM algorithm was repeated, yielding 50 independent rankings of the 29 alternatives.

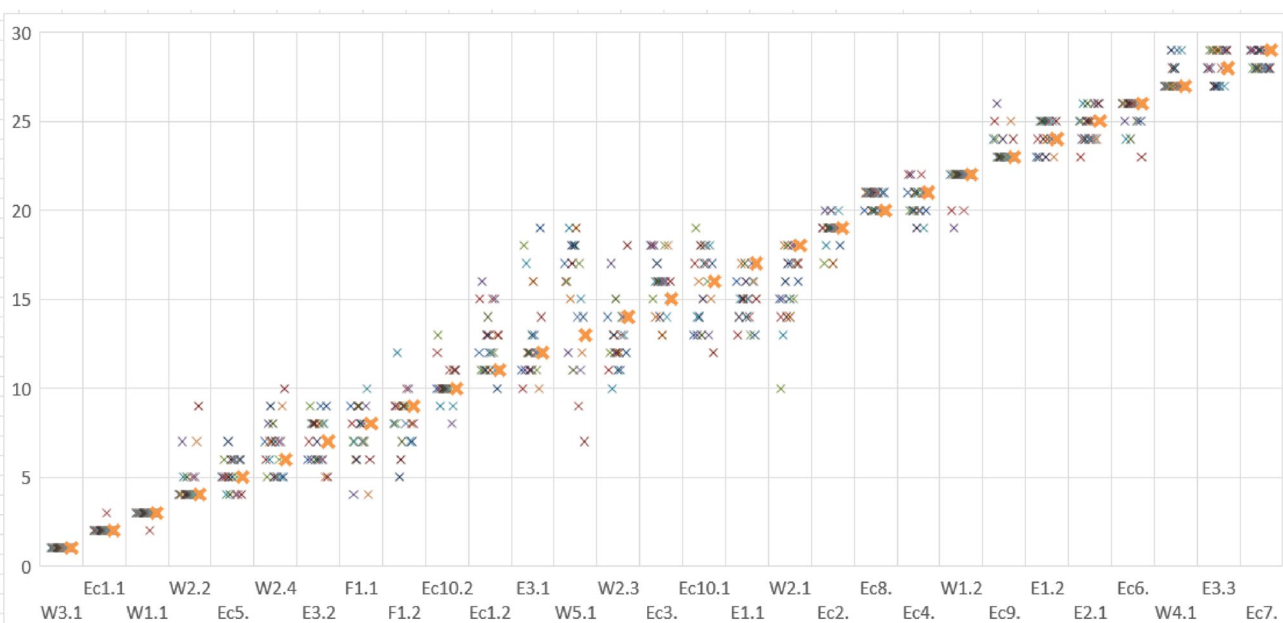

Fig. 3 Distribution of the WSM ranks of the 29 alternatives across 50 perturbed weight scenarios (±25% variation around baseline weights), together with the baseline ranking shown as a bold orange series. Stable alternatives show narrow rank ranges (e.g. W3.1), whereas others exhibit moderate sensitivity (e.g. W5.1). Overall, rankings remain highly robust (Kendall's W = 0.97)

The agreement among the 50 rankings is extremely high, as quantified by Kendall's W = 0.97, indicating very strong robustness of the ranking to weight perturbations.

Figure 3 shows the distribution of ranks under the 50 weight sets. Some alternatives remain perfectly stable (e.g. W3.1 is consistently ranked first), while others exhibit sensitivity. The most sensitive alternative is W5.1, which ranges between the 7th and 19th positions depending on the weight scenario.

Based on our objective to identify a robust top-performing group for further consideration, we treat the sensitivity analysis results conservatively. Instead of selecting only the top 15 alternatives from the baseline ranking, we retain the top 18 alternatives (up to W2.1), which remain consistently high-performing across virtually all weight sets.

A sensitivity analysis was also performed for the Minimax method using 50 perturbed weight sets generated within ±25% of the baseline stakeholder-defined weights (with normalization). The resulting rankings display a moderate-to-high level of concordance, with a Kendall's W of 0.79, indicating that the Minimax prioritization is robust but exhibits more sensitivity to weight variations than the WSM, which had a W of 0.97.

The graphical representation of the rank distributions in Fig. 4 reveals that the alternatives clearly cluster in two groups: the first 15 alternatives consistently rank within the top 15 positions across all scenarios, whereas the remaining 14 alternatives consistently occupy lower rankings. This indicates a natural robustness threshold between a high-performing and low-performing group.

