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A Participatory Approach to Exploring Nexus Challenges: A Case Study on the Pinios River Basin, Greece

Dimitrios Malamataris [1], Anna Chatzi [1], Konstantinos Babakos [1], Vassilios Pisinaras [1], Evangelos Hatzigiannakis [1], Barbara A. Willaarts [2], Manuel Bea [2], Alessandro Pagano [3] and Andreas Panagopoulos [1,*]

[1] Soil and Water Resources Institute, Hellenic Agricultural Organization "DEMETER", 57400 Thessaloniki, Greece; d.malamataris@swri.gr (D.M.); a.chatzi@swri.gr (A.C.); k.babakos@swri.gr (K.B.); v.pisinaras@swri.gr (V.P.); e.hatzigiannakis@swri.gr (E.H.)
[2] ICATALIST S.L., Las Rozas de Madrid, 28232 Madrid, Spain; bwillaarts@icatalist.eu (B.A.W.); mbea@icatalist.eu (M.B.)
[3] Consiglio Nazionale delle Ricerche, Istituto di Ricerca Sulle Acque (IRSA-CNR), 70132 Bari, Italy; alessandro.pagano@ba.irsa.cnr.it
* Correspondence: a.panagopoulos@swri.gr; Tel.: +30-2310798790 (ext. 205)

Abstract: The conservation of natural resources is indispensable for supporting sustainable development. Water–Energy–Food–Ecosystem (WEFE) nexus management is widely acknowledged as the utmost priority of our time. Considering the specificities of the different nexus sectors, conflicting views of sustainability may arise from different stakeholders. This paper presents and analyses an effective stakeholders' participation strategy aiming at identifying WEFE challenges in the Pinios River Basin (PRB), the most agriculturally productive and natural resource-stressed basin of Greece. The presented methodology was developed in the context of a Learning and Action Alliance (LAA) scheme adopted by the H2020 REXUS project, intended to support resilient nexus system management with the engagement of stakeholders. The proposed comprehensive methodology comprises multiple phases, including "framing", "mapping", "involvement", "co-production", and "sharing" phases. The involvement phase is the most interactive one, including the organisation and outputs of efficient crowdsourcing theme sessions organised in the framework of the first REXUS PRB stakeholders' workshop. This paper illustrates and analyses stakeholders' perceptions regarding nexus status in the PRB and reveals the most critical challenges in the pilot basin, along with their interdependencies and correlations. The determination of nexus challenges insights by stakeholders could significantly contribute to redefining policies so that they align with sustainable development aims. This methodology is proposed to form the baseline strategy in stakeholders' engagement for future nexus management studies.

Keywords: WEFE nexus; Pinios River Basin; stakeholder engagement; sustainability; Thessaly; Mediterranean area; natural resource management; crowdsourcing; expert knowledge

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1. Introduction

1.1. Natural Resource Security and Nexus

Human activities have currently reached a threshold that could damage the Earth's systems [1]. Worldwide, the agricultural sector accounts for about 70% of freshwater abstractions, the energy sector accounts for about 60% of total greenhouse gas emissions [2], and land use changes have affected 32% of the globe's land area since 1960 [3–5]. The global population is projected to grow to 8.5 and 9.7 billion in 2030 and 2050, respectively, according to the latest projections [2]; thus, we are expected to need 55% more water, 80% more energy, and 60% more food by 2050 [6,7].

Resolving natural resource scarcity, particularly in arid and semi-arid regions, including the Mediterranean region, constitutes a critical challenge for supporting human lives

and improving well-being in the context of sustainable development [8–10]. These regions face common natural pressures, such as increasing temperature, decreasing precipitation, and spatiotemporal imbalances between natural resource supply and demand [11], apart from the management challenges related to stakeholders' involvement in the decision and policy making processes [12,13]. Primarily, water, energy, food/agriculture, and ecosystems/climate are the most precious and essential sectors for sustaining healthy ecosystem functioning to facilitate improved human well-being, stable economic development, and strengthened social cohesion [14–18]. Improved natural resource management constitutes a prerequisite for achieving sustainability in accordance with the Sustainable Development Goals [19]. In this direction, a coordinated and integrated management of resources across sectors, supporting the cost-effective, efficient, and sustainable resources use, is being increasingly promoted [20–22].

Integrated approaches emphasising effective governance [23,24] and the promotion of innovative solutions, such as Nature-based Solutions (NbS) [25], have recently emerged as crucial factors to guarantee natural resource security. The characteristics of governance have also shifted from a state-centric to a decentralised and more transparent approach characterised by the broad participation of stakeholders [26,27]. Increasing attention is being given to cross-sectoral stakeholder collaboration, since impacts of sectoral decisions and policies could easily affect other domains and may result in resource shortages and conflicts among users [28–31].

In 2011, the concept of the Water–Energy–Food (WEF) nexus was conceived and put forward for the first time; water is the core element of this nexus system [32]. In the same year, the Global Risks Report [4] recognised the complex relationships among WEF nexus sectors, characterising their risks as one of the three most important global risks. The WEF link relationship was then further explained by the Asian Development Bank [33] and the Food and Agriculture Organization of the United Nations [5]. Since then, nexus approaches have become widely recognised by academic communities [34–42]. The essence of the nexus is the interconnections between different sectors, and the nexus is inextricably connected to the concept of resource security. Achieving the UN's Sustainable Development Goals (SDGs), including those regarding food (SDG 2), water (SDG 6), and energy (SDG 7), will require substantial, if not transformative, efforts across many sectors and landscapes. Nexus thinking advocates for water, energy, and food systems to be viewed collectively and holistically in order to achieve water, energy, and food (WEF) security. The nexus concept has been also broadened to include other factors, such as ecosystems, land, climate, or emissions [39].

1.2. Stakeholders' Engagement in Nexus Studies

An effective natural resource management of complex nexus systems requires the participation of stakeholders [43–46]. Despite the challenges and potential conflicts related to stakeholder involvement, consultation among stakeholders is fundamental in order to guarantee that existing interlinkages regarding the management of natural resources are highlighted and in order for a line to be drawn between the use and protection of certain limited natural resources [47,48]. Stakeholder participation can be understood as a means through which authorities of different levels and sectors, including end users, local managers, policy and decision makers, academics, organised citizens, and every single user, try to contribute to improving the understanding and management of natural resources [13,49].

Successful stakeholder participation is centred around incorporating, amongst other things, a broad spectrum of heterogeneous backgrounds and knowledge levels of participants, as well as possibly conflicting interests regarding resource allocation to create a "common sense" consensus [50–52]. There is evidence that transparent and democratic stakeholder engagement may result in more well-founded decisions [53], potentially leading to less social resistance, easier implementation [54], and higher efficiency [55]. Stakeholder engagement forms and tools can vary, ranging from questionnaires to forums

and other means of participation [56]. However, whatever the form of engagement is, a participatory approach that involves both qualitative and quantitative methods is thought to be the most appropriate for addressing uncertainties and enhancing the understanding of nexus systems [39,57].

A number of studies involving engaging stakeholders in nexus systems analysis have been carried out. Howarth and Monasterolo investigated the interactions between water, energy, and food in the United Kingdom through the organisation of five themed workshops, recognising the added value of an interdisciplinary approach focused on facilitating a constructive dialogue and more efficient decision making [47,58]. Johnson and Karlberg proposed a participatory scenario building process involving stakeholders with different levels of knowledge and experience and priorities to address water, energy, and food nexus challenges in Ethiopia and Rwanda [59]. Hoolohan et al. collected insights from stakeholders through interviews, case studies, and workshops to examine the value of stakeholder engagement in terms of addressing water, energy, and food nexus challenges [60]. Brethaut et al. analysed results obtained from interviews and workshops to better understand water, food, and energy nexus conflicts in the WWF Conservation Mekong Flooded Forest Landscape in Cambodia, Asia [61]. Kropf et al. conducted semi-structured interviews and a workshop to elicit sectoral stakeholders' perceptions on water, ecosystems, food, and climate nexus sectors' relationships in the Seewinkel agricultural region, Austria [62]. Through stakeholder workshops, Karutz et al. integrated local stakeholder perspectives into a coherent framework for food, water, and energy analysis in Bhima basin, India [63]. Vinca et al. [64] adopted a co-production approach through a series of workshops to identify nexus challenges in the Indus Basin and stakeholders' perspectives on these challenges, and they used this information to co-develop a number of quantitative future scenarios. De Vito et al. [65] used System Dynamics tools to facilitate a dialogue among stakeholders, particularly focusing on water resource management for agriculture, trying to understand the impact of policies and decisions across multiple nexus sectors.

1.3. Literature Gaps and Objective Focus

One of the major obstacles to achieving WEFE nexus sustainability is involving multiple stakeholders with various interests into all of the resource planning and implementation processes [66]. Nonetheless, most of the publications in the literature on stakeholders' engagement in the context of nexus sustainability frameworks focus either on nexus challenges and identifying their interrelations or on the determination of measures. Focusing on the Pinios River Basin (PRB), a highly stressed basin in Greece, the current study investigates and presents an effective stakeholder engagement strategy that can be adapted for any other nexus system. For this study, the perceptions and interpretations of stakeholders in terms of the main PRB WEFE challenges and their interconnections were investigated. Particular attention was given to (i) the collaborative identification of the main challenges for the area in terms of the conservation of natural resources, (ii) and the identification and analysis of the main cross-sectoral interconnections and dependencies related to resource use (and security), (iii) and the collaborative identification of potential sustainability pathways for the study area.

The proposed stakeholder engagement strategy aims to bridge the gap between science and implementation, facilitating the active involvement of stakeholders on the whole roadmap towards achieving nexus sustainability, i.e., from the identification of nexus challenges related to the security of natural resources to the identification and selection of potential measures. To the authors' knowledge, the design and development of a holistic and integrated WEFE nexus system regarding the PRB and shifting from "Nexus Thinking to Nexus Doing" within the context of the climate crisis and based on different stakeholders' viewpoints has not been described in the literature previously.

The remainder of this article is structured as follows: Section 2 presents the WEFE characteristics of the Pinios River Basin and the strategy developed for effective stakeholder participation. Section 3 is divided into five sub-sections dedicated to illustrating and

analysing the stakeholder engagement strategy, including framing, mapping, involvement, co-production, and sharing phases. Emphasis is placed on the presentation of the first REXUS PRB stakeholder workshop organisation and the challenges identified in the study area and the interrelations between them.

2. Materials and Methods

2.1. Study Area

The Pinios River Basin (Figure 1) is situated in Thessaly, Central Greece, covering an area of ca 11,000 km^2. It is characterised by rugged terrain, predominantly along the northern and western–southwestern margins of the basin, with two main plains gently sloping to the southeast and a considerable topographic elevation range spanning from 0 to 2810 m a.s.l. The hydrologic basin is mainly drained by the Pinios River, which has a length of 213 km, constituting the third longest river in Greece. The Pinios River course starts at the northwestern part of the Thessaly plain, crosses a large part of Central Greece, and discharges into the Aegean Sea, forming a NATURA convention-protected delta area. The major tributaries of the Pinios River are the Malakasiotiko, Portaikos, Pamisos, Enippeas, Ion, Lithaios, Neochoritis, and Titarisios rivers, which all drain extensive and heterogenous areas. Agricultural areas predominate, comprising 50.90% of the total area in the PRB, followed by forest and seminatural areas (45.32%), artificial surfaces (2.80%), water bodies (0.82%), and wetlands (0.15%). In-depth information on PRB water balance and detailed analyses of the hydrodynamic mechanisms in the region can be provided and supported, respectively, by the Pinios Hydrologic Observatory (PHO), which was established in the PRB in 2015, belonging to the International Long-Term Ecological Research Network, which aims to promote sustainable ecosystems and natural resource management [67]. However, several studies have been elaborated utilising hydrologic and climatic monitoring data series of the past 5 decades maintained by several public bodies.

