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Research article

An integrated participatory framework for WEFE nexus strategic planning: The Jordan Valley case study

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ABSTRACT

The Jordan Valley (JV) is a critical region where the interplay of water, energy, food, and ecosystem (WEFE) dynamics presents both challenges and opportunities for sustainable development and climate change mitigation and adaptation. In such a transboundary river basin with acute nexus problems and a long history of conflicts, it is essential that conscious efforts are made to pluralize the debate and actively encourage stakeholders' empowerment, participation and fair collaboration in strategic planning. An integrated framework for participatory strategic planning in the WEFE nexus is proposed, which has been developed in the context of the JV case study. The nexus approach emphasizes decentralized, but coordinated decision making as the source of solutions, based on a clear understanding of the challenges faced. The engagement process consisted of living lab sessions where Causal Loop diagrams facilitated discussions with stakeholders by visualizing the complexity and interdependence of WEFE sectors and prioritizing the challenges faced. Community capacity assessment appraised the capacities of each community, identifying barriers to addressing their priorities. Finally, the gap analysis bridged the baseline understanding with actionable targets. The results not only highlight the pressing challenges, priorities, and leverage points for each territory but also outline pathways for fostering resilience and adaptation to the region's intertwined crises. The priorities and capacities across the three territories of the JV reveal significant disparities, reflecting the diverse socio-political, environmental, and economic contexts of the region. The methodologies and overall framework may be replicated in other regions with similar climate and challenges around the world.

1. Introduction

In a time of acute ecological, socio-economic and geopolitical crises, research is expected to take on a new role for actively pursuing sustainability and producing actionable knowledge to tackle real-world sustainability challenges (Ravetz, 2006). The complexity of real-world problems necessitates a research approach that recognizes the interdependence of systems and incorporates diversity of viewpoints and sources of knowledge – within and beyond academia. Such a research approach is becoming the cornerstone of sustainability science, as an emerging transdisciplinary research paradigm (Troullaki et al., 2021).

Among the most pressing contemporary challenges is ensuring the sustainability and security of supply of essential resources, such as

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water, food and energy. The systems related with the life cycle and governance of these resources are highly interconnected, which has led to the development of nexus concepts in research and policy, for analyzing interrelationships, strengthening synergies and minimizing trade-offs across these sectors (Karnib, 2016; Moreira et al., 2022; Baratella et al., 2023). Particularly, the Water-Energy-Food-Ecosystem (WEFE) nexus approach highlights the interdependence of water, energy and food security, as well as the ecosystems underpinning that security (European Commission: Joint Research Center et al., 2021; Vanino et al., 2024). Nexus approaches have thus become a popular framing for research that aims at addressing complex social-ecological challenges, that span across those sectors (Hoolohan et al., 2018), at local (Lilli et al., 2024; Maragkaki et al., 2024), regional or global scales.

The WEFE nexus has proved to be an adept and powerful concept for bridging the science-policy gap (Hejnowicz et al., 2022); as long as stakeholders are meaningfully engaged in the planning process. Participatory approaches are widely recognized in nexus research as the most effective way to identify trade-off solutions between divergent interests (Shahmohammadi et al., 2024; Vanino et al., 2024; Villamor, 2023). Including stakeholders helps ground outputs in reality, making results more relevant for policy makers (Lilli et al., 2020; Sušnik and Staddon, 2022; Masiero et al., 2024). Actually, "*non-academic organizations have been working across the water–energy–food nexus in practice, and for some time, without needing to name it as such. So, there is potentially much to be learnt through interaction with stakeholders operating in this space*" (Hoolohan et al., 2018, p. 1415). "*This approach is also important to guarantee that social and local aspects of sustainability are taken into consideration, while giving the participants opportunity for self-reflection*" (Moreira et al., 2022, p. 2316).

Recognizing the importance of stakeholder's experiences, as well as their role in governing these sectors, has led to increasing popularity of transdisciplinary approaches in nexus research (Harris and Lyon, 2014; Stirling, 2015), *"at least in theory"* (Hoolohan et al., 2018, p. 1416). By synthesizing approaches from different disciplines (interdisciplinarity) coupled with the active participation of stakeholders in the research process (transdisciplinarity), a deeper understanding of systems may be achieved.

Despite this acknowledged potential, the active engagement of stakeholders for the co-creation of knowledge within the nexus research agenda is still limited to date (Hoolohan et al., 2018; Sušnik and Staddon, 2022; Baratella et al., 2023). At the same time, mixed-method approaches from a variety of disciplines are needed to accommodate the complex, non-linear nature of nexus challenges (Hoolohan et al., 2018). For this, better harmonization of quantitative modelling with social science approaches is required (Hejnowicz et al., 2022; Sušnik and Staddon, 2022). While the integration of social science methods in nexus research is actually gaining ground (Sušnik and Staddon, 2022), there are still very few studies that have implemented such a mixed-methods research design combined with active stakeholder engagement in real-world nexus problems.

Consequently, there is both a lack of integrated frameworks for mixed-methods participatory planning in the WEFE nexus and a lack of relevant experience from their actual implementation in the field (Stylianopoulou et al., 2020). It has been argued that the need for common, replicable tools for nexus research is unlikely to be resolved as "*there is no overarching framework or approach that can adequately satisfy the different needs and requirements of every study*" (Sušnik and Staddon, 2022, p. 1192). However, we argue that when performing WEFE nexus research within specific geographical regions, e.g. the Mediterranean, a transferable, replicable methodology to apply in other areas within the region will be extremely useful. To this end, this work seeks to answer the following research question: "How can a transdisciplinary framework for participatory strategic planning effectively address WEFE nexus challenges, and what lessons can be drawn from its application in the Jordan Valley (JV) to inform replicability in regions facing similar challenges?"

This paper outlines an innovative methodological framework for implementing strategic planning in the WEFE nexus. The framework aspires to facilitate transdisciplinary research in the WEFE nexus by integrating mixed-methods from various disciplines with the active engagement of stakeholders throughout the research process. After presenting the framework at conceptual level, its implementation through specific methodologies in the case of the JV is presented in detail. Similar to other regions in the Mediterranean area, the JV is particularly vulnerable to the threat of climate change, exhibiting signs of desertification, water shortages, loss of fertile soil, and degradation of the ecological services provided. In addition, Jordan, the Palestinian Authority and Israel that share the JV area, are in midst of geopolitical conflict (Arab Center Washington, 2024; BBC News, 2024; The New York Times, 2023). It is the unique combination of climate-change and geopolitical threats that the JV is exhibiting, which led us to choose it as a test case for the framework.

The work has been conducted as part of the PRIMA[1] Programme funded research project EcoFuture (https://ecofuture-prima.eu), whose overall objective is to design a strategic plan that will provide security of supply for the major resources (water, energy, food and ecosystems) to the people of the JV, considering the social and economic priorities of the three involved territories (Jordan, Israel and Palestine). The first phase of the framework aims at identifying the challenges, capacities, conflicts, and gaps, and proposing changes with stakeholder engagement. The second phase – which is beyond the scope of this paper – aims at co-designing a strategic plan with key stakeholders, using multi-criteria assessment of WEFE alternatives, techno-economic analysis of policies, and foresight analysis.

2. Methodology

2.1. Case study description

The JV is a rift valley in the Middle East in southwestern Asia, located in modern-day Israel, Jordan and the West Bank, Palestine. It is a critical region where the interplay of water, energy, food, and ecosystem dynamics presents both challenges and opportunities for sustainable development and climate change mitigation and adaptation. The valley's unique geographical and climatic conditions have historically made it a focal point for agriculture, requiring efficient water management strategies to adapt to its arid climate.

The geographic scope of this work is confined to an area that extends the full length of the valley from Lake Tiberias in the north to the Dead Sea in the south (Fig. 1) and up to an elevation of 447 m (Kool, 2016). The Jordan Depression running from Wadi Araba to the Dead Sea is a very distinctive landscape; it is the lowest depression on earth (with the Dead Sea at 419 m below sea level) and includes the Jordan River, flowing through the JV, which is considered the food basket of the region (Al-Bilbisi, 2013).

