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A tool for optimizing the water, energy, food and ecosystem service nexus amidst diverse stakeholder interests

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ABSTRACT

Climate change and population growth are intensifying pressures on agricultural resources, underscoring the need to optimize the water–energy–food–ecosystem (WEFE) nexus. This study applies the Stakeholder WEFE efficiency evaluation tool (SWEET) in Uzbekistan through key informant interviews with representatives from governmental departments managing water, energy, food and environmental sectors. Results reveal divergence and convergence of priorities across departments and sectors, respectively around soil cover, fuel consumption and food crop production. Non-food crops were however consistently deprioritized. SWEET supports the identification of shared priorities and potentially conflicting interests, thereby helping prevent rebound effects and building coherent WEFE governance.

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Priority setting; multi-criteria decision-making; policy coherence; shared vision; Uzbekistan

Introduction

The water–energy–food–ecosystems (WEFE) nexus framework has become an influential approach for conceptualizing and managing complex environmental interdependencies across resource systems. It highlights how actions in one domain – such as groundwater extraction for irrigation – can impact others, including energy consumption and ecosystem sustainability (Rasul, 2016).

The WEFE nexus framework is valued by policymakers because, among other things, it necessitates a systems thinking where all components of the ecosystem are considered and optimized making it well-aligned with relevant Sustainable Development Goals (SDGs) including SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), and SDG 15 (Life on Land; Weitz et al., 2018). However, the operationalization of the WEFE nexus across institutions and governance scales remains highly complex. Government departments often work in silos with differing mandates, resulting in fragmented or even contradictory policies (Hoff, 2011; Schmidt et al., 2024).

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Conflicting stakeholder interests and negative externalities from policy and institutional decisions are often observed globally and can lead to rebound effects – defined as situations where efficiency improvements trigger behavioural or systemic responses that offset the expected resource savings (Paul et al., 2019; Hamidov et al., 2022). For instance, agricultural subsidies – such as those for synthetic fertilizers, fuel, mechanization or improved irrigation technologies – can counteract environmental protection goals aimed at conserving land and water, improving their quality, and reducing emissions (Ringler et al., 2013). Similarly, price support and policies geared to enhancing the adoption of solar-powered irrigation pumps may unintentionally encourage the over-extraction of groundwater, clashing with conservation-oriented groundwater regulations (Giullani et al., 2017). These examples illustrate how conflicting objectives can emerge when sectoral policies are not aligned under an integrated resource management framework. Conversely, some subsidies and price supports may have positive externalities. For example, a policy that supported the wider adoption of the mechanized raised bed technology in Egypt not only led to higher and more stable yields and hence contributed to food security and reduced downside risk, but also to conservation of irrigation water, and by providing good drainage to a potential reduction in soil salinity and fertilizer leaching (Yigezu et al., 2021).

The above examples underscore the need for tools that can help policy and institutional decision makers in setting priorities which optimize the WEFE nexus whereby the synergies (positive externalities) are maximized, and the trade-offs (negative externalities) are minimized. To this effect, such decision support tools (DST) will need to consider multiple criteria in the optimization process.

In operations research, multi-criteria decision analysis (MCDA) is a sub-discipline that explicitly evaluates multiple conflicting criteria in decision making (Franco and Montibeller, 2010). MCDA has also been applied in several policy decision analyses involving multiple stakeholders, and complex synergies and trade-offs between social, economic and environmental factors – such as those found in WEFE nexus governance (Ananda & Herath, 2003; Antoine et al., 1997; Kylili et al., 2016; Mendoza & Martins, 2006). While useful in helping decision making, they often focus narrowly on technical or biophysical aspects and overlook stakeholder perspectives. Many are also project-bound, relying on custom software that becomes unsustainable and hard to update once funding ends. The multi-criteria decision support tool (Verbist & Akramkhanov, 2025) addresses these gaps by combining stakeholder engagement with integrated WEFE management in a simple spreadsheet format. This ensures minimal learning curves, easy adaptation to local contexts, and long-term usability beyond project cycles. It provides a simple but effective and transparent technique for identifying common priorities in multi-stakeholder and complex problem scenarios.

This paper presents the results of an application of the tool described in Verbist and Akramkhanov (2025) to assess perception of stakeholders of WEFE sectors, here we introduce the stakeholder WEFE efficiency evaluation tool (SWEET)¹ for improving the management of the WEFE nexus in Uzbekistan. The research questions that this tries to answer are: 1) Where are stakeholder priorities misaligned? and 2) What are their implications? We hypothesize that stakeholder priorities are not aligned across the WEFE sectors

¹The tool was not known by this name in the past.

while they are in the departments within the sectors. The inconsistency in sectoral priorities, we hypothesize, may be causing rebound effects that reverse the overall effort for maximizing the WEFE nexus.

The remainder of the paper is organized as follows. In the next section, the context, including environmental conditions, governance structures and examples of the challenges for the WEFE nexus are presented. It also provides a description of the methodology detailing the stakeholder survey and decision-support approach. The third section presents the results showing the spread of responses within and across individual departments highlighting sectoral priorities and differences. It also provides the discussions on key insights and limitations. The final section concludes with recommendations for future research and policy development.