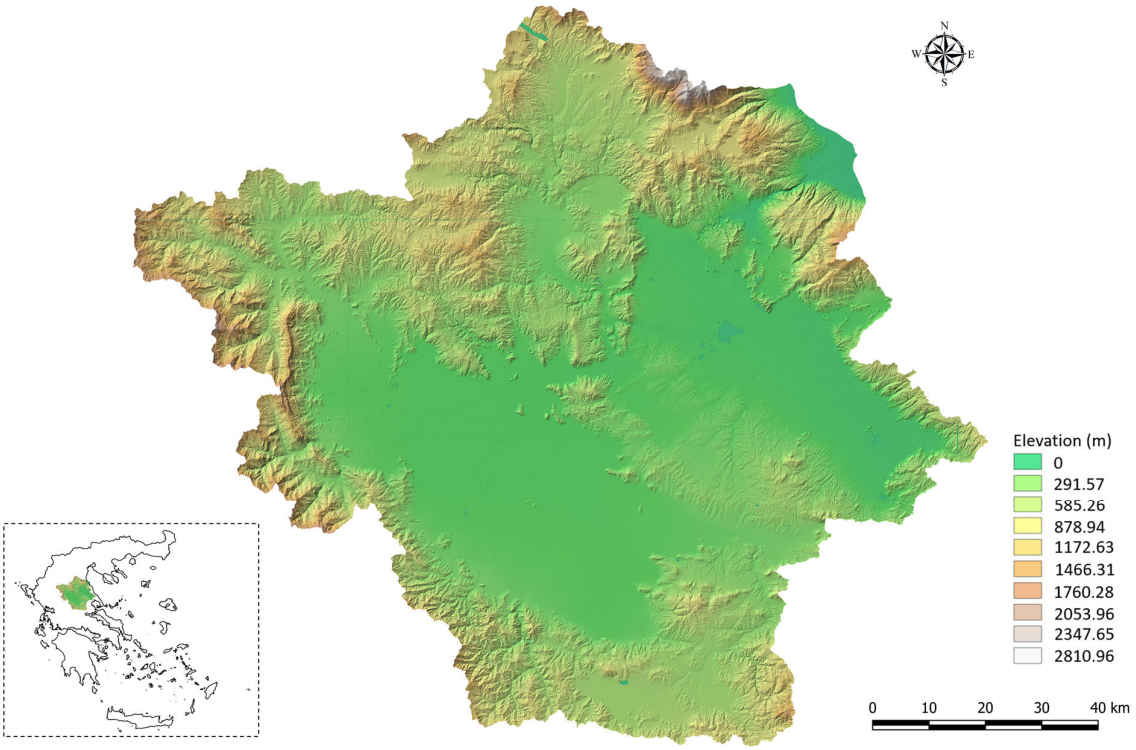


Figure 1. Pinios River Basin pilot area—DEM generated by the Hellenic Cadastre S.A at 5 m spatial resolution.

The PRB presents highly diversified climatic, geological, and hydrogeological conditions [68], supporting developed economic activities that, in turn, create several pressures,

thus shaping a regional nexus scheme that is rather complex to comprehend, analyse, and manage. Climatic conditions vary considerably eastwards, following the dominant topographic discretisation in the eastern central and western parts. In particular, at the western and central parts, the continental climate type is dominant, while at the eastern part of the basin, the typical Mediterranean climate type is apparent. According to Pisinaras et al. [68], long-term average precipitation between 1971 and 2000 was 770 mm/year, ranging between 500 mm/year in the eastern Thessaly plain around the city of Larissa and 1800 mm/year in the western boundary of the basin. Most of the PRB's area is covered by permeable geological formations (44%), followed by impermeable formations (40%), and karstified marbles (16%). The aquifer systems of the plains are rich in the thick alluvial deposits that fill the eastern and western basins and are characterised by high groundwater potential that largely covers the regional water demands. The karstic marbles mostly crop out at the margins of the plains and give rise to high-potential aquifers that play a key role in the hydrodynamic evolution of the alluvial aquifers [69] (Figure 2, in GGRS87 coordinate system).

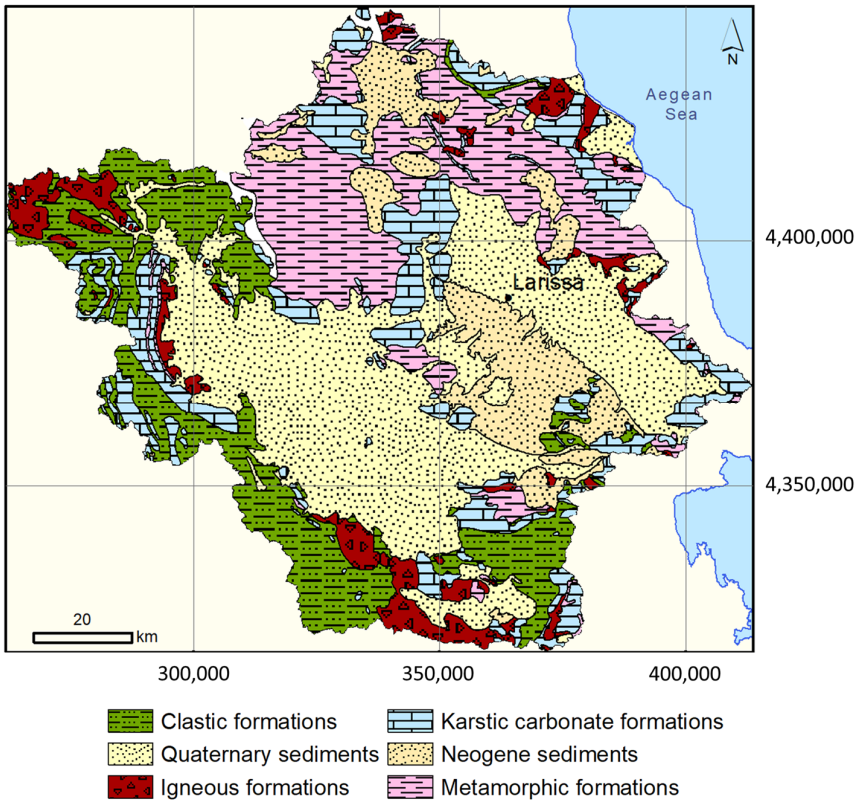
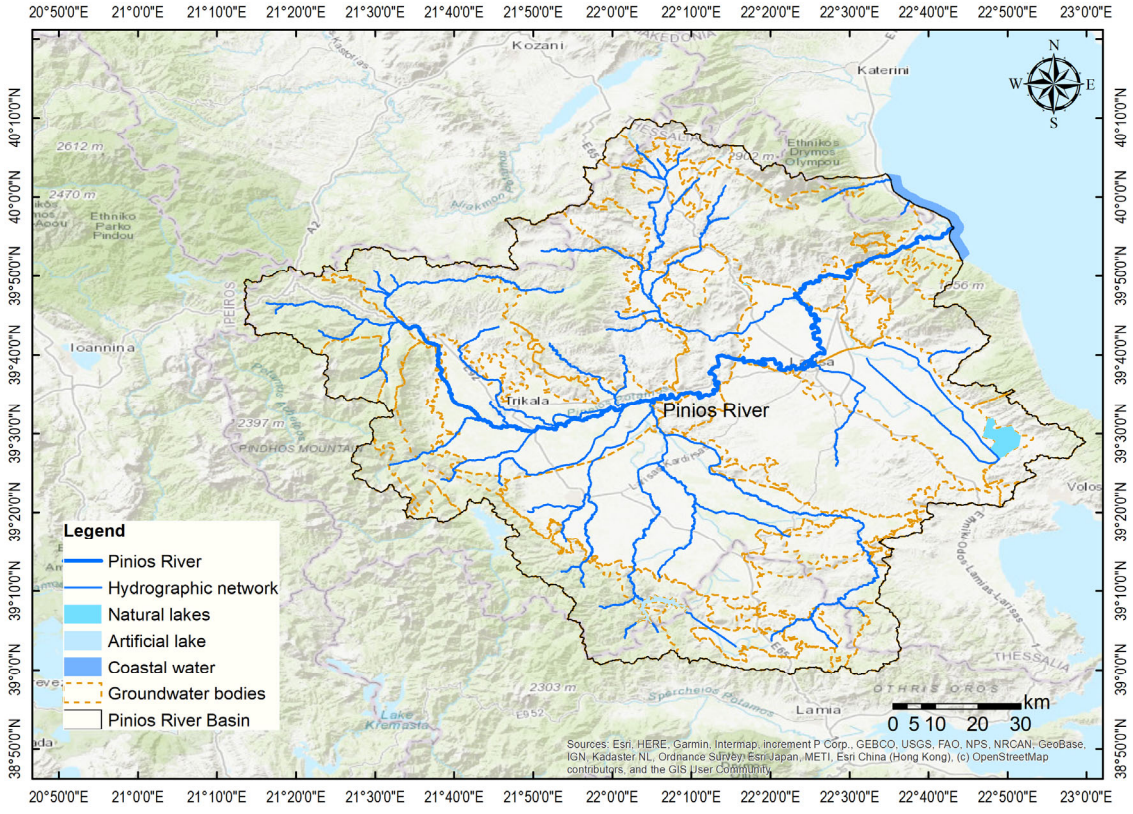


Figure 2. Hydrolithology of the Pinios River Basin.

The Pinios River Basin is considered one of the most characteristic examples of non-sustainable WEFE resource management in Greece, with contradicting opinions regarding the appropriate solutions amongst those involved in the relevant sectors, often leading to many disputes and confrontation, as well as maintaining the long-standing tradition of stakeholder inactivity and disengagement. Intensive agricultural activities have led to the over-exploitation of natural resources and increased environmental and energy pressures, while a notable water deficit for more than the last four decades has been established [70,71]. The identification of the main challenges in the PRB by stakeholders varies significantly, since they present different views and priorities according to differing criteria, including their area(s) of interest, main economic activity, and even social perception, adding to the complexity of the situation. As such, the process of identifying the main PRB challenges becomes a fairly complicated process.

The PRB Water sector: The PRB covers almost 85% of the spatial extent of the Thessaly water district (EL08). In the framework of the 1st Revision of River Basin Management Plans of Thessaly Water District (implemented in accordance with the European Union Water Framework Directive), 64 rivers, 2 natural lakes, 1 artificial lake, 2 coastal water systems, and 40 groundwater systems have been identified in the PRB (Figure 3a, in WGS84 coordinate system). Regarding water allocation, agricultural use constitutes the major reason for water consumption in the PRB, accounting for about 93% of total water consumption (1292 hm^3), followed by domestic (5.5%), livestock (1%), and industrial (0.5%) uses [69]. The systematic over-exploitation of the area's groundwater resources, as well as its surface water resources, was initiated in the PRB in the late 1980s. The highly intensified agricultural activity, in conjunction with irrational irrigation practices, has resulted in a remarkable need for an increase in irrigation water, and attempts to address this need have mainly involved the over-exploitation of groundwater resources. The exploitation of non-renewable groundwater resources, along with nitrate contamination, constitute the most critical threats to groundwater sustainability [72]. The concentration of nitrates in the regional aquifers is expected to increase in the future, mainly due to the decrease in groundwater recharge and increase in water abstraction for several uses [73]. In the past decade, signs of reductions in documented groundwater heads, leading to declining trends and small-scale reversal trends, have been noticed as a result of the rationalisation of the practiced irrigation, the reduction in irrigated land, and the shift to less water-demanding crops [74]. The persistent groundwater deficit underscores the urgent need to develop collective irrigation networks to reduce the excessive reliance on private wells and promote sustainable groundwater resource management [75].