The JV has a semi-arid hot climate: the average temperature is ranged between 15° and 22° from November to March and between 30° and 33° in summer; rainfall is very irregular: from 180 mm/year in the south, it can reach to 400 mm/year in the north of the valley (Suleiman, 2003).

Water scarcity in this region is acute, with recent rainfall records showing that the area is under imminent threat of desertification. For example, precipitation in the North Ghor station was reduced from 395 mm in 1982 to 351 mm in 2021 (11% reduction) and in Mid Ghor from 338 mm in 1982 to 224 mm in 2021 (34% reduction). At the same time, the average temperature has increased by 1.9 °C in both stations during the same period. Water sources, such as the Jordan River and Yarmouk

[1] The Partnership for Research & Innovation in the Mediterranean Area (PRIMA) is an EU program for Research and Innovation solutions in the Mediterranean region. https://prima-med.org.

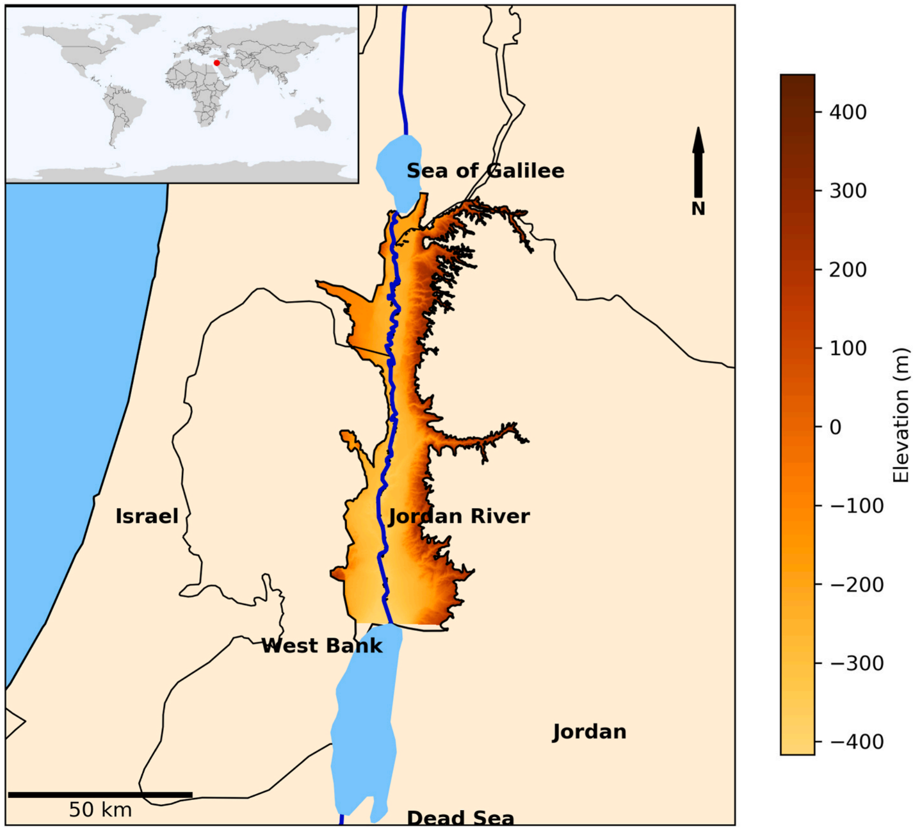

Fig. 1. Topographic map of the study area: The Jordan Valley.

River and underground aquifers, are under increasing pressure from over-extraction and pollution, directly impacting agricultural productivity and food security (Al-Bakri et al., 2013; UN-ESCWA and BGR, 2013).

Energy is another critical component, heavily intertwined with water through the energy-intensive processes of water pumping, treatment, and distribution, as well as in agricultural operations and food processing (FAO, 2014). The food sector in the JV is highly dependent on the sustainable management of water and energy resources, with agriculture accounting for a significant portion of employment and food supply in the three territories, yet facing the challenges of limited water availability and the need for energy-efficient technologies (World Bank, 2017).

The ecosystem of the JV, characterized by rich biodiversity and unique habitats, plays a crucial role in supporting agricultural activities, providing ecosystem services such as pollination, pest control, and soil fertility. However, these ecosystems are under threat from overuse of natural resources, habitat destruction, and climate change impacts, necessitating integrated approaches to management (Molle et al., 2009; GWP and INBO, 2012). The WEFE nexus emerges as a vital framework in this context, emphasizing the interconnectedness of these sectors and the need for a holistic management approach to achieve sustainable well-being for the people and the ecosystems of the valley.

2.2. An integrated framework for participatory strategic planning in the WEFE nexus

The proposed framework, illustrated in Fig. 2, is designed to be both general and replicable, allowing for methodological customization to address the unique characteristics of the case under study. It comprises of two phases: Phase A, involves stakeholder input, and Phase B, entails the co-design of a strategic plan for climate change adaptation and mitigation, with active stakeholder participation. This paper focuses on Phase A, already implemented in the JV, where the methodology aimed to provide stakeholders in each territory with reliable baseline information to facilitate informed discussions on the challenges they face. A central element of Phase A was the participation of stakeholders from the three territories through a series of living labs conducted at both national and transnational levels, fostering a conducive environment for collaboration and problem-solving. The rationale and suitability of each component within Phase A of the framework are detailed below.

- Initially, a **mapping of the WEFE nexus baseline status** is implemented in order to describe the current conditions regarding WEFE resources, socio-ecological dynamics and governance structures in the studied region. In the JV case study, this baseline mapping was performed through the collection of data from official documents (scientific literature, governmental documents) and mathematical modelling, as follows:
  - o WEFE nexus data collection: Through this preparatory step, the data that informs the core methodologies of the framework are gathered. For the JV case study, government reports and datasets from Ministries (such as the Ministry of Water and Irrigation, Ministry of Agriculture, and Ministry of Energy and Mineral Resources), international agencies (such as the Food and Agriculture Organization of the United Nations and the World Bank), and local NGOs in Jordan, Palestine and Israel were utilized.
  - o WEFE mathematical models: The mapping is complemented with an analysis of the WEFE resources of the studied area with mathematical models. In phase A of the framework implemented in the JV case study, three quantitative modelling studies have been conducted to assess the hydrologic balance, the water distribution and the energy supply and demand in the three territories. These studies are the precursors of the follow up studies to be conducted in the second phase of the project. Their results will provide the information for the co-design of WEFE alternatives that will be