Context and methodology

Agriculture plays an important role in Uzbekistan's economy contributing 26% to gross domestic product (GDP) and employing over a quarter of the population (ITA, 2023). Energy is primarily fossil-fuel-based, though solar and hydropower are emerging not only in Uzbekistan but in the whole Central Asia region (Laldjebaev et al., 2021). Uzbekistan's (semi-)arid climate necessitated its agriculture to heavily rely on irrigation. Uzbekistan's food security is anchored in domestic agricultural production which has been on a sound growth trajectory to also generate a dynamic international trade growth. In the face of a growing population, increasing income, and hence increasing demand for food, feed and inputs for manufacturing, the country's aspiration and policies to increase agricultural production including export commodities, and agriculture's heavy reliance on irrigation make trade-offs across the WEFE nexus inevitable.

Economic and political governance in Uzbekistan is centralized, with separate ministries for water, energy, agriculture and the environment operating largely in silos (Bobochlov et al., 2025). This institutional fragmentation contributes to inconsistent policies and limited cross-sectoral coordination (Aminova & Abdullayev, 2009; Urinboyev, 2015). Historically, cotton-centred policies exemplified a focus on production over sustainable resource use, leading to excessive irrigation, land degradation including salinization of agricultural lands (Akramkhanov et al., 2014) and the ecological disaster of the Aral Sea (Huang et al., 2022; Micklin, 2007). Among others, weak institutional capacities at the local, provincial and national levels constrain the implementation of integrated WEFE management approaches failing to minimize the trade-offs involved in the pursuit of different, at times conflicting, goals (Aminova & Abdullayev, 2009; Urinboyev, 2015). We argue that optimization of the WEFE nexus requires coordination between all involved stakeholders, alignment of interests, having common vision and working together towards the same goal. This in turn requires tools that help all stakeholders to align their interests, prioritize their goals, and create a shared vision.

In this study, we applied a multicriteria decision support tool called the 'Stakeholder WEFE Efficiency Evaluation Tool (SWEET)'¹ that supports agricultural resource management decisions within the WEFE nexus framework (Verbist & Akramkhanov, 2025). The tool incorporates different weighting methods including the best-worst method (BWM), point allocation, and Saaty pairwise comparisons to incorporate the perspectives of diverse stakeholders while reflecting their relative importance across the WEFE sectors.

A key feature of the tool is its structured inclusion of stakeholder preferences through criteria weighting, enabling a transparent comparison of alternative agricultural resource management practices. The tool enables elaborate analysis – visualizing the synergy, and the socio-economic, biophysical and environmental performance or benefits of each decision on prioritization, as well as the trade-offs between alternative pursuits in the WEFE nexus. In this paper the emphasis is the results of the stakeholder weighting survey. The technical performance ranking of alternative suites (i.e., in this case innovation option) is based on expert ranking and literature, to show applicability of trade-off graphs in guiding policy decisions.

Key informant interviews

In the stakeholder survey carried out in Uzbekistan during 2023–2024, respondents included representatives from governmental departments and agencies responsible for the WEFE sectors (agriculture, irrigation water, energy and environment) who were visited in person and individually asked to allocate points to a set of criteria developed through expert consultation and a review of relevant literature and policy documents. This method, known as ‘Point Allocation’, requires respondents to distribute a set of 100 points across the criteria based on their perceived importance – that is, the more points a criterion receives, the more important it is considered by the respondent (Doyle et al., 1997). The exercise was applied to a total of 22 predefined criteria, structured into six prioritization groups (Verbist & Akramkhanov, 2025).

Six prioritization groups cover the four nexus domains (water, energy, food, ecosystems) alongside socio-economic aspects. This framework builds on our earlier work (Verbist & Akramkhanov, 2025), where indicators were identified based on relevance, measurability and applicability in data-scarce contexts. We believe these criteria allow for an integrated assessment of trade-offs and synergies across the WEFE nexus. They are not prescriptive but can be tailored depending on the local context, data availability and decision priorities.

This design ensured that no group contained more than five criteria, thereby keeping the cognitive load within the recommended threshold for working memory (Miller, 1956; Saaty, 1980). The exercise included both prioritization within WEFE sectors (e.g., comparing water-related criteria) and an overall ranking across sectors (e.g., weighing water vs energy vs food vs ecosystem) provided by the different WEFE departments. Conducting the survey individually ensured that each stakeholder’s perspective was captured independently and was not influenced by group dynamics or consensus-building processes. A total of 37 stakeholders participated in the survey, distributed across sectors as follows: water (10 respondents), energy (10), food (seven) and environment (10).

While the sample size might appear modest, it can be considered substantial in the context of key informant interviews (KII) involving some institutional leaders because, engaging government officials in survey-based research remains challenging (Ysmanova, 2024). In the context of the study, for example, researchers often need official permission letters from ministries, and interviews can be subject to supervision by local committees (Ysmanova, 2024).

While more advanced weighing methods such as the best–worst method (BWM) offer greater consistency and robustness in multi-criteria decision-making, point allocation was

Table 1. Description of the proposed innovation and current practices. Source: based on Agostini et al. (2020).