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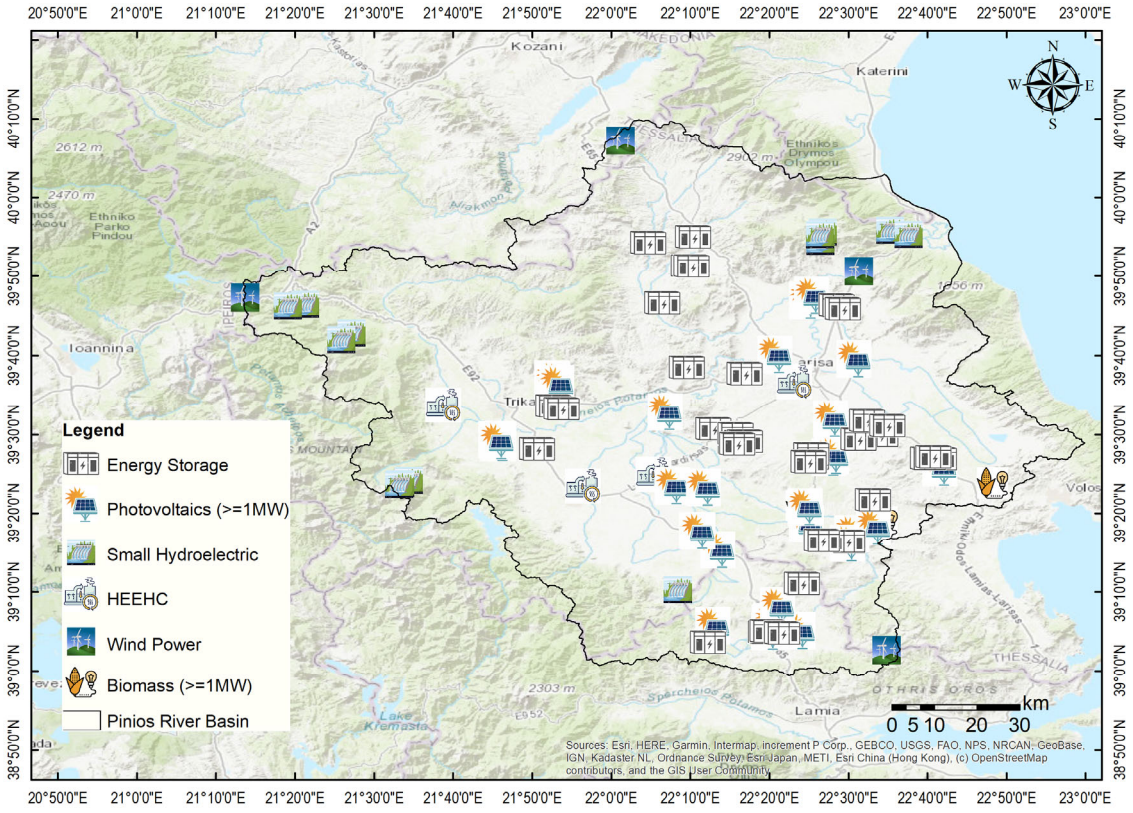

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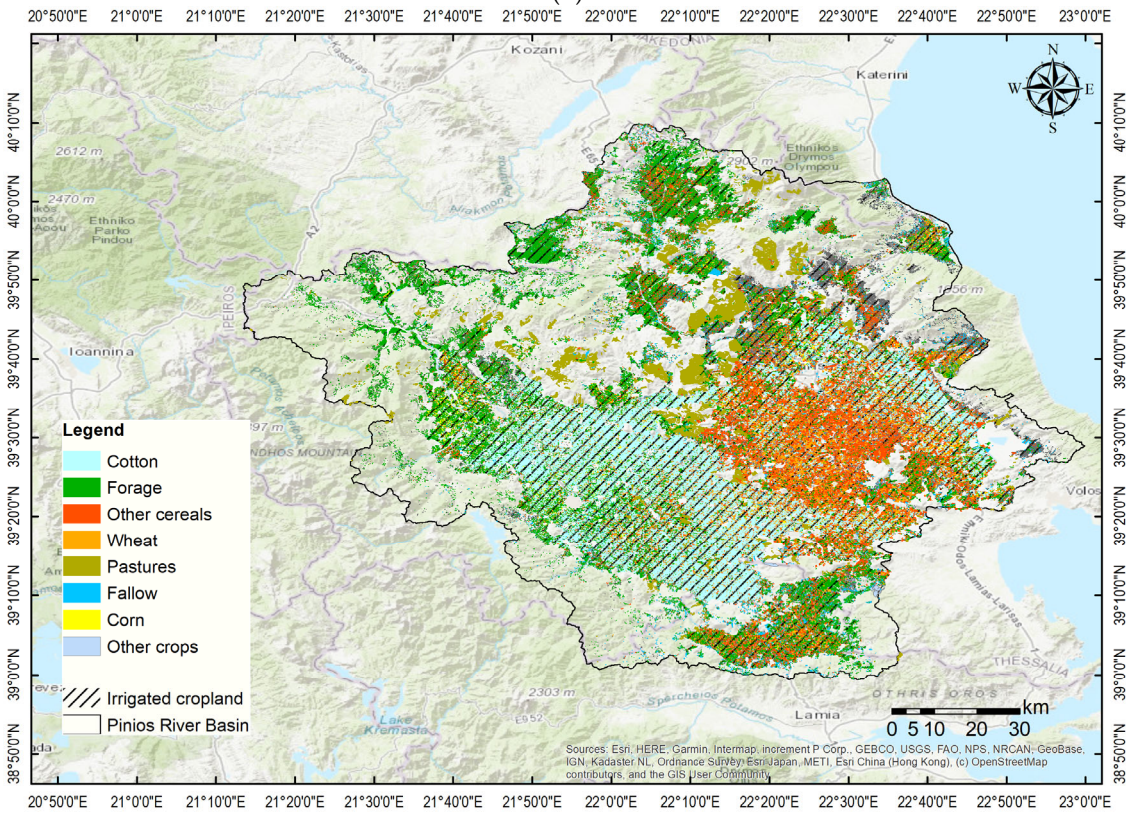

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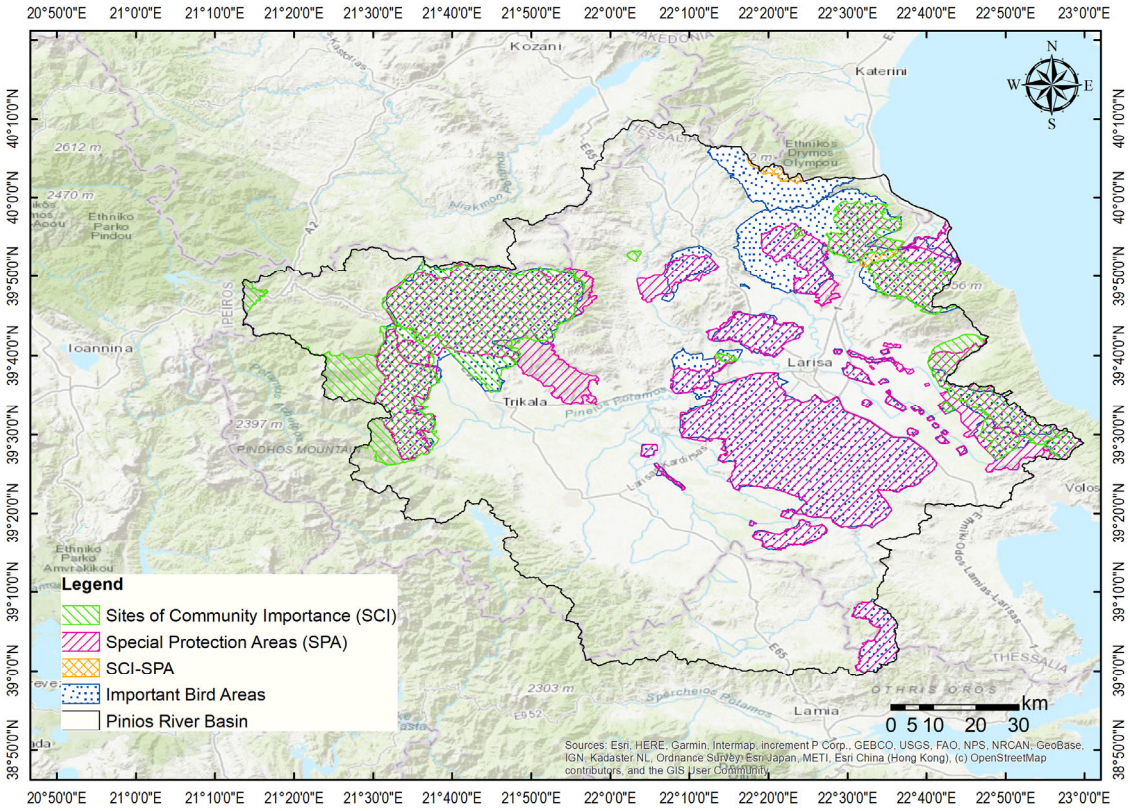

(**d**)

Figure 3. (**a**) Water sector in the Pinios River Basin. (**b**) Energy sector in the Pinios River Basin. (**c**) Food/Agriculture sector in the Pinios River Basin. (**d**) Ecosystems/Climate sector in the Pinios River Basin.

The PRB Energy sector: The water-intensive agricultural sector in the PRB has led to an increase in energy consumption for irrigation purposes, especially considering that most needs are covered by groundwater at declining levels, i.e., greater abstraction depths. This, in turn, results in a significant increase in agricultural production costs, magnified in recent years by the energy crisis. To this end, a wide expansion of installed Renewable Energy Sources (RES) is thought to be imperative for Greece, among other countries, in view of meeting the European Union RES expansion targets in the framework of the post-lignite era developments. However, the availability of suitable sites, land use competitiveness (mainly with agriculture), and the limited capacity of the national power grid pose additional constraining factors in the complex PRB nexus framework. Based on the latest available data provided by the Geospatial Map of the Hellenic Regulatory Authority for Energy [76], the currently installed and licensed RES units that operate in the PRB include 36 energy storage units, 33 photovoltaic stations (each with a power capacity of over 1 MW), 15 small hydroelectric stations, 5 high-efficiency electricity–heat cogeneration (HEEHC) stations, 4 wind power stations, and 3 biomass stations (each with a power capacity of more than 1 MW) (Figure 3b, in WGS84 coordinate system).

The PRB Food/Agriculture sector: The PRB constitutes the most productive and intensively cultivated agricultural basin in Greece [77]. The plains cover almost 45% of the PRB's spatial extent and are divided through a low-lying hill split into two parts: (a) a western part, including the cities of Trikala and Karditsa, and (b) an eastern part, including the city of Larisa. Cotton is the dominant crop in the PRB (19.81%), followed by forage (17.29%), other cereals (15.80%), wheat (13.52%), pastures (7.72%), fallow (4.63%), corn (4.20%), nuts (3.04%), energy crops (2.00%), olives (1.77%), legumes (1.70%), seeds for sowing (1.08%), other forest crops (1.01%), and other crops (6.43%), according to data from

2021 from the records of the Payment and Control Agency for Guidance and Guarantee Community Aid (Figure 3c, in WGS84 coordinate system). Almost 55% of the cropland area is under irrigation, of which almost 35–40% is dedicated to collective irrigation networks, while the rest is dedicated to private irrigation networks [78].

The PRB Ecosystems/Climate sector: The PRB is considered one of the most important hydro-ecosystems in Central Greece, with 34% of its total area, i.e., 3762 km^2, included in the EU Natura2000 protected areas and Important Bird Areas. In particular, in the PRB, there are 10 Sites of Community Importance (SCI), which amount to a total area of 1516 km^2, 13 Special Protection Areas (SPA), covering a total area of 2947 km^2, 2 SCI-SPA areas, covering a total are of 288 km^2, and 11 Important Bird Areas (IBA), spanning a total area of 3170 km^2 (Figure 3d, in WGS84 coordinate system).