By taking the intersection of the robust groups identified by both methods (WSM and Minimax), we obtain a consistent subset of alternatives that remain in the top-ranked positions across both methods and across all weight perturbations. These 13 alternatives (W3.1, Ec1.1, W1.1, W2.2, Ec5.1, W2.4, E3.2, F1.1, F1.2, Ec10.1, Ec10.2, E1.1, W2.1) can therefore be considered the robust top-performing group, resilient to both preference uncertainty and aggregation-rule uncertainty. This subset represents the most reliable portfolio of measures for further analysis and stakeholder deliberation during the strategic design phase.

3.2 Preliminary outputs of the strategic design phase

This subsection presents the preliminary outputs of the strategic design steps outlined in Sect. 2.3. While these steps have been fully developed methodologically, they have not yet been implemented with stakeholders; their operationalization will take place during the upcoming living lab with Jordanian and Palestinian stakeholders. Nevertheless, the participatory MCDA process has already provided an indication of the governance requirements, implementation pathways and systemic enablers likely to shape the ATS. These preliminary insights demonstrate how analytical prioritization begins to translate into strategic considerations for action.

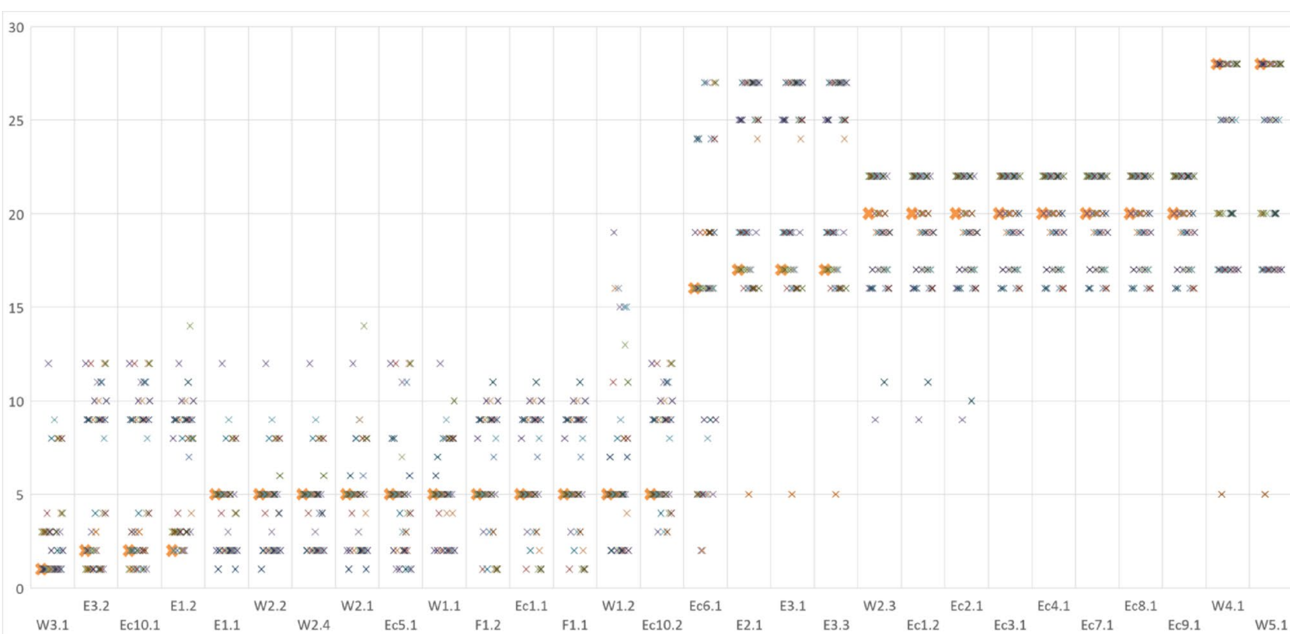

Fig. 4 Distribution of the Minimax ranks of the 29 alternatives across 50 perturbed weight sets (±25% variation around baseline weights), together with the baseline ranking shown as a bold orange series. The graph reveals two clusters: the first 15 alternatives consistently rank higher than the remaining 14

3.2.1 Governance actions

As outlined in Sect. 2.3.1, priority measures identified in the MCDA imply the need for several governance reforms for their operationalization. These include cross-ministerial coordination mechanisms, regulatory updates in water allocation, irrigation standards, soil conservation, and wastewater reuse, financial instruments supporting farmer adoption of high-scoring measures, and enhanced data-sharing and monitoring systems.