Innovation options	Description of current practices	Proposed new innovations
Food crop production systems	Dominated by cotton and wheat monocultures under state production quotas, with most irrigated land allocated to these crops. Productivity gains have come mainly from intensive crop management, where crop diversification remains limited.	To expand food crop production together with resource-efficient techniques such as conservation agriculture, crop diversification, use of high-yield and climate-resilient varieties (heat/drought/salt/cold tolerant) and laser-assisted land levelling.
Water management	Predominantly reliant on traditional furrow and flood irrigation methods, with low overall water use efficiency. Irrigation scheduling is often calendar-based rather than need-based, and canal systems are prone to seepage losses.	To enhance water use efficiency through implementing efficient irrigation systems (e.g., drip irrigation, sprinkler irrigation, improved canal lining), weather-based irrigation scheduling.
Forest production	Natural forest cover is limited and largely degraded, with challenging reforestation activities. Existing efforts focus more on protecting remaining vegetation on large-scale planting.	To create forest lands through reforestation with native tree/shrub species, protection and management of vegetation, and agroforestry using water harvesting where suitable.
Livestock and rangeland management	Livestock is mainly raised on smallholder (dehkan) farms using low-input systems, often dependent on crop residues and limited pasture resources. Overgrazing and degradation of rangelands are common issues.	To create sustainable livestock production through practices such as rotational grazing, seasonal resting, establishing pastures on poor croplands and re-planting native shrubs.
Business-as-usual production	Intensive, large-scale cotton-wheat farming, using outdated techniques such as inefficient irrigation and heavy input use and limited crop rotation.	

applied in this study due to its simplicity and ease of understanding. Prior research has shown that more sophisticated methods like BWM can impose a higher cognitive burden on participants and may lead to lower engagement, particularly when respondents are unfamiliar with the underlying methodology (Liang et al., 2020; Rezaei et al., 2021). Naturally, point allocation has its own disadvantages such as the equalizing bias, which will be discussed more in depth in the discussion section.

Alternatives: innovations options

In multi-criteria decision-making, alternatives are compared based on priorities (i.e., weights) and technical performance. For this study, we consider four generic suites as alternative innovation options, along with one business-as-usual scenario, to illustrate how a stakeholder might prefer a given innovation option over another compared to the business-as-usual. These options are described in Table 1 and are based on Agostini et al. (2020).

Constructing trade-off graphs

To compare stakeholder preferences with the technical performance of innovation alternatives, we computed a nexus score as presented in Equation (1), that integrates sectoral and criterion weights derived from the stakeholder survey with technical performance scores of each innovation option (ranks from 1 to 5). This composite score provides

a transparent way to visualize synergies and trade-offs across alternatives in trade-off graphs. The Nexus Score for alternative A and stakeholder S is calculated as follows:

Equation 1: Nexus Score

$$\text{Nexus Score}(A, s) = \sum_{g=1}^G W_{g,s} * \left(\sum_{i \in g} w_{i|g,s} * p_{i,A} \right)$$

where A = an innovation option (the alternative) under consideration,

s = the stakeholder (department, or individual respondent),

$g = 1, \dots, G$ = the nexus sectors (water, energy, food, ecosystem),

$i \in g$ = the criteria belonging to sector g ,

$W_{g,s}$ = normalized weight of stakeholder s for sector g .

$w_{i|g,s}$ = normalized weight for criterion i of stakeholder s within sector g ,

$p_{i,A}$ = expert-assessed technical performance score (1–5 scale) of alternative A on criterion i .

Results

The findings of a survey conducted among stakeholders from the WEFE-related ministerial departments in Uzbekistan. are presented in two parts: first, individual data points are shown to illustrate the degree of variation and internal alignment within each department; second, departmental averages are compared to reveal areas of synergy as well as conflicting priorities across sectors. We also use trade-off graphs to illustrate guiding policy decisions. Lastly, the limitations of this study are presented.

Table 2. Overview of ranking of the alternative options and business as usual.

Criteria	Sub criteria	Policy, institutional, and technological options				Business as usual
		Sustainable crop production	Efficient water management	Forestation	Livestock	
Water	Applied irrigation	3	5	5	5	2
	Irrigation efficiency	3	5	5	5	1
	Crop water efficiency	4	3	5	5	3
	Rain use efficiency	4	4	5	5	2
Energy	Machine use	3	2	3	4	3
	Fuel consumption	2	3	3	4	2
	Fertilizer use	2	3	3	5	2
	Number of machines	2	2	5	3	3
Food	Food (crop) production	5	3	1	1	1
	Livestock density	2	1	1	5	1
	Cotton production	1	5	1	1	3
	Other non-food production	1	1	1	2	1
Ecosystem	Soil cover	3	2	5	4	2
	Pesticide use	3	2	5	4	2
	Crop diversity	4	2	5	4	2
Socio-economics	Net-profit	4	5	1	2	3
	Investment cost	2	3	3	4	5
	Employment	4	3	1	2	3
SUM		52	54	58	65	41

Innovation options

In this study, expert judgement was applied to assign technical performance scores on a 1–5 scale to demonstrate the potential of trade-off graphs, based on data presented in Agostini, et al. (2024). The resulting scores are presented in Table 2. A score of 1 represents poor performance (e.g., high pesticide or water use, or low yield), while a score of 5 represents strong performance (e.g., efficient resource use and high yield). These scores were assigned for each innovation option across the various criteria.