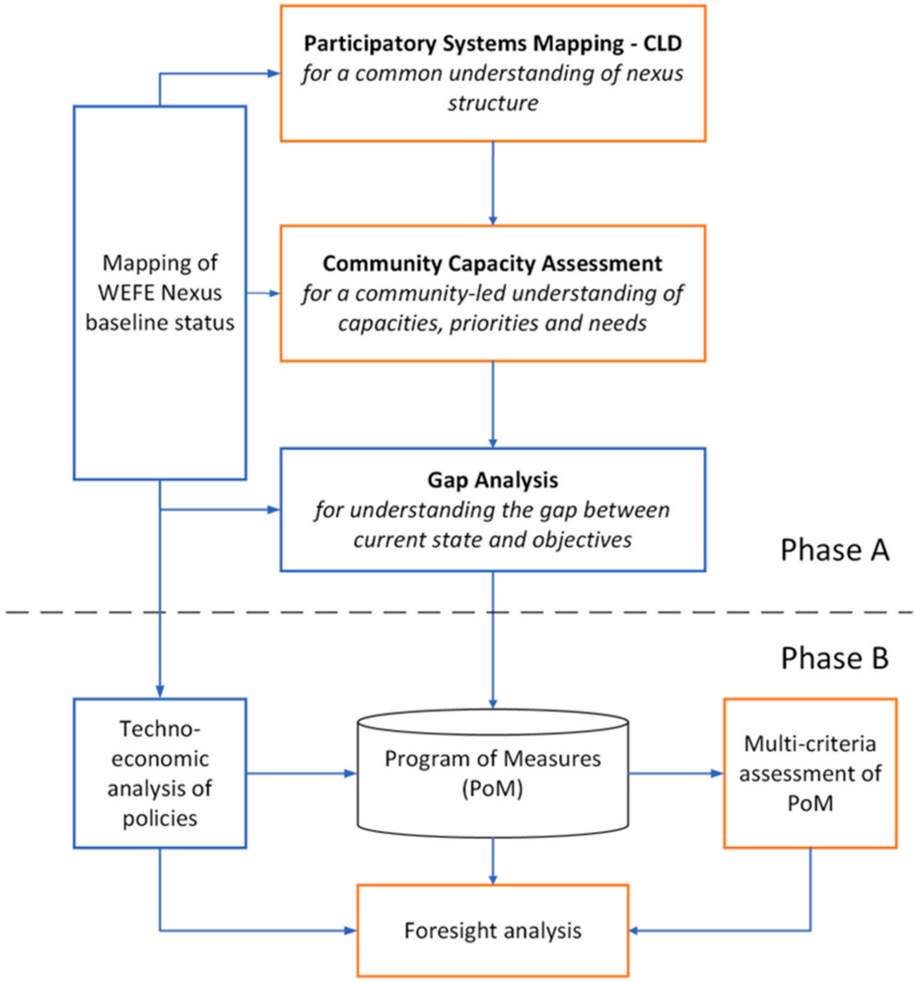

Fig. 2. An integrated framework for participatory strategic planning in the WEFE nexus. This paper focuses on Phase A of the strategic planning process. The methodologies that were conducted with stakeholder participation in living labs are signified with an orange borderline. CLD: Causal Loop Diagrams.

included in the strategic plan. Specifically, to evaluate the available water resources in the JV the hydrologic model Karst-SWAT was used (Nikolaidis et al., 2013); the Multi-Year Water Allocation System (MYWAS) model (Fisher and Huber-Lee, 2011; Reznik et al., 2016, 2017) was used for the water allocation analysis; and to assess the potential for renewable energy, the System Advisor Model of the National Renewable Energy Laboratories was employed. More information about the three modelling studies is available as Supplementary Material (S.1).

Following the mapping of the WEFE Nexus baseline conditions, the core methodologies of the framework are implemented.

- **Participatory systems mapping (PSM)** is an essential component in transdisciplinary research and increasingly used for strategic planning (Shahmohammadi et al., 2024; Villamor, 2023). By engaging stakeholders and synthesizing their understanding of a system in a unified diagram, it enables a shift from sectoral perspectives to a holistic understanding of system interconnections (Hoolohan et al., 2018). Such a systemic viewpoint helps building a shared understanding of the challenges, dynamics and leverage points for system change in a studied area, ultimately facilitating the design of policies and actions towards sustainability (Giordano et al., 2025). Among the available PSM methods, Causal Loop Diagrams (CLDs) were applied in this study. CLDs serve as an intuitive precursor to System Dynamics models, facilitating the initial stages of the modeling process before transitioning to stock-and-flow diagrams and differential equations (Barbrook and Penn, 2022). The System Dynamics approach aims to address the inherent complexities of systems and sectors, enabling the development of effective, "high-leverage" policies (Sterman, 2002). Among the various stakeholder participation methodologies, CLDs are widely recognized as a visual diagramming tool grounded in systems thinking (Aikenhead et al., 2015). Recently, CLDs have been increasingly employed in WEFE nexus studies to elucidate critical interlinkages within complex systems (Purwanto et al., 2019; Zhang et al., 2021). In the JV case study, the CLD was constructed through a series of living labs in Jordan, Palestine and Israel.
- **Community capacity assessment** (CCA) is a community engagement and empowerment approach that seeks to support community development and the strategic planning process. The concept of 'community capacities' has become a core concept in community-based programs in recent years (Gamo and Park, 2022; Lee, 2021). Community capacities can be broadly defined as the resources a community has that potentially can be used for community development and transformation towards sustainability. CCA may be considered as a family of approaches used to evaluate community capacities, and different definitions and categorization of capacities may be adopted (Birgel et al., 2023). In the context of WEFE strategic planning, CCA may be used to explore whether the community has the skills and assets to tackle the challenges it faces, as well as to identify the kind of support the community needs to further develop its capacities and achieve certain goals. In the JV case study, community capacities were assessed in a transnational living lab setting.

- **Gap analysis** (GA) is a process that involves the comparison of actual performance with potential or desired performance. It has recently been introduced in water studies by the Water Framework Directive for the development of a programme of measures to improve water ecosystems (Pellegrini et al., 2023; WATECO, 2003). The selection of the package of measures to be evaluated, in fact, is based on the distance between the baseline scenario and the objectives. This distance is measured through the selection of relevant indicators that correspond to the identified WEFE goals. These indicators, which are used for describing the current and target state of the WEFE nexus and measure the gap, may also be used later in the strategic planning process for assessing the WEFE alternatives. In fact, "*the identification of relevant indicators and target values to be used for assessing trade-offs and synergies are among the current issues with regards to the use of the nexus approach in the sustainability context*" (Estoque, 2023, p. 10). For all the above reasons, while GA has not yet been applied in WEFE nexus literature, we consider it an essential step for linking all the previous methodologies with the preparation of the WEFE alternatives to be evaluated. In the JV case study, gaps were assessed for a series of key performance indicators (KPIs) that were selected and rated by a group of experts for each region.

Implementing Phase A of the framework, as described above, sets the basis for the long-term engagement of key stakeholders in the strategic planning process. The three main methods used (PSM, CCA and GA) help build a shared understanding of the WEFE Nexus challenges, capacities and gaps in the studied region, functioning as a preparatory step for the selection of specific WEFE solutions to address these issues.

3. Results

A detailed description of the results obtained from each component of the methodology follows, by presenting first the results of the mapping of WEFE nexus baseline conditions, then those of the CLD and CCA living labs, and finally the outcomes of the GA.

3.1. Mapping of WEFE nexus baseline conditions

3.1.1. Mapping of governance structures

The existing governance structures in Jordan, Israel and Palestine were identified in order to gain a better understanding of the challenges facing the effective management of WEFE resources. In total in the three territories, there are 33 key types of stakeholders/institutions (Ministries, NGOs, governmental authorities, companies, international organizations, cooperatives, agencies, academic and research institutions, local communities etc.) that are involved in the water sector, 29 in the Energy sector, 22 in the Food sector and 11 in the Ecosystem sector. To manage the WEFE nexus, 95 key types of stakeholders have to be involved in the JV. The multitude and variety of the entities that are involved in the management of each sector, and the division of responsibilities are not clear, make the governance of WEFE in the JV an extremely complicated procedure. While the three territories share the same environment, the current governance structures and their supporting regulations are not aligned. An optimal socio-economic WEFE-resources management can be achieved only if the future policies are agreed between Jordan, Israel and Palestine.

3.1.2. Socio-ecological mapping

The socio-ecological mapping revealed distinct discrepancies between the three territories in terms of population growth, economic status and unemployment as well as access to resources and opportunities for development. Despite the very different socio-economic and political circumstances between Palestinians, Israelis and Jordanians, they all face common challenges such as land degradation, water scarcity and quality decline which have been extenuated by climate change. The resulting decrease in precipitation, increased urbanization/population, as well as competition between agricultural lands and natural landscapes are causes of environmental degradation and stress on water, energy and biodiversity resources.

Overall, the land use distribution in the JV comprises of 61.5% of natural/uncultivated land, 32.9% agricultural land and aquaculture and the remaining to be urban areas, wadis and reservoirs.[2] Pollution sources in the JV include untreated wastewater, solid waste disposal, impacts from agriculture and aquaculture as well as land mines remnants of historical conflicts. Pollution sources and geogenic origin salinity have deteriorated the water quality of Jordan River and over-exploitation has decreased dramatically its flow (Kool, 2016; Royal HaskoningDHV & MASAR Center Jordan, 2015). The surface water network of the JV is in urgent need for ecological restoration.

The socio-ecological landscape on one hand presents significant challenges, and on the other, ecological actions that would address preservation of biodiversity, sustainable water management, rehabilitation of degraded landscapes, sustainable agriculture, development of renewable energy and ecotourism and nature-based recreation, would guide the region towards socio-ecological sustainability.