Territory-specific insights indicate that governance barriers differ significantly between Jordan and Palestine. In Jordan, modernization of water distribution networks, reduction of technical and administrative losses, and upgrading of metering systems are priority needs. Coordination exists across ministries, but financial constraints and bureaucratic fragmentation remain obstacles. In Palestine, governance challenges are compounded by restrictions on infrastructure development, dependence on external water sources, high tariff burdens and limited control over strategic water assets.

3.2.2 Implementation pathways

Implementation pathways specify how the top-ranked measures can progress from concept to action, including technical prerequisites, organizational roles, financing mechanisms and sequenced timelines. The preliminary analysis reveals that implementation may follow different pathways in Jordan and Palestine. In Jordan, the main barriers relate to aging infrastructure and the need for sustained maintenance and investment. In Palestine, constrained access to water, limited energy security and high costs of desalination and wastewater reuse challenge implementation feasibility. In both territories, small farm sizes and farmer vulnerability reduce the likelihood of technology uptake unless supported by subsidies, cooperatives and targeted capacity-building programmes. These elements will guide the development of full implementation pathways during the living labs and form the backbone of the ATS implementation roadmap.

3.2.3 Systemic enablers

The strategic design framework also identifies systemic enablers that create the conditions for long-term, scalable implementation of the ATS. Preliminary enablers include:

- Capacity-building programs for farmers and local authorities,
- Cooperative models for irrigation modernization and renewable-energy deployment,
- Market incentives for sustainable agricultural practices and products, and.
- Institutional reforms around data governance and long-term planning.

Systemic enablers vary across the two territories. In Jordan, relatively stronger institutional capacity can facilitate coordinated interventions if financing and governance coherence are strengthened. In Palestine, political fragmentation, limited mobility and energy insecurity require enablers that address systemic constraints directly, including innovative financing models, community-based schemes and decentralized technologies.

3.3 A strategic bundling example

This subsection provides an example of how bundling, especially for measures that perform well in some areas but are penalized for underperformance in others, can support the strategic planning process. Table 4 presents examples of synergistic measure bundles designed to enhance implementation feasibility and maximize cross-sectoral benefits. This illustrative bundling exercise demonstrates the design logic of the methodology, showing how analytical results (Sect. 3.1) can inform the configuration of strategies.

For example, bundling soil moisture monitoring technologies (W2.1) with rainwater harvesting (W3.1), smart irrigation tools (W2.2), water loss infrastructure repair (W1.1) and improving pressure in irrigation systems (W2.4) improves overall water-use efficiency and technical coherence. Similarly, pairing permaculture practices (F1.2) with agrivoltaics (E1.2) and organic fertilizer production (E3.2) promotes climate smart agriculture while increasing market access and the farmers' income and energy resilience. These thematic bundles also emphasize the role of the horizontal measures proposed such as education, monitoring, and institutional support (e.g., H1.1–H1.5) as catalysts of transformative change.

Figure 5 illustrates the performance of each bundle compared to its corresponding core measure, using radar charts that visualize performance across the fourteen decision criteria. Two visual elements in each graph help assess the bundle's value: the shape formed by the outermost lines of all individual measures and the average line representing the mean score of the bundle across criteria. Together, these two elements provide complementary insights. The outer perimeter of the radar chart offers a visual impression of the overall spread and balance of the measures' strengths and weaknesses, highlighting which criteria are strongly supported and where there may be persistent weaknesses. The average line quantifies the central tendency of the bundle's performance, providing a summary indication of its overall robustness and contribution to nexus goals.

Table 4 Illustrative WEFE bundles developed as part of the strategic design phase

Purpose of bundling	Core measure	Suggested bundled measures
Improve performance in water security and technical feasibility	W2.1 Installation of soil moisture meters and data transmitters	W3.1 Implementation of rainwater collection systems W1.1 Technology-driven water loss detection & infrastructure repair W2.2 Development of a mobile application for smart irrigation management W2.4 Improving pressure uniformity in irrigation systems H1.4 Pilot measures for the implementation of precision agriculture
Enhance income generation, energy use, and market access	F1.2 Permaculture and agroforestry for sustainable land use	E3.2 Organic fertilizer production from biomass residues E1.2 Adoption of agrivoltaics for sustainable agriculture H1.1: Professional training of farmers and livestock breeders
Maximize co-benefits of water, energy, and food while increasing public understanding and acceptance	F1.1 Carbon addition for soil health and climate resilience	W2.1 Installation of soil moisture meters and data transmitters E1.2 Adoption of agrivoltaics for sustainable agriculture H1.2 Public awareness and sensitization on water issues
Support biodiversity, ecosystem services and cultural transformation through nature-based interventions and educational programs	Ec10.2 Enhance the management of existing protected areas	Ec1.1: Nature-inclusive agriculture F1.2 Permaculture and agroforestry for sustainable land use Ec5.1 Construct and maintain terraces H1.3 Enhancing environmental programs in primary, secondary & higher education