Based on technical performance, livestock ranks highest overall, while cotton production scores lowest. Livestock and forestation perform well on water-related criteria because they require little irrigation. Efficient water management also scores strongly on applied irrigation and irrigation efficiency. However, in line with earlier findings, such efficiency gains may not automatically translate into proportional water savings. Instead, they can trigger rebound effects, as the saved water may be used to expand irrigated areas, compensate for existing water deficits or shift towards more water-intensive crops (Hamidov et al., 2022; Xu et al., 2021).

Preference results within departments

Figure 1 presents the mean (square) and spread (line) of individual weightings. The spread within departments is often considerable, suggesting diverging priorities among respondents (including some individuals in the leadership) within the same ministerial department. The highest standard deviation within a single department was 0.19 (Energy Department for quantity of irrigation water applied 'Applied Irrigation'), while the lowest was 0.04 (Food Department for rainwater use efficiency 'Rain Use Efficiency'). The average standard deviation across all departments and criteria was 0.11. Although this may appear low on a 0 to 1 scale, it is substantial when compared to the range of average weights, which only ranged between 0.15 and 0.46, with an overall average of 0.26.

The lack of alignment within governmental departments is noteworthy, as many WEFE frameworks – such as proposed by Rasul and Neupane (2021) – operate at higher levels and often seem to assume there are shared priorities within stakeholder groups. This internal misalignment may therefore pose a serious gap for sectoral priority setting and project implementation. Mayar et al. (2024) advocates for downscaling WEFE approaches to sub-national and local levels, making the development of common priorities within departments – such as presented in this study – a fitting and necessary step. This multi-level perspective aligns with the optimization framework proposed by Ma et al. (2024), whose multi-layered WEFE optimization model demonstrates how decision hierarchies – from national to local levels – can be operationalized for improved cross-scale coherence.

Preference results across departments

The results presented in the Figure 2 provide an overview of sector-wide priorities based on the sum of averaged weightings, consequently. Several collective