3.1.3. Mapping of WEFE resources

Based on the WEFE nexus mapping conducted for the JV, the following issues have been identified as of the highest priority to address:

- **Water deficit** – The agricultural water uses accounts for 91% of the total water supply where 16% is used for aquaculture and 75% for irrigation. The irrigation rates range from 385 mm/dunum[3] for Israel to 622 mm/dunum for Jordan and 566 mm/dunum for Palestine. The differences in irrigation rates are due to water losses/leakages in the network that is estimated to be about 30% for Jordan and 40–50% for Palestine. If we account for water losses in the distribution network in Jordan and Palestine, only half of this water is reaching the consumers. Reuse of treated wastewater is also very low in Palestine. On the other hand, the demand for both drinking and agricultural water use is quite significant in Jordan and especially in Palestine (where only a small fraction of the agricultural land is irrigated) creating a significant deficit between supply and demand.
- **Water quality** – The available water supply in the JV has been impacted by high water salinity levels of geogenic origin. In addition, the main sources of anthropogenic pollution in the JV are wastewater from treatment plants and unsewered areas, fertilizer, pesticide and herbicide pollution from agriculture, urban solid waste disposal sites, aquaculture water use, and small "industrial" facilities mostly related to agriculture have impacted the water quality of Jordan River and create an additional stress on the ecosystem (Kool, 2016; Al-Mashagbah, 2015).
- **Energy mapping** – Energy supply appears to meet current demand; however, energy demand increases are expected to be high, necessitating in this way the development of an integrated strategy for the JV that should be based on renewable energy. Renewable energy supply from the JV has a huge potential, far higher than the expected demand, even in year 2050.
- **Soil degradation** – The agricultural land has been degraded due to continuous cultivation for millennia which has as a result extremely low soil organic carbon. The impact of this situation is depicted in the estimated production yields for the JV. This is a common problem for the three territories of the JV necessitating measures for soil restoration using agro-ecological practices and active carbon additions to

[2] Data obtained from the Food and Agriculture Organization's Global Land Cover SHARE: https://www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1036355/.

[3] 1 dunum equals 1000 square metres.

soils that will improve soil quality, fertility and health (Maragkaki et al., 2024).

- **Ecosystem degradation** – The environmental pressures exerted in the JV are the result of intensive agricultural activities (agriculture, livestock and aquaculture), tourism, climate change, geogenic pollution, population and migration and invasive species. These pressures have resulted in significant impacts to the WEFE Nexus with surface water flow decline, groundwater depletion, high groundwater salinity, pollution and loss of biodiversity. To ensure the long-term sustainability of the region's ecosystems, integrated and sustainable management approaches are essential to mitigate these impacts (Kool, 2016; Royal HaskoningDHVMASAR Center Jordan, 2015; UN-ESCWA and BGR, 2013).

Hydrologic modeling was used to determine the annual average flow of the Jordan River before it enters the Dead Sea and establish an average hydrologic budget for the JV. The hydrologic system of the JV is heavily modified with many reservoirs, canals and pumping stations that divert water for irrigation and drinking water supply. The available water resources in the JV are extremely limited, heavily utilized and are expected to decline due to climate change with significant impact on the ecosystem and the biodiversity as well as the available water supply to cover the demand for drinking water and agriculture (Supplementary material, S1.1). In addition, water allocation modeling was applied to simulate various scenarios and assess their implications on the water and agricultural economies of the JV, while accounting for the distribution of water scarcity across regions and time (Supplementary material. S1.2). Finally, energy modeling highlighted the fact that the three territories can provide satisfactory energy supply and demand services by mainly non-renewable sources as well as the critical need for coordinated efforts to upgrade infrastructure, integrate renewable energy sources, and address data gaps to ensure a sustainable and secure energy future for the JV (Supplementary material. S1.3).

3.2. Shaping a common understanding of the nexus structure with CLDs

The CLD analysis (Fig. 3) has been used as a first step of stakeholder engagement within the project and for the identification of challenges and their priorities in the JV.

Specifically, the methodology of the CLD was used to illustrate and discuss with the stakeholders the complexity and the interdependence of the WEFE sectors and the interlinking of the main challenges. The stakeholder meetings were conducted in the three territories as part of the National Living Labs. The composition of the Jordanian living lab was as follows: 10 people in total attended. 3 were farmers and civil society members, 4 policy makers and 3 scientists and experts. The composition of the Israeli workshop was the following: 8 people attended in total. 1 was policy maker, 2 from academia/experts, 3 from civil society, 1 farmer and 1 from private sector. The composition of the Palestinian workshop was the following: 11 people attended in total. 6 were policy makers, 3 from academia/experts, 1 from civil society and 1 farmer.

A three-pronged approach was used to develop and analyze the CLD for the JV. The process was to first create a draft CLD for the JV based on literature review and expert knowledge, and then validate it in collaboration with the EcoFuture partners. The partners were asked to confirm

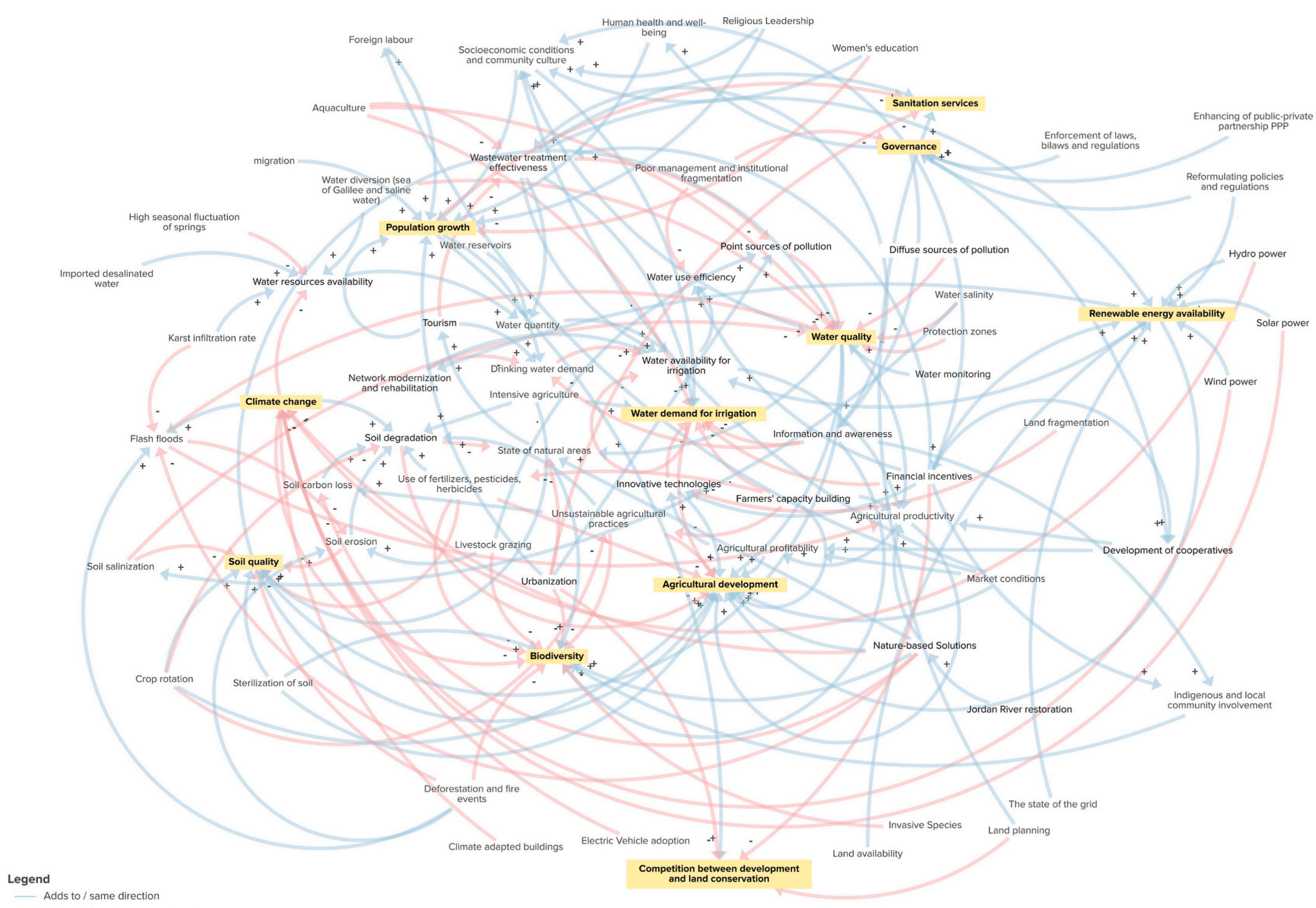

Fig. 3. CLD created for the JV, illustrating the conceptualization and mapping of challenges and their interconnections within the WEFE nexus.