It is worth noting how bundling shifts performance profiles from uneven or narrowly focused (as seen in some core measures) to more holistic and synergistic patterns. In the case of bundle 1, while the core intervention (W2.1 Soil moisture meters) shows limitations in dimensions such as equity implications, technical feasibility and maturity and affordability, the addition of well-aligned complementary measures (like rainwater harvesting and infrastructure repair) enhances performance across these criteria. As illustrated in the radar chart, the first bundle overall achieves a more balanced and robust profile compared to the initial core measure.

These findings confirm the value of bundling as a strategy to overcome individual measure limitations and enhance systemic impact. Furthermore, the radar charts offer a communicative device to visualize synergies and trade-offs, supporting the development of shared understanding among stakeholders in participatory planning processes.

4 Discussion

4.1 From diagnosis to implementation: bridging the operationalization gap

A recurring critique of nexus research is that it often remains descriptive or analytical, mapping interlinkages without offering actionable pathways for implementation. The phased methodology developed in this study directly addresses this gap by connecting system diagnosis, analytical assessment and prioritization, and strategic co-design within an integrated and participatory procedure. Each methodological phase builds upon the previous one: the initial WEFE mapping phase establishes a shared evidence base; participatory MCDA, then, operationalizes decision-making through transparent, multi-criteria assessment; and the strategic design phase translates prioritized measures into governance actions, implementation pathways, enabling conditions and synergistic bundles. This approach therefore advances WEFE nexus operationalization by offering a structured progression from analysis to action, enabling decision makers to move beyond conceptual framing toward the design of implementable strategies.

4.2 A shift in agricultural and resource planning paradigms

The design of policies reflects the way problems are framed and the underlying ideological orientation of those developing them (Weitz et al. 2017). In the context of agricultural development and resource planning in the Jordan Valley, past interventions have predominantly relied on technocratic, centralized, and supply-driven approaches, emphasizing large-scale grey infrastructure, resource extraction, and sectoral fragmentation. These interventions have often resulted in ecological degradation, resource inefficiency, and social marginalization, particularly for smallholder farmers (Hanna 2020; Molle et al. 2018).

The planning approach adopted in this paper is informed by the WEFE nexus concept and, additionally, guided by values of regeneration, circularity, minimum intervention and adaptability to local conditions. Rather than intensifying inputs and engineering control over nature, this paradigm seeks to work with natural processes to restore and maintain ecological functions, close resource loops, reduce demand and support low-impact, high-synergy solutions.