2.2. Stakeholders' Participation

Based on the presented analysis of the basin, the PRB is characterised by critical issues that need to be resolved in a coordinated way to ensure that it has a long-lasting future. Complex nexus interdependencies need to be analysed in-depth in order to address the challenges it faces in a comprehensive and efficient manner. To this end, ideally, a broad spectrum of stakeholders covering all 4 identified key sectors of the WEFE nexus, all levels of hierarchy, and the entire productive web of the basin needs to be recruited into an actively participating group that collaborate to unravel the challenges of the basin and shape appropriate measures for their alleviation.

The stakeholders' participatory activities developed in the PRB have followed backbone guidelines proposed in the REXUS project. These guidelines provide overall strategy clustering as core (common in all pilots) and additional (pilot-specific) activities for efficient stakeholder engagement from the perspectives of both conceptual and practical implementation. This means that the developed strategy, from its onset, is meant to be replicable and flexible enough to be customised to different contexts, even beyond the scope of the European Union's goals.

Stakeholders' sampling and approaching processes are dictated by the resources and time available, although the inclusion of multiple different views and opinions is important. Participatory workshops, forums, surveys, or other methods are useful for capturing stakeholders' perceptions, depending also on the level of desired detail concerning the collected information.

Background information on the stakeholders could be helpful if external factors are thought to be influencing their perceptions and priorities, limiting discussions and negotiations among stakeholders, and, in turn, inhibiting them from establishing a common ground of understanding.

3. Results and Discussion

The proposed stakeholder engagement strategy comprises both individual and group activities. The use of individual activities (in the form of semi-structured interviews) primarily allowed us to directly take into account individual viewpoints regarding the 'sectoral' perspective each stakeholder could provide. This analysis included a preliminary investigation of the main needs and challenges (related to resources security) each stakeholder typically faced (including, e.g., conflicting uses of resources and the impacts of climate change on resource availability and state). Participants were initially offered the option to express themselves freely in private in their own environment, without the pressure of time and/or potential challenges in the form of refusal, opposition, or provocation by other members of the group, all of which could have been limiting factors. Subsequently, the analysts worked on developing a 'summary' of the main issues that emerged from the interviews, asking either the stakeholders or the leaders of the study for specific clarifications on potential inconsistencies or conflicting views. Lastly, a summary of the outcomes of the individual interviews was presented and discussed—without any reference to individual stakeholders—in group exercises during a stakeholder workshop.

During the workshop, some results of modelling activities were also presented in order to supplement the discussion with scientific evidence. The support of facilitators during the workshop was crucial to building a consensus while discussing potentially contrasting viewpoints and keeping track of the differences in perspectives.

Throughout the whole stakeholder engagement process, key principles have to be followed to optimise the results. In particular, creating a friendly environment allows everyone to become invested and join in, limiting the possibility of anyone feeling excluded from the participatory process. Transparency in every decision taken and methodological step followed has to be ensured, thus avoiding the feeling of lobbying in decision making. The viewpoints and perceptions of participants have to be respected and valued, disregarding the level of appeal they may have to wider society. The time devoted by the participants and their privacy have to be respected to encourage free and goal-oriented discussions. The adoption of a neutral position among all of the facilitators also supports the freedom of the discussions. In addition, iterative processes that allow for the building of knowledge and progressive shaping of actions have to be followed to develop sound and acceptable pathways to safety. Regarding all the Learning and Action Alliances (LAAs) actions, the "co-" prefix constitutes the key synthetic in terms of working with the stakeholders, for the stakeholders, and their working and living ecosystem. The needs of the stakeholders have to be identified and addressed to the best possible degree, as these may relate to expressing their viewpoints, their complaints, their ideas, and their proposals, in a context shaped to ensure an amicable, equitable, and respectful environment. In light of this, the "mere" data provision process has to be distinguished from stakeholder engagement, and in no case should stakeholders get the impression that they have been approached or recruited to simply act as data providers. Furthermore, patience and time availability always have to be considered, since stakeholders need time to warm and open up and feel like they are in a non-hostile, inviting environment wherein their voice is respected and taken into consideration beyond formalities, thus building a sphere of trust and a sense of belonging among the project's scientific team and the stakeholders. Stakeholders' specificities have to be respected, but boundaries must be set, and stakeholders should not order others around or impose their ideas on the group, regardless of their level of expertise of influence.

The developed strategy comprises five main steps, consisting of framing, mapping, involvement, co-production, and sharing processes (Figure 4).

The following sub-sections contain more in-depth discussions on the proposed approach and the key points that should be considered when applying the methodology.

3.1. Framing

Initial Study of Challenges: Firstly, the key challenges to be addressed were identified. A baseline investigation of the study area, which helped to identify the key problems faced across the PRB, was carried out through conducting research in the study area and utilising the research team's expertise and key consultancy skills. The identification of the PRB's challenges not only enabled the research team to pinpoint the key sectors to focus efforts on but also allowed for an initial characterisation of the basin and the identification of sub-basins for more specific discussions. The preliminary identification of challenges was also supported by the information provided by stakeholders in the round of individual interviews. Indeed, part of the questions focused on the selection of their main needs related to the use of natural resources and potential barriers to fulfilling these needs (including biophysical and governance aspects). Subsequently, the key approaches and methodological frameworks to be tested were proposed. This process was accompanied by the definition of a wish list of data requirements. Key sectoral challenges, cross-sectoral interrelations, data requirements and availability, potential levels of intervention, and the spatial distribution of issues were preliminarily determined. This step also involved the preliminary selection of which stakeholders should be invited to participate in the LAA.

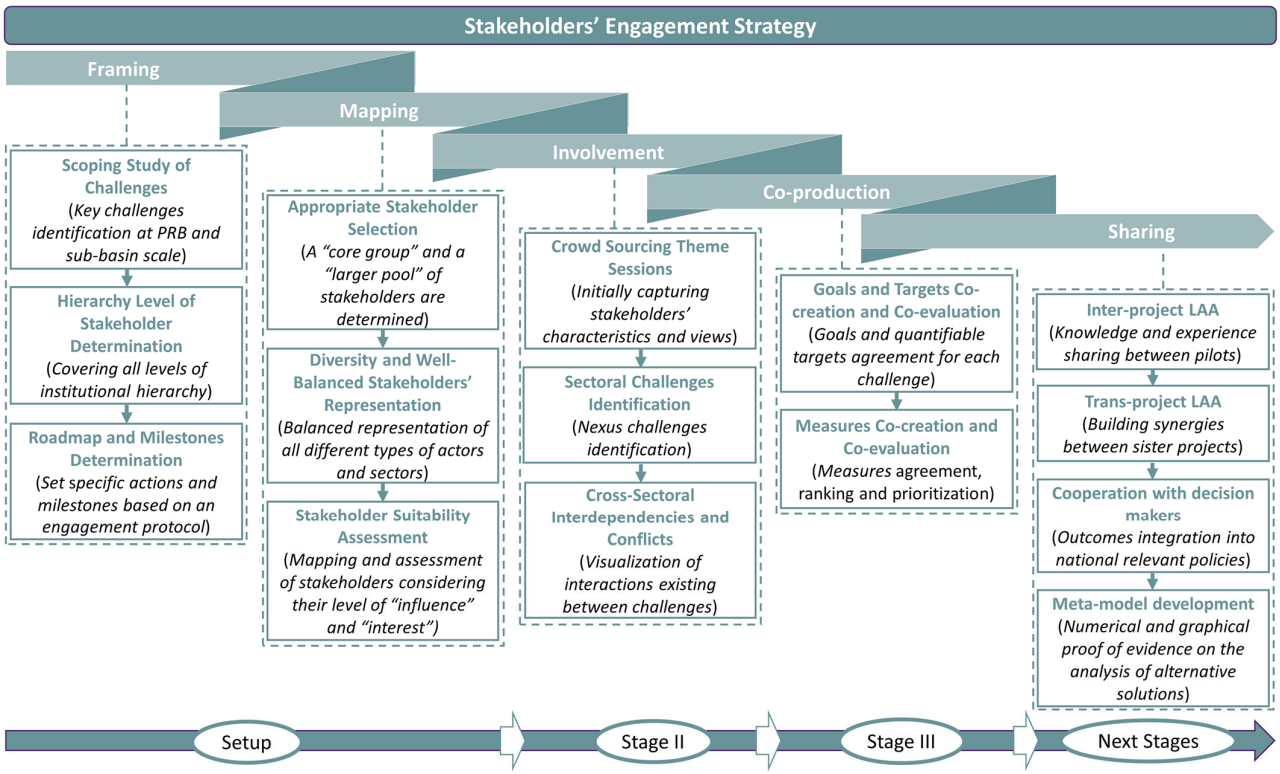

Figure 4. Stakeholder engagement strategy as part of the PRB LAA development process.

Determination of the Hierarchy Levels of Stakeholders: Identifying the hierarchy levels that need to be covered and the institutional profiles that need to be included in the pool of stakeholders greatly depends upon the size of the study area, the nature of the identified issues, the envisaged problems' resolution plans, the need to perform in depth analyses at small scales, and the need to consider potential institutional changes, awareness raising, and capacity building initiatives. Evidently, the more comprehensive and wide the pool of key stakeholders is, the more representative it is, lowering the possibility of omitting/missing criticalities in the construction of a holistic management plan. On the other hand, the wider the pool of stakeholders, the greater the likelihood of conflicts arising and the consultation concluding without a consensus being reached. In the case of the PRB, in view of the multitude of complex issues that need to be tackled, an expanded stakeholders' panel was set up. Therefore, the adopted approach aimed to cover all levels of institutional hierarchy, such as end users, decision makers, strategic planning/policy makers, non-governmental organisations, experts, research institutions, and private companies, to the best possible degree, thus potentially facilitating interaction throughout the entire pyramid (i.e., from the bottom to the top and from the top to the bottom).

Roadmap and Milestone Construction: A roadmap and milestones for the stakeholder engagement strategy were then constructed. Starting from when the stakeholders were initially approached, a specific engagement protocol was drawn up and followed to ensure the highest possible engagement level and a low incidence of stakeholders declining to participate. This protocol was based on systematic and frequent follow-up contact on a personalised level, starting with phone calls and also involving regular e-mail communication, followed, in due time, by individual in-person interviews and small group meetings. Achieving high success rates in recruitment necessitates making use of existing personal contacts, gaining new personal contacts, and developing relationships in a continuous effort to build and maintain/confirm trust. Stakeholders' individual characteristics and profiles, along with the profiles of the body they represent, were studied prior to approaching them and collaborating with them.

The stakeholder engagement strategy has been strategically shaped to address the demands of the project whilst taking into account stakeholders' characteristics, the key features of the study area, the institutional capacity and structure surrounding the project, and the level of knowledge among the stakeholders about the nexus approach and nexus concepts. Based on the tasks to be accomplished by the project and the focus developed for the study, a roadmap mapping the whole trajectory of the project and specific actions and milestones was established in collaboration with the involved partners. Hence, a series of meetings, workshops, and desk work sessions have been defined to be elaborated with specific content and target and a precise timeline to reach the required result. In every step of the process, it has to be clearly understood that successful stakeholder engagement is an elaborate and long investment that needs to be developed on the basis of mutual understanding and respect.

3.2. Mapping

Appropriate Stakeholder Selection: An initial list of potential stakeholders was drafted, based largely on the work experience of the REXUS research team regarding the region of Thessaly, and augmented by the personal relations that were developed among them. In parallel, a wide search for additional stakeholders was performed; this search for stakeholders was carried out through using the snowball technique, partially ensuring their high level of interest, and an online search for potential stakeholders who represent significant actors in the study area; however, the a priori assurance of their willingness to actively participate in the project was not part of this search. An initial list of more than 150 stakeholders was compiled.