the draft nexus challenges, add missing challenges and rank the challenges in each area (Stage I). Once their feedback was received, the revised CLD can accommodate all the changes and weights can be applied so the statistics reflect the priorities of the challenges ranked by the partners. The next step was to validate the CLD with key stakeholders involved in the National living labs and revise it according to stakeholder feedback if necessary and rank the challenges. Once this process was completed in the three territories, a unified CLD for the JV was created (Stage II). The third stage (Stage III) was to analyze the unified CLD and compare and contrast the prioritization of the challenges in each of the three territories. The final step was to present the unified CLD to the WEFE prioritization workshop. This methodology allowed to identify the priorities regarding the Nexus challenges of the three territories and conflicting actions within and between territories as well as achieving a common understanding of the challenges, problems and impacts to the WEFE Nexus for the JV.

Through this analysis, the challenges that face JV were identified and prioritized. Ensure water demand for irrigation, water quality, agricultural development, renewable energy availability, biodiversity loss, climate change (adaptation or mitigation), population growth, was the initial list of identified challenges in the area according to the scientific experts. The Jordanian partners added two more challenges in the initial list of challenges: soil quality and governance, while Israeli partners added competition between development and land conservation and sanitation services (wastewater & solid waste). The ranking of the challenges of the Jordanian stakeholders was the same as identified by the EcoFuture Jordanian partners indicating the importance of close collaboration with the JV stakeholders in understanding their needs and priorities.

There are similarities and differences in priorities for the three territories according to the Israeli, Jordanian, Palestinian stakeholders (Table 1). The top four challenges according to the Jordanian and Palestinian stakeholders are mainly related to agriculture: water quality, water demand for irrigation, and agricultural development. Soil quality is included in the list of the top challenges from Jordanian perspective, while renewable energy availability is included in the list from Palestinian perspective. On the other hand, for Israeli stakeholders, climate change, competition between development and land conservation, biodiversity and renewable energy availability are of high priority. The next (lesser) priorities for Jordanian and Palestinian stakeholders are biodiversity and climate change. Jordanian stakeholders included among the list of challenges of lesser priorities the renewable energy availability and governance. For Israeli stakeholders, population growth, sanitation services, agricultural development and water quality constitute the next (lesser) priorities. The last priority for Jordanian and Palestinian stakeholders is population growth while for Israeli stakeholders is water demand for irrigation (Table 1). From the results of the prioritization of challenges, it is concluded that the priorities for Palestinian and Jordanian stakeholders are similar while Israeli stakeholders have other priorities.

3.3. Appraising community priorities and capacities with CCA

Based on the mapping of the WEFE resources, the CLD developed for the JV, and the hydrologic, water allocation and energy analysis of the region, two living labs were conducted with the stakeholders to identify the priorities for each country and for the JV as a whole. The initial idea was to conduct a transnational living lab between the three territories. However, the geopolitical conflict in the region affected all partners of the project and particularly the implementation of the transnational living labs. Given the situation, instead of one transnational living lab with all stakeholders, two living labs have been conducted, one Jordanian and Palestinian Joint workshop and one Israeli workshop. This decision was strengthened by the fact that according to CLD analysis, the Jordanian and Palestinian stakeholders had set similar highest priorities, while Israeli stakeholders set different priorities. In the workshops, a CCA methodology was followed (Ahmad, 2004; Bouabid, 2004), where the capacity of each community to address its highest priority challenges was assessed and the main barriers that need to be overcome to address them were identified. In particular, the following four challenges were assessed in the Jordanian/Palestinian workshop: water quality, water demand for irrigation, soil quality and agricultural development. The challenge 'Renewable energy availability' was assessed as part of the energy capacity horizontally. Similarly, the Israeli workshop addressed the following four challenges: 'Climate change', 'Competition between development and land conservation', 'Biodiversity', 'Renewable energy availability'.

The composition of the Jordanian/Palestinian workshop was as follows: 27 people in total attended the workshop (17 Jordanians and 10 Palestinians). 12 were farmers, 2 policy makers and 13 scientists and experts. The composition of the Israeli workshop was the following: 14 people in total. 6 were farmers, 4 policy makers and 4 scientists and experts.

Through the CCA methodology, the institutional, human resources, technical, economic and financial, and energy capacity for each of the identified challenges were assessed. The status of each capacity was described by assessing a set of requirements with the help of specific questions (Supplementary Information -S1.2) developed for this purpose. The list of requirements may be edited and updated based on the collected data regarding the current situation. Table 2 presents the requirements used in this study to measure five capacity factors. By quantifying these capacities, the status of the community can be better described, leading to a better understanding of the type of intervention needed and the community capacities that will need to get more attention.

The assessment of various capacities among farmers in Jordan and Palestine highlighted several key findings and areas for improvement. In terms of human resources capacity, participants had diverse educational backgrounds, with limited agricultural specialization. Training primarily focused on basic aspects of water quality and irrigation, with a lack of comprehensive understanding in soil quality and cooperative functions. Improvement is needed in specialized training and awareness of agricultural cooperatives. Regarding technical capacity, there was a reactive approach to maintenance and limited use of advanced technologies. While basic irrigation technologies were accessible, the use of laboratory analyses for water quality was rare. Enhanced technical training and access to advanced tools are recommended.

In terms of institutional capacity, participants had limited knowledge of regulations and standards for water and soil management. Key institutions were recognized, but there was a lack of understanding regarding the legal framework governing agricultural cooperatives. Increasing awareness and knowledge of relevant laws and regulations is crucial. Financial constraints were a significant barrier to adopting new technologies and improving agricultural practices. Costs for water and energy were burdensome, with participants generally dissatisfied with financial returns. Financial support and cost-effective solutions are needed to alleviate these issues. Finally, regarding energy capacity, reliance on the national electrical grid was predominant, with minimal use of renewable energy sources. Energy costs impacted income, highlighting the need for affordable and sustainable energy options.

On the other hand, the key findings from the Israeli living lab workshop were as follows. The participants displayed a foundational understanding of climate change issues, particularly concerning water accessibility and extreme weather events. They highlighted the necessity of intergenerational information exchange for effective adaptation, yet revealed gaps in their preparedness and knowledge, especially regarding Nature-Based Solutions (NBS) and dual land use. While they possessed good technical knowledge of relevant technologies, financial constraints and hesitations about practical experience remain significant barriers. Additionally, the participants demonstrated a comprehensive awareness of the roles and regulations of key institutions involved in climate adaptation, despite lacking detailed insights into transboundary issues.

Table 1
Stakeholder prioritization of challenges facing in the JV.

	Jordan	Israel	Palestine
Highest priorities	1) Water quality 2) Water demand for irrigation 3) Soil quality 4) Agricultural development	1) Climate change 2) Competition between development and land conservation 3) Biodiversity 4) Renewable energy availability	1) Water demand for irrigation 2) Water quality 3) Agricultural development 4) Renewable energy availability
Lesser priorities	5) Biodiversity 6) Climate change 7) Renewable energy availability 8) Governance	5) Population growth and Sanitation services 6) Agricultural development 7) Water quality	5) Climate change 6) Biodiversity
Last priority	9) Population growth	8) Water demand for irrigation	7) Population growth

Table 2
Requirements used in this study to measure the five capacity factors.