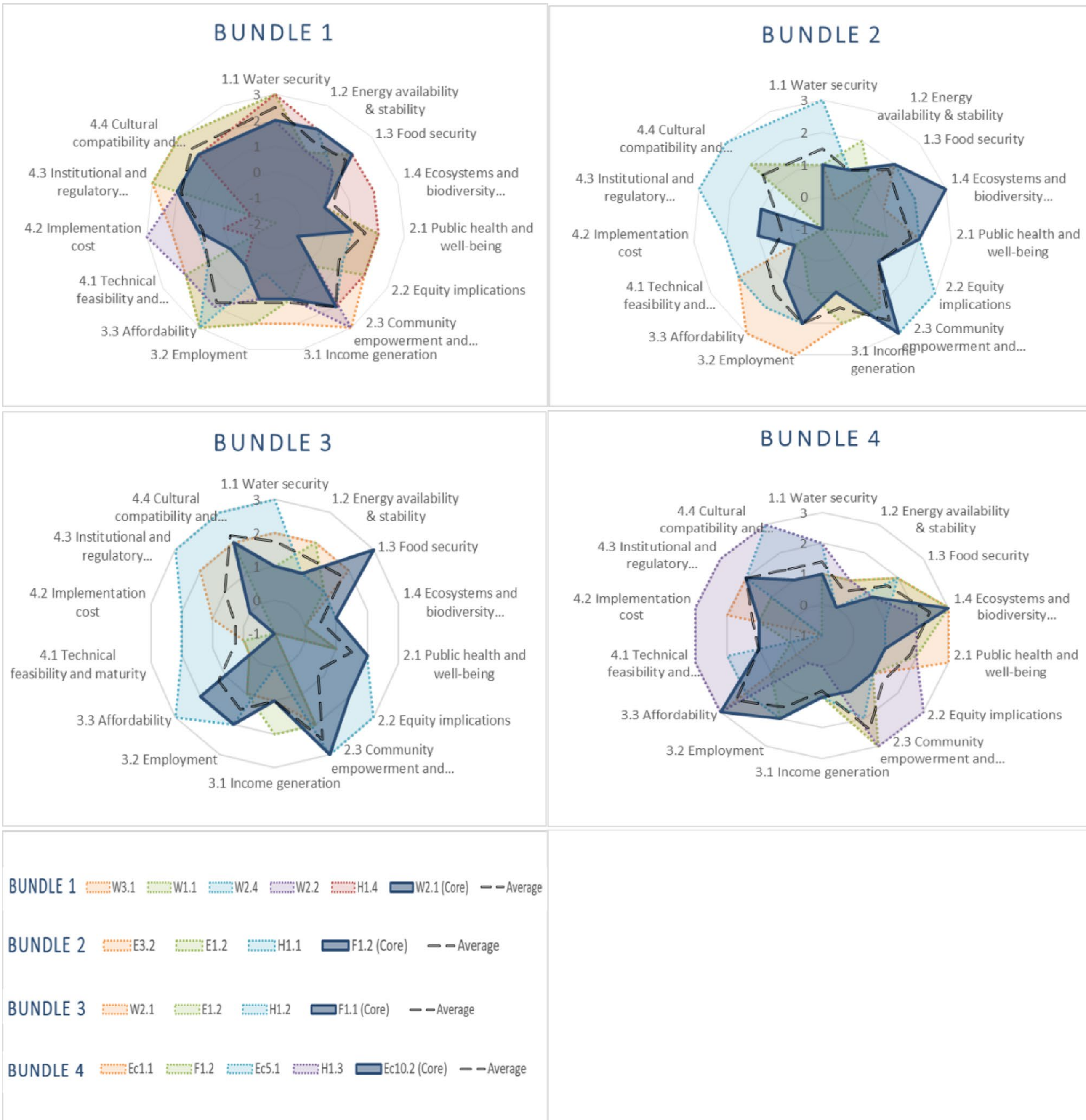

Fig. 5 Graphical illustration of the performance of the bundles compared to the initial core measures

4.3 Operationalization of the nexus

To translate this vision into actionable strategies, this work developed and applied an integrated, phased procedure for participatory strategic planning in the WEFE nexus. In this context, the WEFE nexus is understood not as a static conceptual framework but as an integrative planning logic that shapes decisions at every stage of the process. The operationalization of the nexus is evident in the following complementary mechanisms of the methodology:

(i) WEFE-aligned solution design: Alternative measures were designed to explicitly favour nature-based, water-saving, soil-restoring, energy-efficient and ecosystem-enhancing approaches. This design principle naturally filtered out measures with severe cross-sectoral trade-offs.

(ii) WEFE-informed assessment criteria: The MCDA framework explicitly incorporated WEFE criteria (water security, food security, energy security, ecosystems health), ensuring that synergies and trade-offs could be identified and evaluated.
(iii) Non-compensatory decision algorithm: In the MCDA process we have applied both the WSM and the Minimax algorithms. While WSM is fully compensatory, potentially hiding trade-offs between WEFE sectors, Minimax penalizes low performance in individual criteria. By triangulating the WSM results with the Minimax method, we ensured that interventions performing poorly on priority WEFE dimensions were not hidden by compensatory effects.
(iv) WEFE-aligned implementation design: The identification of governance actions, implementation pathways and enabling conditions is guided by the goal to reduce institutional fragmentation and support coordination across water, energy, food, and environmental authorities. Additionally, we illustrate how measures may be reconfigured into bundles that enhance WEFE synergies and systemic impact across criteria.

Through these mechanisms, the planning procedure translates the WEFE nexus from a conceptual lens into a practical, decision-oriented framework that informs both analytical assessment and strategic design.

4.4 Implications for nexus research and policy

The paper has presented a structured, phased procedure for operationalizing the nexus, moving from system diagnosis to the assessment of measures and strategic design for their implementation. This stepwise structure responds directly to calls in the literature for methods that support actionable planning.