Starting with this list, specific criteria were used to reduce the final number of stakeholders; these criteria were as follows: representativeness of all sectors, coverage of all hierarchy levels, participation of key actors, wide geographical coverage, presence of critical policy and decision making as well as implementation bodies, representation of all key socio-economic activities, pluralism in stated viewpoints (including the academic literature, consultancy, production, society, technocrats, etc.). Subsequently, the list of preselected stakeholders comprised approximately 50 people, all of which were invited to participate in the REXUS project. This number was assumed to be realistic in helping the research team achieve effective and representative results. Invitations were extended on a personalised level through telephone calls, e-mails, and in-person visits when requested to communicate the targets of the project and explain the role of the stakeholders and their engagement in the active participatory approach towards developing holistic management solutions. Approximately 35 people responded positively to the invitation, forming the initial group of stakeholders for the project. This number was increased to 44 following the suggestions offered by the participating stakeholders, as some nominated their contemporaries to ensure a higher degree of representativeness.

Orientation criteria and hints for the selection of appropriate stakeholders were employed, resulting in the construction of a list of two distinct groups of stakeholders. The "core group" consisted of stakeholders who mainly focused on most of the feedback in the co-mapping of the challenges, the co-identification of the constraints and criticalities, and the co-design and redefinition of a potential set of solutions in the holistic management strategy. These are the people that presented the highest interest, influential capacity, and decision making power while possessing the deepest knowledge of the study area. The "larger pool" incorporated the aforementioned group but also included a large number of stakeholders that essentially formed a conclusive list of existing representatives of all sectors and levels with variable degrees of knowledge and scholarly education, involvement, abilities to influence and/or motivate, and decision capacities, but every one still had a vast knowledge of the study area and/or the sectoral issues.

Both groups were dynamically altered as the project progressed to adjust to its needs and ensure alignment with the responses of the stakeholders. To this end, the opinions and suggestions of the stakeholders were seriously considered to inform their inclusion in either

group. Overall, the key criteria considered for stakeholders' inclusion in the core group included "representativeness", "coverage", "performance", "experience", "influence", "collaboration", and "satisfaction/preference". Adequate representativeness of the nexus sectors and societal groups at regional and local scales under all the identified institutional levels has to be ensured. Both a holistic coverage of sectors and topics that ensures no critical challenge, impacted system, or activity is left unconsidered and a trans-sectoral coverage enabling improved and more efficient designs of acceptable and applicable "working" holistic solutions have to be achieved. Also, the entire spectrum of performance (from poor to excellent) has to be covered with regard to resource management at the regional level, as long as stakeholders directly or indirectly become involved in problem solving for the study area. The adoption of best practices by stakeholders and their responses to troublesome, inadequate, or mismanaged resources and occurrences in their respective sectors, along with everything in between, are of great interest. Obviously, well-performing stakeholders were prioritised, as they are normally aware of issues, needs, and problems and capable of actively assisting in shaping best practices for holistic management with the aim of increasing resilience and enhancing sectoral security. However, it is strongly believed that considering the viewpoints and analyses of poorly performing stakeholders may help considerably in mapping problems and perhaps even more so in understanding the reasons behind their poor performance. In the end, these are the stakeholders that need to participate in the co-decision process on the development of solutions that merit social consent, inclusivity, justice, and acceptability in order to ensure full-scale implementation. In addition, having a wealth of collective experiences to share and diffuse amongst the core group of stakeholders is of the utmost importance to achieve a deep and conclusive understanding of the current conditions of the study area and improve the likelihood of the designed solutions being applied successfully. The potential influence of stakeholders should be considered to improve the feasibility of the co-designed solutions and ensure they are efficiently communicated, as increasing the probability their actual implementation is of great interest, as is the ability of stakeholders to collaborate with other stakeholders and scientific teams, ensuring a healthy, fruitful, and overall amicable collaboration with the highest possible degree of efficiency. Moreover, sometimes, the appointed representative of the stakeholders' board of directors does not necessarily choose with the most appropriate or obvious choice amongst the available options, but ensuring that a consensus is met is critical in finding and, more importantly, implementing solutions.

The group of engaged "core stakeholders" comprised 44 members and was synthesised as presented synoptically in Figure 5 and detailed in Appendix A (Table A1). A unique code was provided to each different stakeholder based on their main related nexus sector (i.e., the prefixes W, EN, F, and EC refer to the water, energy, food, and ecosystem sectors, respectively). Overall, the water, energy, food, and ecosystem sectors were represented by 11, 3, 23, and 7 stakeholders, respectively (Figure 5a). In addition, stakeholders were categorised according to their type; i.e., there were 15 decision makers and policy-makers (POL), 11 representatives of end users and individual end users (USER), 2 citizens and NGOs (CIT), 3 individual experts (EXP), 3 representatives of private companies (COM), and 10 research and academia representatives (RES) (Figure 5b). Levels of influence and interest were also assigned to each stakeholder, as presented in Table A1.

Diversity and Well-Balanced Stakeholders Representation: Diversity and a well-balanced representation of all WEFE nexus sectors and institutional/governance levels and types constitutes a prerequisite for a nexus approach and therefore has to be ensured. The higher number of stakeholders representing the food and water nexus components is attributed to the dominance of the agricultural and water-related sectors in the PRB; however, these sectors were not treated favourably compared to the other sectors since the engaged stakeholders were asked to express their views on all of the nexus components. This is illustrated in Figure 5, where it is clear to see that the water and food sectors outnumber the others, especially the energy sector. Still, as energy is strongly interrelated to the water and food sectors, especially due to the financial aspects escalating from contemporary

critical issues, the energy sector was indirectly but responsibly covered in equal terms by the group of stakeholders. Interestingly enough, the assessments and categorisations made by our research team for each stakeholder with regard to the key sector each one represents best on the basis of their profiles shifted towards the water sector, as proved by the self-determination exercise practiced in the very first meeting that was held, as explained in Section 3.3.

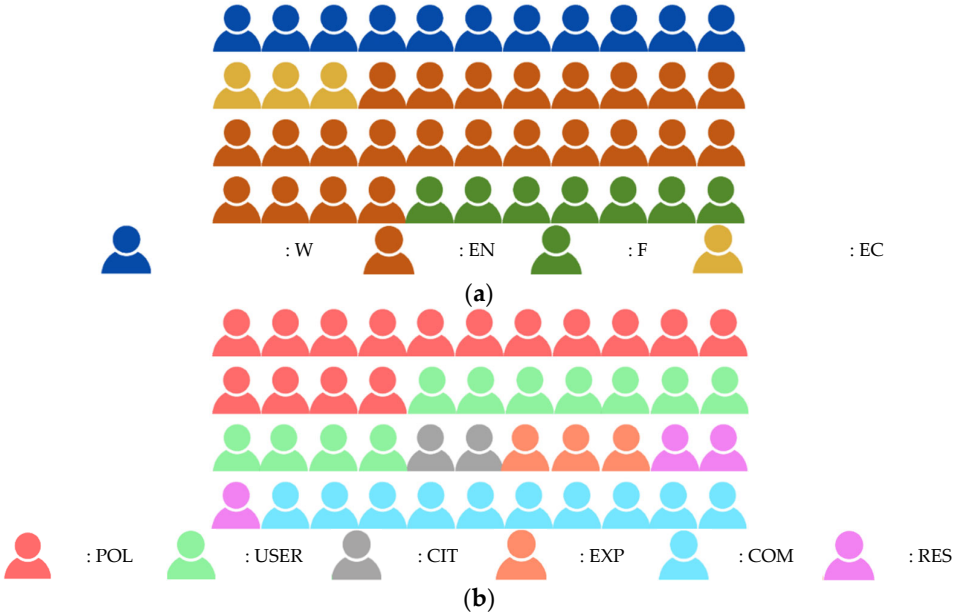

Figure 5. Characteristics of engaged stakeholders based on (**a**) their related nexus sector and (**b**) their type.

Stakeholders' Suitability Assessment: Once the list of selected stakeholders was created, stakeholders were characterised and mapped in terms of their influence and interest criteria. The idea of developing a stakeholder power grid to visualise the influence and interest of stakeholders was conceived by Mendelow in 1991 [79]. Stakeholders differ in how much influence they have and in how much they are interested in a particular topic. The term "influence" refers to the capacity/power of stakeholders to solve or exacerbate a problem, while the term "interest" refers to the importance of a problem in the eyes of stakeholders regarding the level of relevance it has to their business. Our research team's approach involved the stakeholders being categorised into four classes: "promoters", "defenders", "latents", and "apathetics" [80]. Promoters are those who usually have both great interest in an issue and the power to help resolve it successfully, defenders are stakeholders who have a vested interest and can voice their support in the community but may have little actual power to influence the issue in any way, latents are those who have no particular interest or involvement in an issue but have the power to influence it greatly if they become interested, and apathetics include stakeholders who have little interest, little power, and may not even be aware of an issue. The stakeholders were mapped on a four-quadrant plot based on their levels of influence and interest, and this plot is depicted in Figure 6.

The distribution of stakeholders in the four quadrants reflects the perception of the analysts. However, in our case, to facilitate LAA activities through the active engagement of the different groups of stakeholders, the selection procedure involved assessing each individual's level of influence and interest. Hence, members of the group that were assigned to the bottom two quadrants (apathetics and latents) were filtered out and not considered further. All the engaged stakeholders were therefore distributed in the upper two quadrants of the mapping diagram, meaning that they were characterised as promoters and defenders and that they were all interested in the nexus issues. The filtering out of the latents and apathetics in the developed PRB LAA activities was carried out to avoid

the negative effect they may have on the implementation of a project and its outcomes. About a third of engaged stakeholders (15) were characterised as promoters (those with high levels of influence and interest), with the remaining 29 being classed as "defenders". Interestingly, the distribution between the two categories is rather balanced for three of the four sectors too. As already stated, the mapping described herein is the result of filtering the initially compiled stakeholders' pool to ensure a group of stakeholders with the potential to leverage decision making on nexus management throughout the whole project. However, stakeholder characterisation and mapping can dynamically change as a result of several factors, including potential erroneous assessments by the scientific team members, changes in the prioritisation and obligations of the stakeholders, failing to the attract attention of the stakeholders to the scope of the project/process, a lack of genuine interest in the process among participants, and disproportionate requirements for investing time in the process.

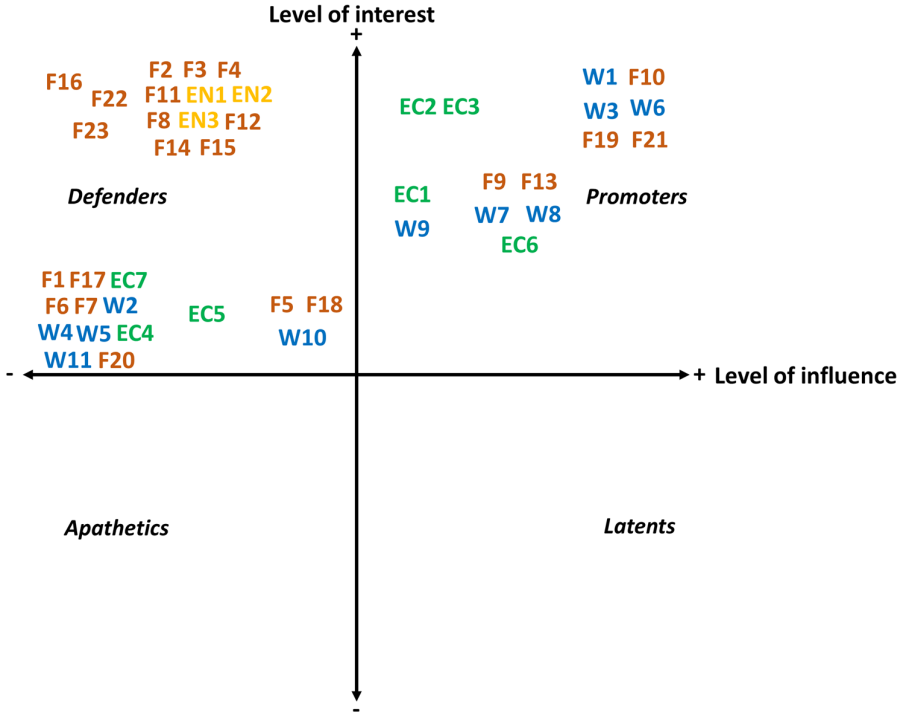

Figure 6. Selected stakeholders' classification based on influence and interest criteria.