Capacity factors	Requirements
Human capacity relates to the labor that is available to provide the services and its level of training.	- Educational level - The level of knowledge of their own system - Received training on the technology and involvement in operating the system - Ability to perform the required operation and maintenance - The understanding and acceptance of the use of treated greywater in irrigation
Technical capacity relates to the logistics necessary to address the components of technology that are needed for the implementation of solutions.	- Operations, maintenance, upgrading or adaptation, and supplies. - Understanding of the technology - Understanding the restrictions in treated water use - Ability to operate the system - Ability to maintain the system - Current status of the system
Institutional capacity defines the components of the institutional framework that needs to be in place to provide the services.	- Associated regulation - CSO support and follow-up - Existing structure - Water supply (quality and quantity)
Financial and economic capacity represents the financing of the services, the availability of loans, and the financial assets in the community.	- Income generating activities - Income/expenditure ratio -Expenditures priorities - Water and sanitation costs - Willingness to pay (system cost, O&M)
Energy capacity deals with the available energy, its availability, its costs, and reliability.	- Primary sources - Back-up sources - Percentage of budget - Rate of outage

Lastly, financial concerns, particularly the rising cost of water, emerged as a critical economic challenge for their businesses. Overall, these findings underscore the need for improved education, financial support, and institutional collaboration to enhance the community's capacity to adapt to climate change.

Overall, there is a noticeable disparity in the levels of various capacities among the participants from different jurisdictions. Jordanians and Palestinians face challenges due to a limited educational background, limited access to proper training and capacity-building activities, a limited understanding of regulations and standards and additionally, they lack access to new technologies. In contrast, Israelis benefit from a more established environment, where the primary challenge is financial rather than access to training and expertise. They also possess a deeper understanding of regulations and better community organization.

To address these challenges, it is crucial to design interventions that not only address the identified priorities but also consider these existing differences. A comprehensive approach should include targeted training programs, improved access to modern technologies, and enhanced understanding of regulatory frameworks (Supplementary Material S3). Financial assistance and the promotion of renewable energy sources are also essential. These measures will help develop a resilient and sustainable agricultural sector in the region.

3.4. Paving the way for the selection of WEFE alternatives with GA

The GA is the final step of the framework presented in this paper, which leads to the design of WEFE solutions and links the outcomes of the first phase with the second phase of the project. For implementing the GA, we focused on the challenges that had been highly prioritized by the stakeholders in the three territories during the living labs. These WEFE challenges have been expressed as goals, and subsequently a set of KPIs has been selected to monitor the current and target states regarding the achievement of these goals. The selection was performed by the EcoFuture consortium by reviewing both the Sustainable Development Goals (SDG) indicators and the indicators developed by the European Commission to assess NBS (European Commission: Directorate-General for Research and Innovation et al., 2021), while at the same time considering their appropriateness to the identified goals and their applicability in the case of the JV.

Subsequently, the current and target state of the indicators was identified based on the baseline mapping of the region ('mapping of WEFE nexus baseline status' phase of the methodology), and where necessary complemented with more inputs from the partners. For each of these indicators, the gap is represented by the difference between the target and the current state. The highly prioritized WEFE nexus goals, their indicators and the measured gaps are presented in Table 3.

The GA provides a detailed and quantitative overview of the WEFE challenges faced in the JV. It presents in a systematic manner the gaps in the 'WEFE performance' of the three territories, facilitating comparative assessment between the territories and among different goals. For Jordan and Palestine, the highest priority goals are those related to water, i. e. to 'Meet water demand for irrigation' and to 'Ensure water quality'. The next priority for both Jordan and Palestine is to 'Ensure agricultural development'. 'Ensure soil quality' is also included in the list of the top goals from the Jordanian perspective, while 'Ensure renewable energy availability' is included in the list from the Palestinian perspective.

On the contrary, for Israel, the water-related issues have been given lower priority, therefore they are not systematically presented in the GA. This does not mean that the gap for these goals would be smaller in Israel. In fact, Israel is in a better current state but has set more ambitious objectives regarding these goals. For example, Israel aims to raise the water supply for irrigation from 1200 MCM/year to 1950 MCM/year to meet the expected future demand. It also aims to raise its desalination capacity from 700 MCM to 1000 MCM, and the reuse of treated wastewater in agriculture from 484 MCM/year to 758 MCM/year. However, considering the adequate current state of these indicators, other more pressing issues have been given higher priority by the Israeli stakeholders. Specifically, 'Climate change adaptation and mitigation', 'Development stresses mitigation', 'Biodiversity loss mitigation' and 'Renewable energy availability' are those given the highest priority and, thus, included in the GA.

The results of the GA for the three territories are discussed below.

Table 3
Highly prioritized goals, their indicators and measured gaps in each country.

WEFE Nexus Goals	Indicators	Target state	Current state	Gap	Source
Jordan					
Ensure water quality	Proportion of wastewater safely treated (%)	95	89	6	Tawfik et al., 2023
	Effectiveness of wastewater treatment (BOD load reduction) (%)	95	80	15	NWMP-3 (2023)
	Proportion of saline groundwater desalinated (%)	45	10	35	Qteishat et al. (2024)
	Effectiveness of desalination (%)	90	82	8	Expert discussions
	Effectiveness of aquaculture water treatment (%)	50	0	50	NWMP-3 (2023)
Meet water demand for irrigation	Quantity of water supply (MCM/yr)	426	230	196	NWMP-3 (2023)
	Irrigation losses from infrastructure (%)	15	30	15	National Water Strategy, 2023
	Proportion of TWW that is reused for irrigation (%)	70	42	28	MWI (2023)
	Use of alternative water supplies from on farm water harvesting (%)	10	3	7	Experts discussions
	Use of desalinated water (%)	10	5	5	Experts discussions
	Degree of integrated water resources management implementation (%)	80	64	16	Status report (IWRM), 2021
Ensure soil quality	Proportion of degraded agricultural land (low carbon & salinization) (%)	40	70	30	Ammari et al. (2013)
	Proportion of farms with active carbon addition (%)	50	25	25	Expert discussions
	Proportion of farms using agroecological practices (%)	5	1	4	
	Productivity yield gap (%)	10	20	10	DoS, 2023
Ensure agricultural development	Average annual income of small-scale food producers (USD)	5000	2000	3000	Sergaki and Michailidis, 2020
	Total official flows to the agricultural sector (5-point Likert scale)	4-good	2-poor	2	Rabboh et al. (2023)
	Proportion of farmers participating in cooperative agricultural schemes (%)	30	10	20	ARDI, 2022
	Farmer capacity building actions (5-point Likert scale)	4-good	2-poor	2	Rabboh et al. (2023)
Palestine					
Ensure water quality	Proportion of wastewater safely treated (%)	90	43	47	Expert discussions
	Effectiveness of wastewater treatment (%)	90	70	20	Expert discussions
	Proportion of saline groundwater desalinated (%)	90	10	80	Expert discussions
	Effectiveness of desalination (%)	90	50	40	Expert discussions
	Effectiveness of aquaculture water treatment (%)	50	0	50	Expert discussions
Ensure water availability for irrigation	Quantity of water supply (MCM/yr)	182	52	130	Expert discussions
	Irrigation losses from infrastructure (%)	15	40	25	Expert discussions
	Proportion of TWW that is reused for irrigation (%)	30	2	28	Expert discussions
	Use of alternative water supplies from on farm water harvesting (%)	10	2	8	Expert discussions
	Use of desalinated water (%)	5	1	4	Expert discussions
	Degree of integrated water resources management implementation (%)	80	20	60	Expert discussions
Ensure agricultural development	Average annual income of small-scale food producers (USD)	8880	4440	4440	Expert discussions
	Total official flows to the agricultural sector (5-point Likert scale)	4-good	2-poor	2	Expert discussions
	Proportion of farmers participating in cooperative agricultural schemes (%)	50	10	40	Expert discussions
	Farmers capacity building actions (5-point Likert scale)	4-good	2-poor	2	Expert discussions
Ensure renewable energy availability	Renewable energy share in total final energy consumption (%)	33	2	31	Expert discussions
	Proportion of renewable energy over total energy used in agriculture (%)	20	0.2	19.8	Expert discussions
	Electrical grid modernization status (5-point Likert scale)	4-good	2-poor	2	Expert discussions
Israel					
Ensure renewable energy availability	Renewable energy share in total final energy consumption (achievable target - 2030 National Plan) (%).	30	7	23	National Plan, 2020
	Renewable energy share in total final energy consumption (ambitious target - energy experts) (%).	90	7	83	Expert discussions
	Proportion of renewable energy over total energy used in agriculture (achievable target - 2030 National Plan) (%)	30	10	20	Expert discussions
	Proportion of renewable energy over total energy used in agriculture (ambitious target – energy experts) (%)	90	10	80	Expert discussions
	Electrical grid modernization status (5-point Likert scale)	4-Good	4-Good	0	Expert discussions
Climate change adaptation and mitigation	Existing policy for climate change (5-point Likert scale)	4-Good	2-Poor	2	Expert discussions
	Local capacity building actions for climate change adaptation and mitigation (5-point Likert scale)	4-Good	4-Good	0	Expert discussions
	National capacity building actions for climate change adaptation and mitigation (5-point Likert scale)	4-Good	2-Poor	2	Expert discussions
	Actions for carbon removal/storage in vegetation or soil (5-point Likert scale)	4-Good	3-Acceptable	1	Expert discussions
Development stresses mitigation	*Local* regulations for land planning and land conservation (5-point Likert scale)	4-Good	3-Acceptable	1	Expert discussions
	National regulations for land planning and land conservation (5-point Likert scale)	4-Good	2-Poor	2	Expert discussions
	Proportion of natural and protected areas (%)	65.8	65.8	0	Grossbard and Renan (2024)
Biodiversity loss mitigation	Biodiversity conservation regulations and actions (5-point Likert scale)	4-Good	3-Acceptable	1	Expert discussions
	Protection of native species - INPA (5-point Likert scale)	4-Good	4-Good	2	Expert discussions
	National legislation for the control of invasive alien species – INPA (5-point Likert scale)	4-Good	2-Poor	2	Expert discussions