The implementation of the participatory MCDA process was a core strength of this strategic planning process. The TLL successfully engaged a wide range of Jordanian and Palestinian stakeholders (policy makers, scientists and farmers) creating a shared space for learning, deliberation, and co-design. This participatory approach enhanced transparency, promoted cross-sectoral dialogue, and ensured that the selected measures reflect local knowledge, values, and practical experience. The MCDA process also strengthened ownership over the resulting strategies and fostered a stronger foundation for cross-border collaboration.

Additionally, the dual application of the WSM and the Minimax algorithm has provided valuable, complementary insights for prioritizing WEFE measures in the Jordan Valley. While WSM is a standard prioritization method and intuitively comprehensible by non-experts in participatory processes, the Minimax supports risk-sensitive decision-making by penalizing poor performance in any single critical criterion.

In policy discussions, these differences should be framed not as conflicting results but as alternative decision rationales in WEFE planning processes. Importantly, comparing the sensitivity analysis results across both methods enabled the identification of a subset of measures that remain highly ranked under both aggregation rules and across plausible weight variations. This intersection defines a robust group of prioritised measures that is resilient to both preference uncertainty and aggregation-rule uncertainty, thereby strengthening confidence in the policy relevance of the final shortlist.

The preliminary strategic design insights highlight several implications for policymaking in Jordan and Palestine. The implementation of the agricultural transformation strategy requires the governments of the two nations to spearhead policy initiatives, as well as extensive farmer training and capacity building in order to overcome the legislative, financial and technological barriers and inertia for change from the current agricultural practices. The ATS can be used as a marketing tool to access new markets and showcase how JV can be revitalized for the generations to come.

Looking ahead, the successful implementation of this strategic plan will depend on sustained political commitment, cross-border collaboration, and the development of adaptive governance frameworks capable of responding to emerging risks and opportunities. Four priority actions stand out as particularly urgent for both territories: first, to formally adopt the agricultural transformation strategy at the highest levels of government, embedding principles of regeneration, circularity, and sustainability at the core of policy; second, to pursue legislative and institutional reforms that reflect this shift and align investment frameworks accordingly; third, to launch coordinated capacity-building efforts that extend beyond farmers to include government officials, extension services, and private-sector actors; and finally, to establish “lighthouse” initiatives, i.e. demonstration hubs for ongoing farmer training, technical assistance and peer learning. These actions will help operationalize the proposed paradigm, enabling the Jordan Valley to serve not only for combating desertification but also as a regional model for integrated, climate-adaptive development.

5 Conclusions

The Jordan Valley, the “bread basket” of Jordan and Palestine, is already experiencing the impacts of climate change with reduced water availability, loss of soil fertility, and degradation of ecosystem services. The region is facing significant challenges related with water demand for irrigation, water and soil quality, agricultural development and renewable energy availability. The current geopolitical conflict further aggravates the critical situation, undermining the capacity to provide resource security and improve the livelihood of the people in the region. In this context, the strategic plan presented in this paper outlines a clear, actionable path forward. Developed through an integrated and participatory methodology, and employing the WEFE nexus as a planning approach, it ensures that proposed solutions enhance WEFE synergies, while remaining context-sensitive and feasible.

This paper presented a phased methodology for operationalizing the WEFE nexus in the Jordan Valley, addressing a key gap in the literature: the absence of structured procedures that move from system diagnosis to analytical prioritization and implementation planning. The approach integrates WEFE baseline diagnosis with participatory multi-criteria analysis and strategic design, resulting in a coherent framework for strategic planning.

The methodology yielded a prioritized set of interventions—the Agricultural Transformation Strategy—that reflects nature-based, regenerative, circular and resource-conscious practices. It also generated preliminary insights into governance requirements, implementation challenges and enabling conditions in both Jordan and Palestine. Although the strategic design phase will be further refined during the upcoming Living Labs, the results presented here demonstrate the practical feasibility and added value of the methodology.

More broadly, the study highlights that operationalizing the WEFE nexus requires an interdisciplinary toolbox combining methods from diverse disciplines, as well as a commitment to both scientific rigor and participatory co-production. The approach developed here aspires to offer insights for other WEFE-guided strategic planning efforts, especially in resource-scarce and institutionally fragmented regions facing climate pressures, where coordinated action across water, energy, food and ecosystems is essential for long-term resilience and well-being.

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Declarations

Competing interests The authors have no competing interests to declare that are relevant to the content of this article.

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