3.3. Involvement

This phase is central for the stakeholder engagement, as it centres around enabling the active participation of relevant stakeholders through a series of participatory activities, details of which are provided in the following sub-sections. This phase is centred on the 'diagnosis' of PRB conditions and is carried out to both select relevant sectoral challenges for the area and to better understand cross-sectoral interdependencies.

Crowd Sourcing Theme Sessions: The next step consisted of the preparation and realisation of the first meeting of the REXUS PRB stakeholders, which took place online on 30 November 2021. The meeting consisted of three crowd sourcing theme sessions to initially capture stakeholders' characteristics and views and two virtual roundtable discussions to involve all the stakeholders in a common virtual discussion.

In particular, 15 online questions were included in the framework of the three crowd sourcing theme sessions of the REXUS PRB Learning and Action Alliance kick-off meeting, allowing for immediate feedback on the overall status of the stakeholders' perceptions. The questions, along with an analysis of the stakeholders' responses, are presented synoptically below and in-depth in Appendix B. Each session involved asking five questions to stoke the interest of the audience regarding the nexus system issues and register their viewpoints on the fly. The Mentimeter online platform was employed for this purpose.

In fact, the first session acted as an ice breaking session for the stakeholders, elucidating their linkages to the PRB, perceptions of the nexus approach, and their expectations for the REXUS project. Almost 80% of the participated stakeholders have ties to the water and food/agriculture sectors, revealing the agricultural nature of the PRB. The vast majority of them are familiar with the PRB nexus system, and they could decisively contribute to the analysis of cross-sectoral challenges, while half of them are mainly ministers and academics who could influence the decision making process. A high level of nexus principle understanding was also revealed by the fact that most stakeholders acknowledged the need for each WEFE sector to be approached equally, while this perspective did not seem to be clear enough among stakeholders related to the food/agriculture sector, highlighting the complexity of the agricultural sector in the PRB. The main reasons for stakeholders' involvement were related to their intentions to express their interest in and concerns about the challenges associated with the PRB, along with their desire to co-design a sustainable future.

The second session was developed to capture stakeholders' viewpoints on the PRB's conditions. The management framework of the PRB nexus system was characterised as very complex or complex among the vast majority of stakeholders, exposing the limited effectiveness of already implemented measures. The water sector of the PRB faces the most crucial challenges, a fact that was recognised by stakeholders from all the different nexus sectors. In addition, the water and food/agriculture sectors appeared to have the highest importance and were the most thoroughly investigated PRB sectors.

The third session was conducted to capture the perception of stakeholders on the implemented management practices. The efficiency of the already implemented measures was characterised as moderate, with a selection of these measures mainly being affected by the influential capacity of some stakeholders. The water and food/agriculture sectors present the strongest interaction and are either already being significantly affected or expected to be affected by the climate crisis.

The Identification of Sectoral Challenges: In the framework of the first REXUS meeting of the PRB stakeholders, a roundtable discussion was organised and conducted to select the most critical nexus challenges. As mentioned before, a series of individual semi-structured interviews were conducted, either in-person or virtually, with each different stakeholder, and this resulted in an extensive list of challenges that should be addressed to ensure the sustainability of the study area (Figure 7). As highlighted in the figure below, the focus was firstly on the nexus sectors in isolation. Interestingly enough, governance issues were identified as central issues in all sectors. The process was not influenced by any direct or indirect indications on the challenges to consider. As a result, the identification of the most important ones was based on the stakeholders' own critical judgment only through a specific session organised during the stakeholders' workshop.

A set of critical challenges was thus identified for each sector, in addition to the major issue of governance. Governance is a multidimensional concept that refers to the political, social, economic, and administrative systems in place that influence the development and management of resources such as water, land, or energy. In the water sector, several frameworks have been developed to diagnose water governance and support the development of action planning [81–84]. Despite the different focuses of governance assessments and target groups, diagnosis focuses on analysing formal structures (i.e., the existence, adequacy, and coherence of the policy and regulatory framework and the roles and responsibilities of the different institutions managing the resources and financing) and how well processes work in practice (i.e., level of coordination, cooperation, implementation, and performance). As the Organisation for Economic Co-operation and Development [85] describes, it is about exploring the effectiveness and efficiency of formal and procedural aspects, as well as trust and engagement (Figure 8).

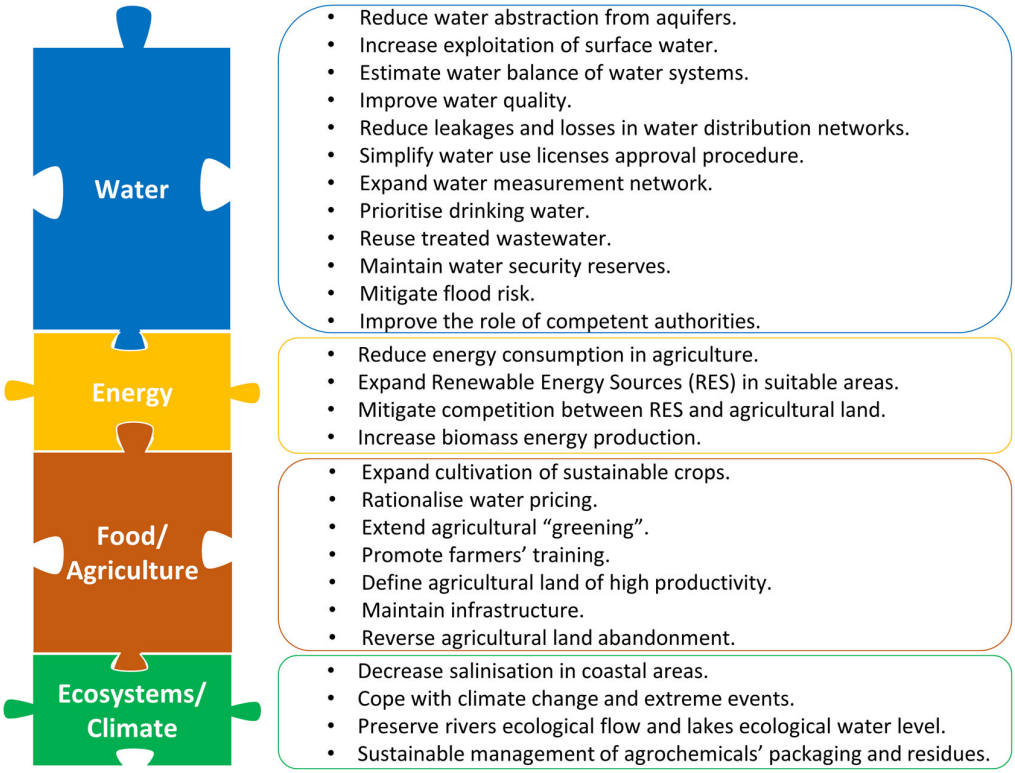

Figure 7. Critical nexus challenges with respect to the Pinios River Basin.

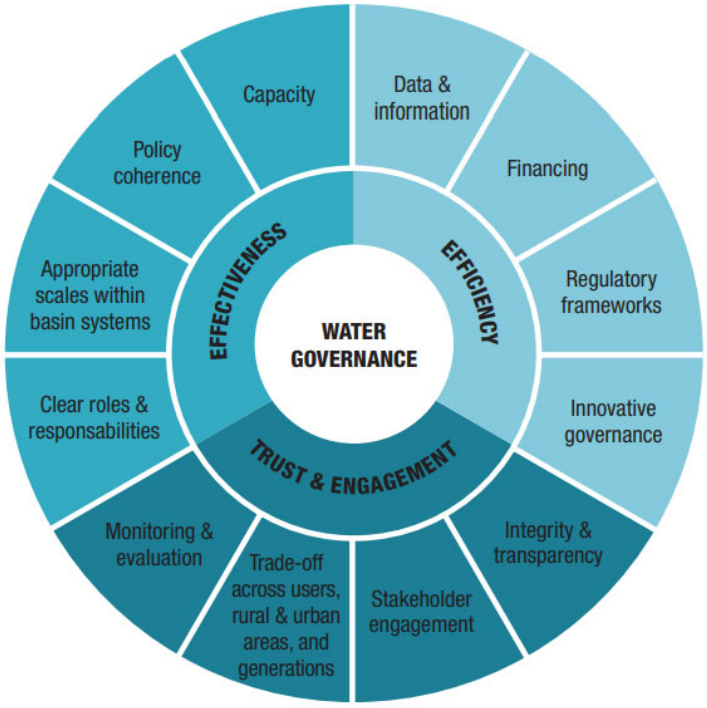

Figure 8. OECD principles regarding water governance [85].

Effective administration and governance in the PRB is of paramount importance and directly or indirectly reflected in all four sectors as a challenge. Its importance lies in the fact that none of the measures defined and proposed for implementation in order to address the identified challenges may be successful and meaningfully impact the system unless the governance structure is well developed and supplemented by efficient administrative units.

Complex legislation framework and scattered responsibilities among competent authorities were identified as the most critical barriers in the PRB, hindering effective administration and governance.

The water-associated challenges primarily relate to ensuring sufficiency in terms of fair spatiotemporal distribution to ensure the coverage of all socio-economic activities without disregarding quality, especially in specific parts of the basin and with respect to agriculture-related pollutants. In parallel, as part of the management practices proposed to address the water-related challenges, flood risk mitigation, resilience to shortages due to droughts, and the utilisation of treated domestic effluents are high on the agenda. The food-related challenges pertain to the development of viable and sustainable agriculture, towards which production cost rationalisation and greening are thought to be of paramount importance, as are the productive utilisation of agricultural land and the training of farmers. The rehabilitation and preservation of ecosystems and their functions are the key challenges relating to the environment and, along with the sustainable management of agrochemical' residues and the preservation of ecological river flows and minimum lake levels. High use efficiency lies at the essence of the identified energy-related challenges; the energy sector's challenges include the expansion of renewable and biomass energy production to resolve issues such as the antagonistic use of high-productivity land and reducing energy consumption in the agricultural sector.

The PRB challenges were also critically analysed through reviewing previous studies. Groundwater overexploitation and water quality deterioration are triggered mainly by non-sustainable agricultural management practices which have been carried out since the mid-1980s [67]. Mean annual precipitation in the PRB is projected to decrease, while temperature and evaporation are projected to increase until 2100, resulting in a significant decrease in water availability, which is strongly related to the projected declining groundwater recharge trend and increasing trend in relation to irrigation water demand. Ecological flow is difficult to preserve in some rivers in the PRB, presenting low to zero discharge during the summer months in recent years [78], while the total runoff in the PRB is projected to decrease further from 22% to 66% until 2080 compared to the 1980–2000 period [14,71]. Flood occurrences increased between 1990–2010 and 1979–1989 in the PRB, with most flood events being recorded in the southern part of the PRB and most of the damage occurring in rural areas [86]. The PRB has also experienced severe, extreme, and persistent droughts that have affected large areas since the late 1970s and became more evident and frequent during the last three decades, especially over the past 5–7 years.