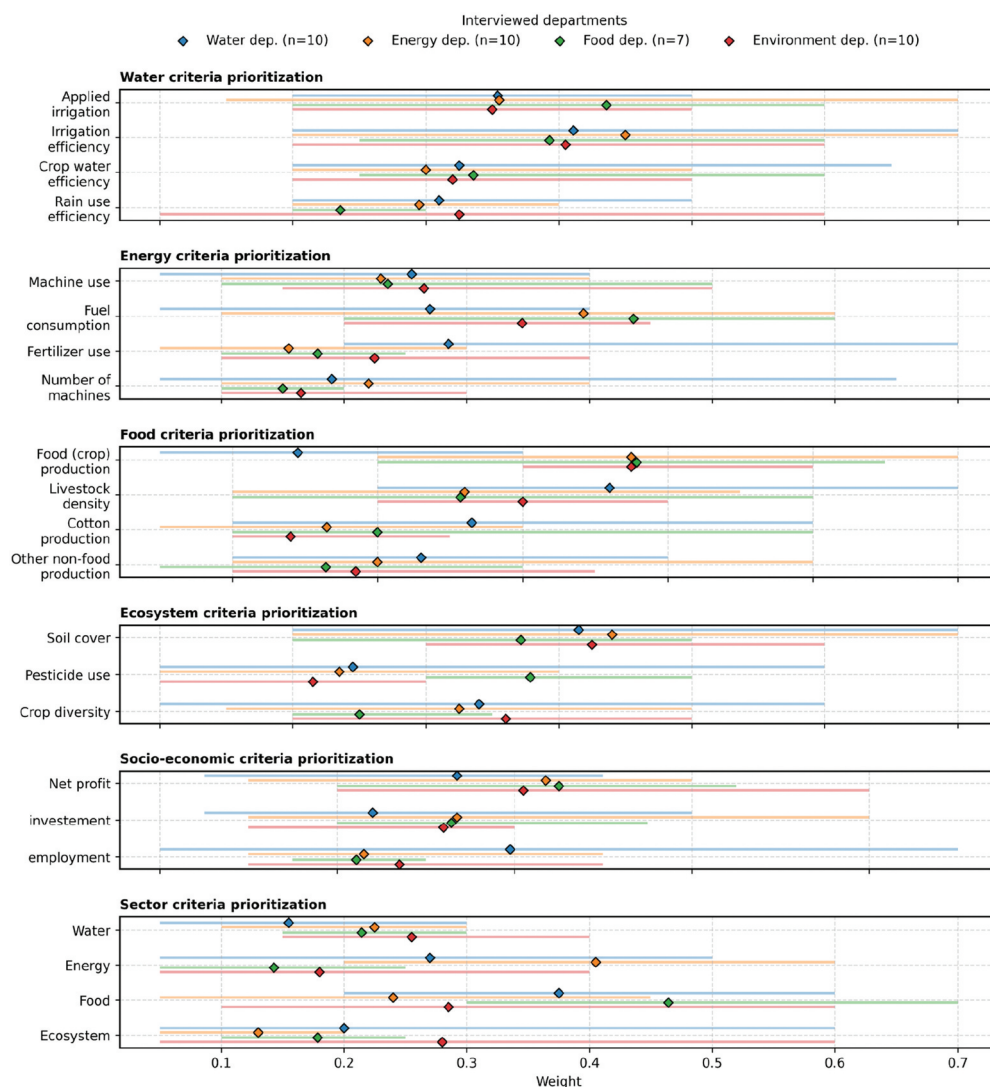


Figure 1. Averages (diamond) and spread (line) of weights within departments.

priorities emerged across the WEFE departments. For example, soil cover received consistently high weights, indicating broad recognition of its importance across all participating departments. This emphasis likely reflects the common understanding of the risk of sand and dust storms in Uzbekistan and their associated health impacts, such as respiratory problems. Increasing soil cover is a proven intervention to mitigate land degradation and reduce dust emissions (Akramkhanov et al., 2024; Strohmeier et al., 2023). Another cross-sectoral priority is fuel consumption, likely linked to both its ever-increasing importance and demand, and hence the national and global efforts to reduce greenhouse gas emissions and transition towards sustainable energy practices, as emphasized in the Paris Agreement (United Nations, 2015).

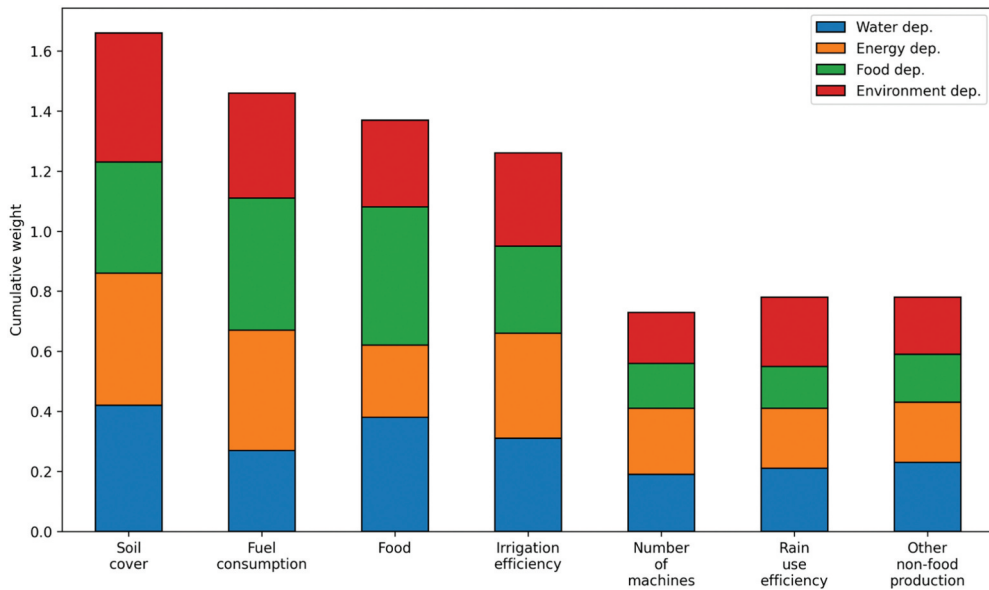


Figure 2. Stacked bar chart of the arithmetic weights of departments for the top three criteria, Irrigation efficiency, and the three lowest criteria.

In terms of overall sector prioritization, the food sector emerged as the highest priority sector, while the other sectors ranked lower. This suggests that including a food security component in policy initiatives may help ensure broader support across all departments.

Trade-off graphs

Figure 3 shows the trade-offs when considering individuals within the same department. Although it generally reveals that livestock-related innovations are more preferred than those of forestry, the relatively large distance between data points should be noted. This indicates that there is limited shared vision within the department. To illustrate the usefulness of the trade-off graph, we follow respondent number seven (diamond). The water efficiency innovation poses a win-win, as it provides some socio-economic and nexus gains. However, clear trade-offs can be seen between water, crop production and forestry; socio-economic preferences decrease, while nexus score improves. Additionally, it becomes evident that in this example, forestry is inefficient compared to livestock, leading to less improvement in the nexus score and higher socio-economic costs.