The gap for each goal for the three territories is comparatively presented.

Specifically,

- The **'water quality'** indicators assess the wastewater treatment, desalination and aquaculture water treatment performance in the territories. Jordan shows a relatively small gap in the proportion of treated wastewater but a considerable gap in wastewater treatment effectiveness, which needs to rise from 80% to 95% (15% gap) to meet the target. Desalination effectiveness presents a small gap, but the proportion of desalinated water needs to rise from 10% to 45% (35% gap). Finally, a wide gap (50%) is recorded for aquaculture water treatment effectiveness, as treatment of aquaculture water is currently not practiced in Jordan. The situation for Palestine is even more challenging, with wide gaps across all water quality indicators. The proportion of treated wastewater needs to rise from 43% to 90% (52% gap), and the treatment effectiveness from 70% to 90% (20% gap). The proportion of saline groundwater desalinated needs to rise from 10% to 90% (80%) and the desalination effectiveness from 50% to 90% (40% gap). Similarly to Jordan, a 50% gap exists in the effectiveness of aquaculture water treatment, as it is not yet practiced in Palestine.
- The '**water demand for irrigation**' indicators assess the quantity of water supply, the use of alternative water sources and their management. In Jordan, the water supply needs to rise by 196 MCM/year. The next indicators indicate how this rise could be implemented. The reuse of treated wastewater for irrigation needs to increase from 42 to 70% (28% gap), the use of desalinated water from 5% to 10% (5% gap) and the use of alternative water supplies from on-farm water harvesting from 3% to 10% (7% gap). Overall, the implementation of integrated water resources management shows a 30% gap. Also, a 30% of the irrigation water is currently lost due to infrastructural problems and there is a target to reduce this percentage to 15% (15% gap). In Palestine, the gaps for covering the future water demand are even wider. The quantity of water supply is currently at 52 MCM/year and the objective is to increase it to 182 MCM/year (130 MCM/year gap). The losses in the irrigation network need to be reduced from 40% to 15% (25% gap). The proportion of treated wastewater that is reused for irrigation need to rise from only 2%–30% (28% gap), the use of desalinated water from 1% to 5% (4% gap) and the use of alternative water supplies from on-farm water harvesting from 2% to 10% (8% gap). Overall, the degree of implementation of integrated water resources management is currently 20% and the target is to rise to 80% (60% gap).
- The indicators of the goal '**Ensure agricultural development**' (prioritized by Jordan and Palestine) assess mainly socio-economic gaps in the agricultural sector. In Jordan and Palestine, the average annual income of small-scale food producers exhibits a 3000 USD and 4440 USD gap respectively. Small-scale farmers are among the most vulnerable and face significant economic challenges. Studies indicate that smallholder farmers in Jordan and Palestine often earn much less than the national average income due to factors such as limited land ownership, water scarcity, and reliance on low-value crops (Sergaki and Michailidis, 2020). In Jordan, the proportion of farmers participating in cooperative agricultural schemes need to rise from 10% to 30% (20% gap), while Palestine has set a more ambitious target, necessitating an increase in the proportion from 10% to 50% (40% gap). Next, two qualitative indicators have been assessed with a 5-point Likert scale (from 1-Very poor to 3-Acceptable to 5-Very good). The total official flows to the agricultural sector are currently considered 'poor' both in Jordan and Palestine, while the desired target is 'good', exhibiting a gap of 2 points in the Likert scale. Also, the capacity building actions in the two territories are deemed as 'poor' and the target is to improve them to a 'good' state, indicating again a 2 points gap in the Likert scale.
- The goal to '**Ensure soil quality**' has been highly prioritized by the Jordanian stakeholders and the recorded gaps may explain this priority. Currently, 70% of the agricultural land is considered degraded due to low carbon and salinization, and the target is to reduce this proportion to 40% (30% gap). Farms applying active carbon addition are currently 25% of the total farms, with an aim to increase this proportion to 50% (25% gap); whereas farms currently using agro-ecological practices are only 1% of the total farms, with a more moderate aim to increase them to 5% (4% gap). Finally, the productivity yield (crop yield gap[4]) has been currently assessed at 20% with the aim to reduce this gap to 10%.
- Next, the goal to '**Ensure renewable energy availability**' is assessed for Palestine, concluding its GA, and is also assessed as the highest priority goal for Israel. The share of renewable energy in total final energy consumption is currently estimated at 2% in Palestine with an aim to increase this to 33% (31% gap). The proportion of renewable energy over the total energy used in agriculture is currently only 0.2% with an aim to increase it to 20% (19.8% gap). Finally, the status of the electrical grid modernization in Palestine is assessed as 'poor', with a target to improve it to a 'good' state, which is expressed as a 2 point gap in the Likert scale. For Israel, the Renewable energy share in total final energy consumption is currently 7%. The 2030 National Plan has set an achievable target to increase this share to 30%, which indicates a 23% gap. However, energy experts believe that the 2030 goal set by the government is too conservative and that a much higher goal could be achieved by utilizing solar and waste-to-energy technologies. According to this more ambitious approach, the renewable energy share could be increased to 90%, resulting in a much larger, 83% gap. This example clearly indicates how a larger gap (compared to the respective gap of Palestine) does not necessarily mean a worse current state but rather a more ambitious target. Regarding the proportion of renewable energy over the total energy used in agriculture, again two targets are presented for Israel: the 2030 government target is to increase this share from 10% to 30% (20% gap), whereas the more ambitious experts' target is to increase it to 90% (80% gap). According to the latter, agrivoltaics and reservoir coverage with solar panels offer opportunities to go far beyond the government's conservative 2030 goal in the agricultural sector. As for the electrical grid modernization status in Israel, it is considered to be 'good', necessitating only some infrastructural improvements to meet the 2030 (and beyond) demand.

The GA results that we discuss below concern the remaining goals that are highly-prioritized by Israel.