Cross-Sectoral Interdependencies and Conflicts: During one stakeholders' meeting, a second roundtable discussion was conducted to explore the transectoral relations between the identified challenges in order to facilitate a holistic approach. The identified interrelations were then finalised, and further details on them were obtained from personal interviews with stakeholders. The final interrelations were drawn up and visualised (Figure 9). The colour selected for each connecting line refers to the nexus sector of the related driving challenge (i.e., the blue, yellow, brown, and green lines refer to water-, energy-, food/agriculture- and ecosystems/climate-related challenges, respectively).

Cross-sectoral interdependencies provide a comprehensive understanding of the bonds between nexus sectors, helping to identify how and where exactly each sector interacts and depends on another. Unless these dependencies are fully mapped, understood, and taken into account, any attempt to design and successfully implement management measures will inevitably be of limited efficiency and impact. Successful holistic approaches involve a global overview and examination of the sectors that form the nexus of a system and require a common understanding of the identified issues, challenges, and interdependencies in order to reach a wide consensus on ways to improve progress towards sustainable management.

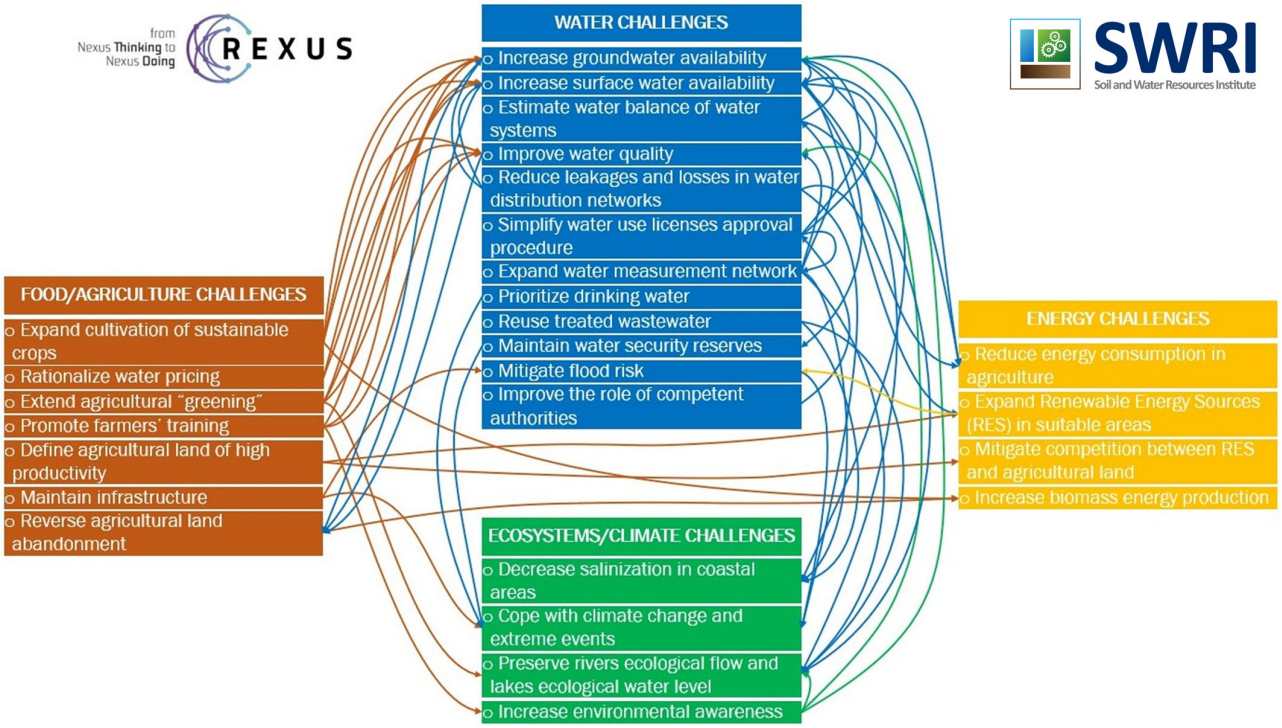

Figure 9. Interrelations of critical challenges in the Pinios River Basin.

The canvas illustrated in Figure 9, which summarises the feedback from participants, clearly shows the complexity of the studied nexus and the tight bonds amongst its sectors. Especially between the water and food/agriculture sectors, multiple and multi-level dependencies are denoted for the PRB, clearly suggesting that managing an element of one sector would inevitably influence the other. Interestingly enough, a very strong dependency was identified between the former two sectors and the ecosystems/climate sector, which mainly reflects concerns surrounding the current management conditions and perceived sustainability status. Evidently, the stakeholders acknowledge that there are less interdependencies for the energy sector. This can be attributed to the limited knowledge on the local relevance of the sector, considering the challenges that are faced worldwide.

3.4. Co-Production

The Co-creation and Co-evaluation of Goals and Targets: The challenges that emerged from the involvement phase helped in setting the goals for achieving nexus sustainability. Clear goal setting could help policy and decision makers to improve their performance in terms of sustainable development [87]. In addition, quantifiable targets have to be determined to measure the satisfaction level of defined goals and thus promote WEFE security.

To promote their applicability and effectiveness, targets should be in compliance with international and national WEFE legislative regimes. The Sustainable Development Goals (SDGs) included in the 2030 Agenda for Sustainable Development [19] were established in compliance with the rights and commitments of the United Nations, and they are considered political goals, not legal rules. The SDGs and associated targets serve as inspirational statements that constitute crucial parts of international legislative instruments and aim to trigger action that will yield results in critical areas for the well-being of humans and the planet by 2030. The SDGs attempt to orchestrate the wide variety and diversity of targets already embedded in various international agreements.

Regarding the PRB, proposed goals and targets should be in accordance with European and national policies. European Union (EU) legislation pervades the national policies of all member states while regulating most of aspects of the WEFE nexus. In terms of the water sector, the Water Framework Directive (2000/60/EC) sets out rules to prevent water

status deterioration and achieve a good status for all deteriorated surface and groundwater bodies [88]. Regarding the energy sector, the recent Revision of the Renewable Energy Directive (COM/2022/230) proposes to further increase the target of renewable energy sources in the EU to 45% by 2030 [89]. In the field of agriculture and rural development, the Common Agricultural Policy (CAP) 2023–27, implemented on 1 January 2023, aims to ensure stable food supply, ensure farmers' incomes, and keep rural areas vibrant within the context of environmental sustainability [90]. In terms of EU climate action, initiatives include engaging all parts of society in climate-benefitting actions, further reducing emissions by 2030, and making Europe the world's first climate-neutral continent by 2050 [91].

The proposed goals and targets may interact among each other, mirroring the interrelations and critical trade-offs among the WEFE challenges. In particular, some goals and targets seem to be independent of each other, while others may reinforce or impose constraints on others due to the competition for scarce natural resources. However, effective stakeholder engagement and involving stakeholders in common discussions could mitigate potential policy conflicts, resulting in the development of a coherent set of goals and targets and a complete consensus, ultimately shifting goals and targets from being centred around achieving acceptable trade-offs to achieving win–win scenarios.

The Co-creation and Co-evaluation of Measures: Defined goals and targets call for both sustained and sustainable development through the compilation and implementation of specific measures. Policy makers and decision makers need to elaborate on how to integrate goals and targets into management policies to address nexus challenges. A wide range of sustainable measures could be implemented, including supply-side and demand-side options, across all nexus sectors. Supply measures are mainly related to infrastructure and treatment technologies, while demand management measures include resource efficiency promotion, changes in resource allocation mechanisms, and improvements in resource productivity and availability. However, each measure presents specific strengths and weaknesses which have to be properly considered. Efforts should be made to analyse, rank, and prioritise measures using as wide a range of objective criteria as possible, covering technical, social, and other characteristics. The creation of effective measures may secure reliable supplies of natural resources to meet future demands.

There is an increasing awareness of Nature-based Solutions (NbS), which have the potential to address both climate mitigation and adaptation challenges at a quite low cost while promoting human and nature benefits. NbS promote the sustainable use and management of natural resources while tackling economic and environmental challenges and sustaining human well-being. In addition, NbS emerge as an integrated approach that mitigate trade-offs and promotes synergy among the SDGs. The importance of promoting NbS is even greater considering that some SDGs, including those centred around stabilisation and adaptation to climate change (SDG13) and biodiversity protection (SDGs 14 and 15), are unlikely to be met by 2030 [92]. The importance of NbS was recognised by their endorsement in the Climate Change and Land Report of the Intergovernmental Panel on Climate Change (IPCC) [93] and the fact that they were included in a COP cover policy for the first time during the 27th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP27).

3.5. Sharing

Inter- and trans-project approaches can significantly advance nexus management towards resilient WEFE systems and drive sustainability transitions.

Inter-project LAA: Horizontal knowledge is expected to be enhanced through the development of an inter-project LAA centred around knowledge sharing between pilot areas of the project. Dialogue on policy integration needs and gears across pilot areas is promoted. In addition, cross-fertilisation amongst the project's pilots is being practiced to improve the developed strategies for nexus management, rectifying what has been found to not yield results and strengthening the efficient parts of the existing strategies.

Trans-project LAA: The produced experience will be further disseminated across other projects under the nexus scheme through the development of a trans-project LAA. This way, alignment with similar projects and building synergy among them will be achieved. The role of the trans-project LAA can prove crucial in a much broader context since integrating the lessons learnt from engagement strategies in areas with different particularities provide give a significant boost to align agendas and policies in a trans-sectoral perspective.

Cooperation with Decision Makers: Experience and information sharing may be practiced among influential decision making bodies and authorities, again aiming to improve the decisions to be made and perfect the outcomes of the nexus management project. To this end, within the framework of the REXUS project, the research team has initiated a twofold external collaboration (a) through creating a focal group of the Water Resources Management Plan (WRMP) of the Thessaly district that PRB belongs to and (b) establishing a focal group with the official consultancy for the implementation of the WRMPs on a nationwide level. Focal group (a) consists of high-ranking specialist executives of the Ministry of the Environment and Energy and specialist consultants of the consortium responsible for the second revision of the WRMP at the PRB. The objective of this collaboration is to strengthen and promote the holistic approach towards the effective and sustainable management of the PRB by exchanging viewpoints and aligning information and data that enhances pluralism and integration. The ultimate aim of this collaboration is to establish a revised plan that has a higher chance of being successfully implemented and yielding results. Focal group (b) consists of highly experienced executive technocrats that are responsible for guiding and consulting the ministerial and regional services towards aligned efforts for the efficient implementation of the WRMPs at national level through the consultancy work carried out by several consortia and the regional authorities' scientific staff. They share the vision of holistic nexus management, and the target of this collaboration is to disseminate the virtues and needs for holistic nexus management nationwide through the systematic, active engagement of stakeholders whilst offering help in efforts towards training scientists involved in this activity.

Meta-Model Development: A meta-modelling approach can be employed to visualise and more easily present the main information and outcomes of a project or task. A meta-model transforms produced implicit knowledge into straightforward results, supporting the analysis of information and thus the accumulation of knowledge. The meta-model's layout and component selection could be based on users' opinions, including the indicators, scenarios, and measures that a meta-model could present and the type of visualisations that a meta-model could offer. Specific answers to these generic questions mainly depend on the target audience; thus, meta-model co-development constitutes an inextricably linked component of the whole stakeholder engagement process. An efficient meta-model design could allow users to easily gain insights into the complex nexus systems, supporting decision making processes within a holistic point of view. Its development for the PRB is largely shaped on the needs and requirements of the stakeholders, who we envisage to be amongst the key users of it.

4. Conclusions

The main objective of the present work was to present an effective strategy for incorporating different stakeholders' views and priorities through their active engagement in group discussions to define the critical challenges of WEFE nexus components in the Pinios River Basin. Defining critical challenges and their interconnections in WEFE-stressed areas could help in redefining policies and seeking solutions within an integrated sustainable development context. The findings of the present work are summarized below:

- The identification of key challenges, along with their interconnections and interdependencies, is crucial to supporting policy makers in enhancing the resilience of the study area.