Figure 4 shows the trade-offs using the departmental averages. It reveals a clear trade-off for all departments between the socio-economic score and the nexus score: the livestock-related innovations are more nexus-friendly but less preferred from a socio-economic perspective. At the same time, efficient water management results in modest nexus gains while also delivering socio-economic benefits. The food crop-related innovation options sit in between: while they have little or no socio-economic significance, they

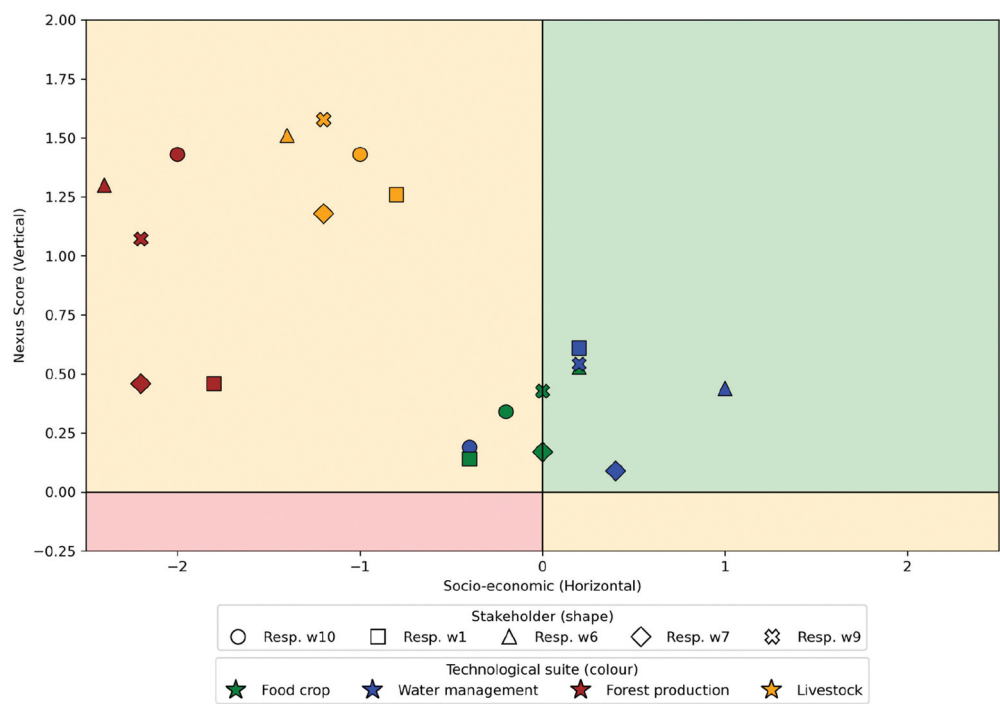


Figure 3. Trade-offs of the innovation options based on stakeholder preference within the water department and technical performance. Origin (0,0) represents the business-as-usual (BaU), i.e., cotton-wheat cultivation.

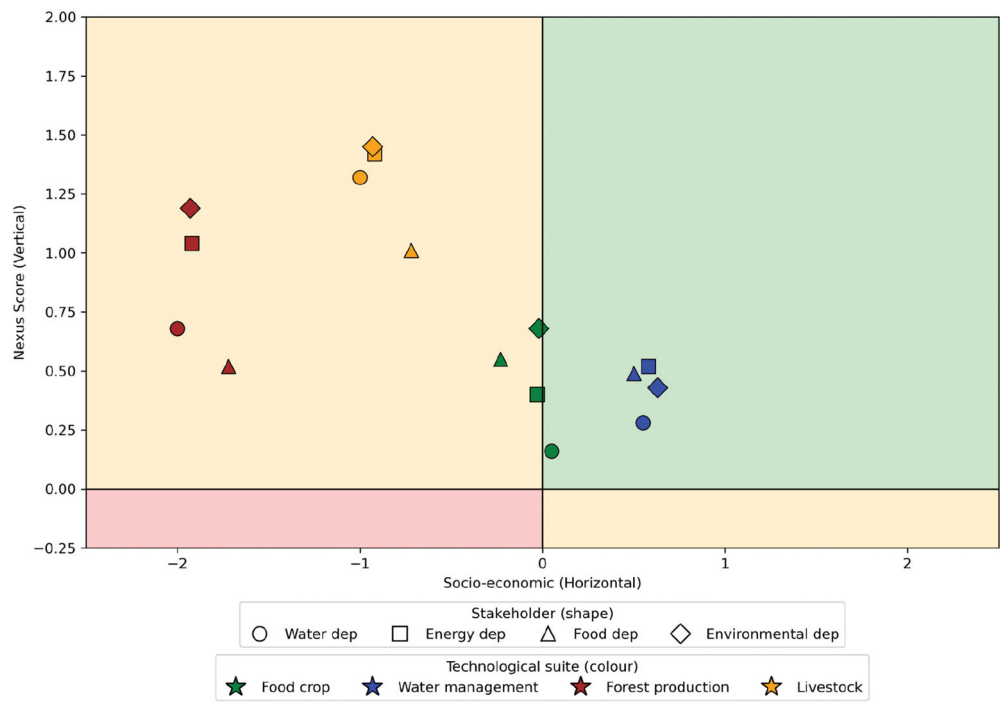


Figure 4. Trade-offs of the innovation option based on stakeholder preference across department and technical performance. Origin (0,0) represents the business-as-usual (BaU), i.e., cotton-wheat cultivation.

still improve the nexus score. Forestry-related innovations remain inefficient options in terms of both nexus and socio-economic significance, making them the least preferred compared to the others.

Discussion

The discussion is organized into three parts. First, we draw on existing literature to connect the results of this study, with possible rebound effects in resource management and their policy implications on the WEFE nexus in Central Asia. Second, we highlight the limitations of the research and, finally, we propose potential directions for future research.