- '**Climate change adaptation and mitigation**' indicators assess the policies and interventions towards this goal. The existing policy for climate change is considered 'poor' in Israel, highlighting the need for passing a Climate Change Law. Capacity building actions for climate change adaptation and mitigation are considered good at a local scale but poor at a national scale, as there is currently no national masterplan for climate change capacity building. Finally, actions for carbon removal/storage in vegetation or soil are currently assessed as 'acceptable', considering the forestry activities of the KKL-Jewish National Fund, but need to be considerably improved, e.g. through the passage of a Climate Change Law, the establishment of an Israeli carbon trade market and the establishment of a carbon tax.
- '**Development stresses mitigation**' indicators assess issues of competition between development and land conservation. Urban

[4] The crop yield gap is estimated as the difference between average simulated yield potential (Yp, crop production without water stress) or water-limited yield potential (Yw, rainfed crop production with water stress) minus the average on-farm actual yield.

population in Israel has been recorded as 92% of the total population increasing with a 2% urbanization rate (2022 records). The current local urban population is 60,000 in the Valley of Springs and 11,000 in Beit She'an, and expected to rise to 70,000 and 20,000 respectively. Such urbanization trends are potentially jeopardizing land planning and conservation. The proportion of natural and protected areas is currently estimated at 65.8% with a target to maintain steady state in the coming years. While this is a no-gap result, it does not mean that no interventions are required to maintain the current state of the indicator, since the development stresses are expected to be increasing, potentially putting at risk national and protected areas. Finally, the existing regulations for land planning and conservation are considered 'adequate' at a local scale, with a target to improve them by implementing the existing plans, and 'poor' at a national scale, as there is no national master plan for land conservation.

- Finally, the indicators for **'Biodiversity loss mitigation'** assess the regulations and actions for the achievement of this goal in Israel. Current regulations and actions for biodiversity conservation are assessed as 'acceptable' with a target to improve them to 'good' by implementing the National Plan for Biodiversity. Current protection of native species by the Israel Nature and Parks Authority (INPA) is assessed as 'good', with a target to maintain the same state in the future (no gap), whereas the control of invasive alien species at a national scale is considered 'poor', requiring the implementation of the National Plan for Biodiversity.

4. Discussion

The priorities and capacities across the three territories of the JV reveal significant disparities, reflecting the diverse socio-political, environmental, and economic contexts of the region. While Jordanian and Palestinian stakeholders largely share common challenges and capacities, Israel's WEFE nexus conditions differ substantially. Israel's wide gaps in certain indicators often stem from its more ambitious targets, supported by higher capacities to achieve them. Conversely, the significant gaps observed in Jordan and especially Palestine are primarily driven by their current adverse conditions.

The living labs highlighted distinct drivers of pressures on the WEFE nexus in each territory. In Jordan, water scarcity is closely linked to migration-induced population growth and the non-enforcement of regulatory frameworks. In contrast, Israeli regulations, though generally enforced, often lack relevance to emerging challenges, particularly NBS. For instance, outdated regulations restrict the reuse of wastewater from fishponds in agriculture and arbitrarily limit the adoption of agrivoltaics. In the Palestinian JV, the predominant pressure arises from the requirement to obtain Israeli approval for accessing vital resources.

These disparities underline the importance of designing context-sensitive solutions in the next project phase. Interventions should address both shared and territory-specific challenges, considering the existing differences in capacities. Comprehensive strategies should incorporate targeted training programs, improved access to modern technologies, and a clear understanding of regulatory frameworks. The GA methodology provided a foundational step for assessing and prioritizing specific WEFE solutions. The outcomes of the GA will inform the Multi-Criteria Decision Analysis to be applied in Phase B. At this stage, a preliminary set of potential solutions has been formulated, based on the recorded gaps and key drivers identified during the CLD analysis. This initial program of measures, detailed in the Supplementary Materials (S3), will be refined through further stakeholder engagement and analysis to develop a robust strategic plan for the region.

Reflecting on the effectiveness of the framework to address WEFE nexus challenges in a transdisciplinary way, we aspire that each methodological step contributes to this direction. The CLD has facilitated discussions with stakeholders by visualizing the complexity and interdependence of WEFE sectors. The CCA has collectively appraised the capacities of each community, identifying barriers to addressing their priorities. Finally, the GA has bridged the baseline understanding with actionable targets, making it a distinctive and valuable element of the strategic planning process. Implementing the framework's core steps has synthesized a comprehensive understanding of the WEFE nexus, where all important interrelationships are considered. It has also provided a way to transform this complex understanding into an actionable strategic plan, with the participation of the key stakeholders.

The replicability potential of the framework lies in both its comprehensiveness and its flexibility. It is indicative that the challenges identified in the JV are almost identical to the ones identified in other regions (Giordano et al., 2025), making the results of relevant case studies valuable for future applications. The proposed methodologies are generic enough to be contextualised according to the specificities of each case study, and have already been applied separately in WEFE nexus research or other participatory strategic planning processes. It is the synthesis of the methodologies in a framework that considers systemic, strategic and participatory requirements that generates an added value and contribution to the WEFE nexus research and planning.

It is worth noting that the implementation took place under extreme geopolitical conflict. Nevertheless, its successful deployment should be largely attributed to the establishment of a strong, collaborative network of actors in the three territories. The Palestinian, Jordanian and Israeli partners of EcoFuture comprise a unique group of entities with proven record of collaboration between themselves, as well as with the regulators in all territories and relevant local stakeholders. In addition, the team of the Technical University of Crete, an outsider to the JV, has extensive engineering experience in solving earth science problems. This collaborative approach exemplifies socio-ecological innovation and has been critical for maintaining project continuity under challenging conditions.

Therefore, to successfully replicate the framework in other contexts, besides adopting the proposed methodologies, a careful selection of partners and the establishment of strong collaborative networks will be essential. The process must also prioritize adaptive strategies and innovative risk management to account for geopolitical, cultural, and socio-economic dynamics. The lessons learnt from the JV case study have, thus, highlighted the significance of the process, being consciously transdisciplinary, as well as the synthesis of methodologies, for an effective participatory strategic planning in the WEFE nexus.

5. Conclusions

This study presented and implemented an integrated framework for participatory strategic planning in the WEFE nexus, using the JV as a case study. The framework emphasizes decentralized yet coordinated decision making, grounded in a detailed understanding of the challenges faced by stakeholders in each territory of the JV.

Implementing Phase A of the framework fostered relationships with key stakeholders, enabling a multi-level understanding of the region's complex challenges, community capacities, and gaps for achieving specific goals. Each methodological step contributed to identifying broad solution pathways, which will serve as the foundation for co-designing WEFE alternatives in the subsequent phase. The participatory elements of the framework facilitated knowledge co-creation, enriching the understanding of both stakeholders and researchers.

Despite the challenging geopolitical context, the consortium's commitment ensured the successful delivery of a comprehensive and inclusive analysis of the WEFE nexus. This work not only highlights the pressing challenges, priorities, and leverage points for each territory but also outlines pathways for fostering resilience and adaptation to the region's intertwined crises.

The lessons learned from this implementation underscore the importance of tailoring solutions to local contexts while leveraging participatory methodologies. The replicability potential of this framework lies in its flexibility, making it applicable to other regions with complex, transboundary WEFE challenges. However, successful replication will depend on assembling diverse and collaborative partnerships, aligning methodologies with local conditions, and fostering sustained stakeholder engagement.

Moving forward, the project will refine and expand the proposed solutions, integrating them into a strategic plan that will be co-created with key stakeholders through participatory processes. This plan aims to provide practical, high-leverage interventions to address the WEFE challenges in the JV, contributing to regional sustainability and resilience.

CRediT authorship contribution statement

Nikolaos P. Nikolaidis: Writing – original draft, Supervision, Project administration, Methodology, Formal analysis, Conceptualization. **Katerina Troullaki:** Writing – original draft, Visualization, Methodology, Formal analysis. **Maria A. Lilli:** Writing – original draft, Visualization, Methodology, Formal analysis. **Suleiman Halasah:** Writing – review & editing, Data curation. **David Lehrer:** Writing – review & editing, Data curation. **Stelios Rozakis:** Writing – review & editing, Data curation. **Shlomo Wald:** Writing – review & editing, Data curation. **Ashraf Al Ajrami:** Writing – review & editing, Data curation. **Shaddad Al-Attili:** Writing – review & editing, Data curation. **Shiri Zemah-Shamir:** Writing – review & editing, Data curation. **Anan Jayyousi:** Writing – review & editing, Data curation. **Iddo Kan:** Writing – review & editing, Data curation. **Ami Reznik:** Writing – review & editing, Data curation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Nikolaos P. Nikolaidis reports financial support was provided by European Union through the PRIMA programme. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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Data availability

Data will be made available on request.

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