Possible rebound effects and their policy implications

Our results reveal that the main sources of rebound effects are the divergence of priorities within departments. For example, Yigezu et al. (2024) reported that 55% of irrigation water loss in Uzbekistan occurs during conveyance. In view of this, the legitimate response of the department responsible for infrastructure development and maintenance in the Ministry of Water Resources may be to prioritize canal repair and reduction of conveyance loss. However, such a measure may increase the availability of water possibly causing: 1) farmers to practice excessive application at field level; 2) farmers and some departments to push for increasing the cropping intensity; and/or 3) some departments pushing for expansion of irrigated areas, thereby increasing the total amount of water used (possibly more-than offsetting that which was saved), thereby also increasing tillage and other farm operations. In this scenario, without a corresponding policy to either limit the area or intensity of cultivation and/or increased investment on research to generate technological innovations that increase energy efficiency, the increase in cropping intensity and/or expansion in irrigated area may lead to both higher fuel consumption and increased soil carbon emissions.

Zhang et al. (2020), drew on principal–agent and stakeholder theories, arguing that the rebound effect, exemplified by the irrigation efficiency paradox, is driven by conflicts of interest among stakeholders under asymmetric information and inadequate regulatory capacity. In a similar vein, Hamidov et al. (2022) emphasized that stakeholder priorities and governance should be central in explaining rebound effects. Li and Zhao (2018) went further by arguing that the institutional regime of water rights moderates whether rebound occurs. Taken together, these studies highlight that stakeholder priorities and institutional arrangements are pivotal, yet often overlooked, determinants of rebound effects. This gap can be addressed through interactive and participatory MCDM tools such as SWEET, where structured stakeholder engagement and transparent analysis foster mutual understanding and social learning (Verbist & Akramkhanov, 2025; Karjalainen et al., 2013). Reflecting on the presented results alongside the rebound literature makes clear that, given the diverse priorities within and across departments, rebound effects in WEFE resource management are likely to (re-)emerge in Uzbekistan calling for policy and institutional alignments for minimizing trade-offs, maximizing synergies and optimizing for a healthy WEFE nexus. This will require awareness raising and training on holistic policy formulation thereby transforming the policy formation process to be jointly carried out by all WEFE sectors (Hamidov et al., 2022). While cross-sectoral coordination remains

essential for effective WEFE nexus governance, our findings suggest that downscaling the WEFE approach within individual departments and to sub-national or local levels (Mayar et al., 2024) is equally necessary to mitigate potential rebound effects. At the same time, cross border effects of WEFE systems should be considered, as pressures in one sector or country can be transmitted to others through shared resources and trade (Qin et al., 2022). Similar patterns of intra-group heterogeneity have also been observed in other contexts – for example, Huang et al. (2025) identified significant diversity in stakeholder preferences within Swiss energy policy networks. Addressing such heterogeneity requires decision-making approaches that explicitly accommodate divergent priorities. Advanced multi-criteria decision-making (MCDM) techniques, including clustering-based subgroup identification (Altuzarra et al., 2010), Bayesian analytic hierarchical process (AHP) models that capture intra-group variation (Altuzarra et al., 2010), robust ordinal regression (Greco et al., 2008) and stochastic multicriteria acceptability analysis (SMAA; Lahdelma et al., 1998), offer promising, but more complex, avenues. These methods enable the inclusion of multiple viewpoints without oversimplifying or masking underlying conflicts. Yet more important than methodological refinement, managing heterogeneity – both within and across departments – requires deliberate efforts in social learning and consensus building. Evidence shows that stakeholders are more likely to sustain decisions when involved in the process (Thabrew et al., 2009). Consensus building and social learning are therefore recommended approaches that can benefit from MCDM tools such as SWEET (Li et al., 2020; Schwilch et al., 2009). Recent studies further highlight the potential for online learning with MCDM (Aubert et al., 2024) and the emerging role of large language models in facilitating participatory decision-making (Zhang et al., 2025).

Limitations

As noted in the methodology section, the sample size in absolute terms is limited, which warrants caution when interpreting the results. The findings should not be viewed as a definitive or comprehensive reflection of any particular sector or country's vision on WEFE management, but rather as a preliminary indication of sectoral perspectives. Besides the number of respondents, the sample could also be improved in terms of inclusivity. Governance in Uzbekistan is complex, involving multiple layers and functions – ranging from policy, administrative and implementation roles within ministries to various operational scales, including local, regional and national levels (Schmidt et al., 2024). This study could thus be improved by enhanced inclusivity.

When using point allocation, caution is required, as this method is prone to equalizing bias. This bias occurs when respondents avoid assigning very low or very high weights, instead distributing weights more evenly across criteria (Montibeller & Von Winterfeldt, 2015; Rezaei et al., 2021). In practice, this can lead to an underrepresentation of true differences where, for example, the importance of 'soil cover' may be significantly greater than that of 'number of machines'.

For the trade-off analysis, experts ranked four innovation options as alternatives to the business-as-usual scenarios. This simple and generic approach was used to illustrate the potency of the decision support tool for analysing WEFE nexus. In practice, however, the ranking – a form of normalization – would be expected to be more precise if it were to use rankings between 1 and 10 instead of 1 to 5 thereby providing more granular

values, and if it was drawn based on additional data including the actual quantities of ecosystem services lost and their monetary values due to inaction to change the status-quo (i.e., the cost of not introducing the new innovations) and the returns on investment if the country was to invest in introducing the proposed policy, institutional and technological changes. Moreover, the results can improve if complemented by more information gathered through stakeholder validation workshops, and other inputs. Likewise, spatial characteristics and local solutions should also be considered. For this purpose, the potency of SWEET can be enhanced if it were to be complemented by data generated through other DSTs that generate estimates of the quantities and monetary values of ecosystem services lost due to inaction – possibly a future direction of research to increase the value adding from SWEET (Martunen et al., 2022).

Future research

Future studies could explore the use of more advanced weighting methods – such as the best–worst method (BWM) – to reduce equalizing bias in responses. Moreover, increased participation – in both number and diversity with greater inclusivity pursued by: (a) engaging actors across different levels of government (local, regional, national) and (b) involving non-governmental stakeholders, such as civil society, academia and the private sector, could enhance the precision and credibility of the results.

In addition, the technical performance of the generic innovation options in this study was approximated using simple rankings on a scale from 1 to 5. While this was useful for illustrating how trade-off graphs can guide policy decision-making, more context-specific assessments could strengthen the analysis – for instance, by incorporating spatial variations such as rainfall or soil types. This would allow for more tailor-made results across governance layers. Nonetheless, ranking remains a practical and valuable approach in data-scarce environments.

Conclusions

This paper presents the application of SWEET with results of a KII survey conducted among departments representing the water, energy, agriculture and environment sectors contributing to the water, energy, food and ecosystems (WEFE) nexus in Uzbekistan. The analysis follows the structure of a previously developed decision support tool (DST; Verbist & Akramkhanov, 2025), which enables structured comparison and stakeholder-driven prioritization through multi-criteria decision-making (MCDM).

Two levels of analysis were conducted: within departments and across departments. The first analysis revealed a widespread distribution of priorities as expressed in the weights assigned by respondents from the same department. This suggests that WEFE integration efforts may benefit from initially focusing on internal alignment within departments, before attempting cross-departmental coordination – addressing a gap often overlooked in current WEFE frameworks.

The second analysis involved averaging the weights of individual respondents within each department and comparing them across sectors. This revealed an absence of a shared or coordinated prioritization of WEFE nexus across sectors. However, some collective priorities did emerge. ‘Soil cover’ consistently received the highest weighting, likely due

to the persistent sand and dust storms that affect Uzbekistan. Other cross-sectoral priorities included fuel consumption, and food crop production. These findings suggest that while a unified vision is lacking, there is convergence around a limited number of key WEFE criteria. Among the four sectors, the food sector received the highest average weighting, highlighting its perceived importance and potential as a starting point for integrated WEFE policymaking and an entry point for investment to optimize the WEFE nexus.

Trade-off graphs were constructed based on priorities (i.e., weights) and technical performance of innovation options to illustrate policy decision-making by comparing four generic innovation options (forest production, livestock and rangeland management, water management, and food crop production) as alternatives to the business-as-usual scenario (wheat–cotton cultivation). The analysis was also carried out both within and across departments. In both cases, stakeholders showed a preference for water management innovations, both from an integrated nexus perspective and from a socio-economic perspective. The results also revealed a clear trade-off between water management and livestock: livestock is preferred from a nexus perspective but less so from a socio-economic perspective, with food crop production positioned in between. Furthermore, forest production was found to be inefficient compared to livestock, with lower nexus preference and higher socio-economic costs. The findings underscore the potential and relevance of structured stakeholder engagement for informing WEFE nexus governance. Future research should aim at a more comprehensive application of this approach, expanding both its scale and depth. Our results highlight that, left unchecked, conflict of interest and mismatch of priorities among stakeholders could provide part of the explanation for the rebound effects that counter efforts to enhance the sustainability of agricultural resources. The implications of our results are that, concerted, well thought out, and jointly developed policy and institutional changes are needed to minimize trade-offs, maximize synergies, prevent rebound effects and enhance the WEFE nexus. In this effort, the SWEET tool may help in better aligning and unifying priorities and in identifying common goals and mechanisms to work together to achieving them.

Building on this study and earlier work (Verbist & Akramkhanov, 2025), future research can make a meaningful contribution to integrated WEFE nexus policymaking – more grounded in the priorities of a diverse set of stakeholders across multiple governance levels.

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Ethics statement

This study involved an anonymous survey of participants to collect preference weights. The study did not require formal ethics approval, as it involved minimal risk and collected no identifiable personal data.

Use of generative AI

Generative artificial intelligence (ChatGPT, OpenAI; GPT-5, August 2025 release) was employed exclusively for grammar and language refinement of this manuscript. All intellectual content, data interpretation and conclusions are the sole responsibility of the authors, who carefully reviewed and verified the final text to ensure accuracy and integrity.

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