- Despite the scientific team's extensive experience regarding the study area, the responses of the stakeholders offered new viewpoints and challenges that had not been realised in previous activities.
- The use of a holistic approach as a basis for the engagement process revealed impressive interdependencies amongst the key nexus sectors. More importantly, governance emerged as a hotspot challenge by itself, having been indicated in several ways and shapes as such in all four examined sectors.
- The involvement of a broad spectrum of stakeholders not only improves the representativeness of the identified challenges but also renders the participatory process more transparent. As a consequence, the identified solutions are expected to have wider social acceptance and an increased chance of being successfully and efficiently implemented.

In conclusion, the proposed methodology shows a clear and detailed path of actions that need to be taken to support stakeholder engagement in nexus studies. In the methodology, particular attention is given to the process of stakeholder selection and analysis, as well as to their involvement both in individual activities (interviews) and group exercises. The purpose of this is to have information related to each sector in isolation (e.g., sectoral challenges) but also, even more importantly, on cross-sectoral interdependencies and potential conflicts. The whole approach comprises multiple phases and steps and is flexible enough to be adapted to the specificities of other case studies.

Future research could include the analysis of changes in stakeholders' viewpoints after their most intensive engagement in the actions of the REXUS project, also in view of assessing the effectiveness of the engagement roadmap.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Characteristics of the participating stakeholders, as assessed by the research team.

Code	Stakeholder's (Body) Description	Type	Level of Influence	Level of Interest
F1	Legal advisor, collective irrigation organisations	EXP	- - -	+
F2	Irrigation Organisation A	USER	- -	+ + +
F3	Irrigation Organisation B	USER	- -	+ + +
W1	National-level authority, water services planning and management	POL	+ + +	+ + +
EC1	International NGO related to environment protection	CIT	+	+ +
F4	Agricultural interprofessional organisation, Irrigation Organisation C	USER	- -	+ + +
EC2	Local environmental protection authority	CIT	+	+ + +

Table A1. *Cont.*

Code	Stakeholder's (Body) Description	Type	Level of Influence	Level of Interest
F5	Former representative of relevant chamber and currently involved in several actions for the improvement of water resource management in the basin	EXP	-	+
F6	Professor, expert in crop production and rural environment	RES	- - -	+
F7	Professor, expert in irrigation and water resource management	RES	- - -	+
W2	Professor, expert in water resource management and representative of international organisation for sustainable development	RES	- - -	+
EC3	Professor, expert in ecology and ecosystems	POL	+	+ + +
F8	Farmers' Cooperative of Thessaly	USER	- -	+ + +
F9	Regional authority related to agricultural development	POL	+ +	+ +
EC4	Former member of NGOs related to environmental protection	EXP	- - -	+
EN1	Wind farm development and installation company	COM	- -	+ + +
F10	National-level authority, cultivation systems and crop production	POL	+ + +	+ + +
F11	Agricultural Association A	USER	- -	+ + +
F12	Agricultural Association B	USER	- -	+ + +
W3	National-level authority, water environment protection and management	POL	+ + +	+ + +
F13	Regional-level authority related to agricultural economy and veterinary services	POL	+ +	+ +
W4	Professor, expert in water resource management	RES	- - -	+
F14	Irrigation Organisation D	USER	- -	+ + +
F15	National-scale authority related to irrigation water management	USER	- -	+ + +
EN2	National-scale corporation related to electricity supply	COM	- -	+ + +
W5	Professor specialising in water resource management	RES	- - -	+
F16	Food production and distribution company	COM	- - -	+ + +
W6	National-level authority, water services costing and pricing	POL	+ + +	+ + +
F17	Research organisation related to crop quality control, classification, and standardisation	RES	- - -	+
F18	Regional division of chamber related to geotechnical professionals	POL	-	+
W7	Regional authority responsible for water resource management	POL	+ +	+ +
F19	National authority related to land reclamation and mechanisation	POL	+ + +	+ + +
W8	Regional authority related to hydro-economy	POL	+ +	+ +
W9	Consortium of private companies involved in the development of water resource management studies in the basin	POL	+	+ +
EC5	Research organisation related to groundwater exploitation	RES	- -	+
EN3	Operator of hydroelectric plant	USER	- -	+ + +
F20	Organisation related to agricultural education and training	RES	- - -	+
F21	National authority related to land reclamation, soil, and water	POL	+ + +	+ + +
F22	Young farmer	USER	- - -	+ + +
EC6	Regional authority related to environment and spatial planning	POL	+ +	+ +
W10	Regional department of chamber related to geotechnical professionals	POL	-	+
EC7	National research organisation related to biodiversity and ecosystems	RES	- - -	+
W11	Professor, expert in water resource management and environment protection	RES	- - -	+
F23	Agricultural Cooperative	USER	- - -	+ + +

Appendix B

Appendix B.1 Session A: Ice Breaking

Q1: Which of the following sectors are you mostly associated with? (select 1 out of 4 predefined answers).

A1: More than half (54%) of the stakeholders who participated in the first meeting of the PRB pilot area self-identified as having ties to the water sector, and 25% had ties to the food/agriculture sector; a fact that reveals the importance of these sectors in the PRB. Representatives of the ecosystems/climate and energy sectors accounted for almost 21% of the participants.

Q2: What is your relation with the Pinios River Basin (work-residence-knowledge of PRB's nexus system)? (select 1 out of 4 predefined answers).

A2: The vast majority (90%) of the stakeholders who participated declared that they were familiar with the PRB nexus system, and therefore, they could play a significant role in the framework of the identification of management problems and solutions. Half (50%) of the participants did not reside or work in the basin, and these participants were mainly high-level stakeholders, including ministers and academics. The highest proportion of the stakeholders who were not familiar with the PRB nexus system were the stakeholders related to the energy sector (33%); a fact that is attributed to both the early development stage and the multivariate complexity of this specific sector in the study area.

Q3: How can problems of the Pinios River Basin be resolved to achieve resilience and sustainability? (select 1 out of 3 predefined answers).

A3: Most of the stakeholders (85%) acknowledged the need for equally approaching WEFE sectors to achieve resilience and sustainability; a fact that reveals a high level of understanding of the necessity for a holistic approach in resource management. Only a small proportion of stakeholders (4%) were pessimistic and believed that the problems in the PRB cannot be resolved. More than half (57%) of the stakeholders related to the food/agriculture sector appeared not to have a clear view regarding the pathway to achieve sustainability in the PRB. This is mainly attributed to the complexity of the agricultural sector in the study area, the viability of which presents probably the highest interdependency to the other sectors, and this sector has already suffered the impacts of economic and energy crises and climate change.

Q4: What do you expect to gain from being involved as a stakeholder in the REXUS project? (select maximum 3 out of 4 predefined answers).

A4: Almost 40% of the stakeholders were involved in a project centred around co-developing solutions in the context of a holistic management framework; a fact that demonstrates their high levels of motivation and strong desire for a sustainable future for the PRB, along with a strong belief and a demand for participating in shaping their future by directly affecting the sustainability of the basin or contributing their expertise to shape the future, even if they do not reside in the PRB.

Q5: What do you expect to gain from your participation in the current meeting? (select maximum 2 out of 4 predefined answers).

A5: None of the involved stakeholders considered their participation in the first PRB stakeholders' meeting as a chore. In particular, more than 40% of the stakeholders participated in the meeting in order to become more informed about the ways that they can be actively involved in the tasks and activities of the project. Almost 58% of the stakeholders participated in the meeting to express their interest/concerns regarding the PRB's challenges and also to become informed about the other stakeholders' perceptions.

The answers of stakeholders to Q1-Q5 are presented in Figure A1, where questions 1–5 correspond to responses a–e, respectively.

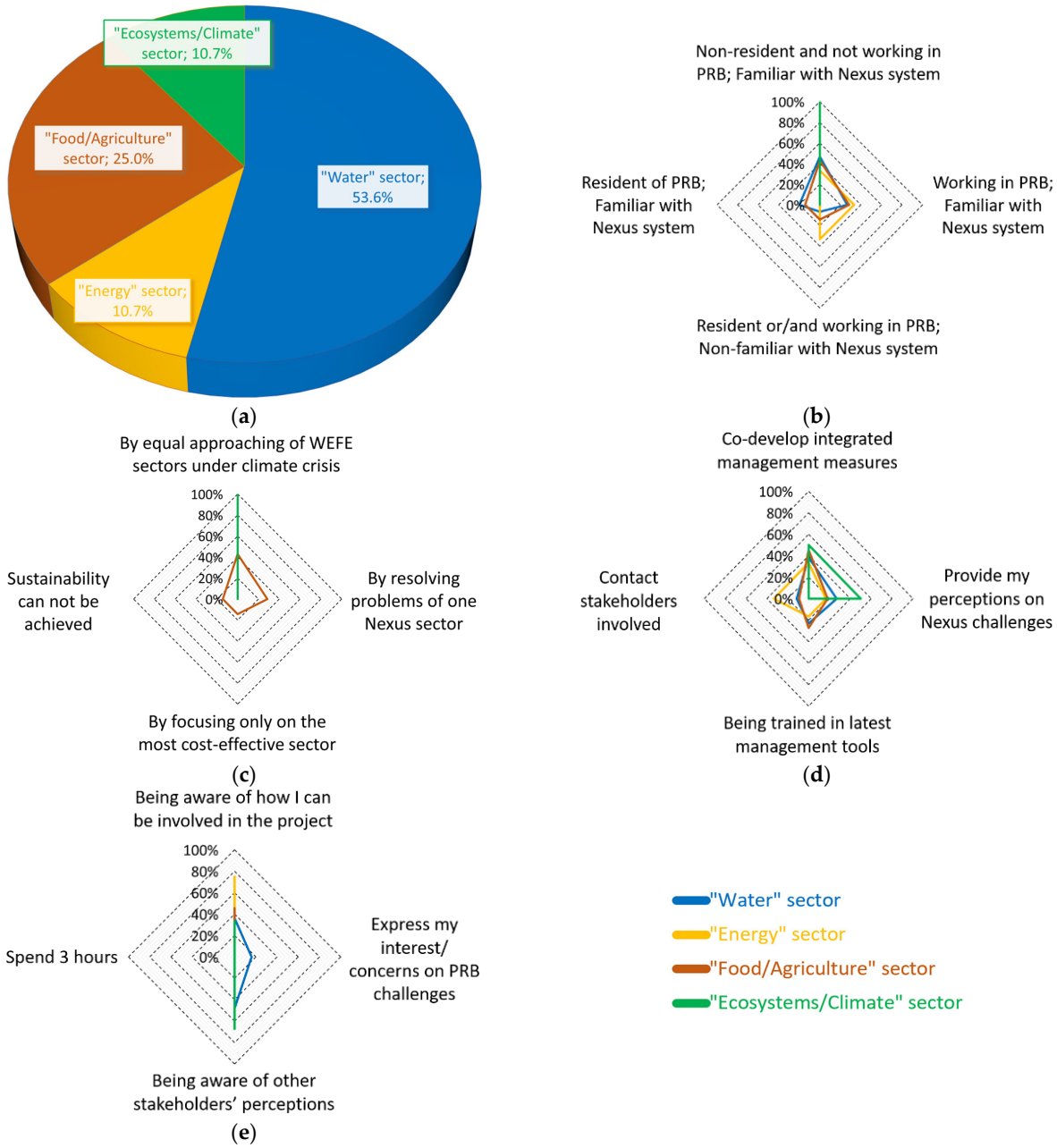

Figure A1. Responses of Pinios River Basin stakeholders to (**a**) Q1, (**b**) Q2, (**c**) Q3, (**d**), Q4 and (**e**) Q5 of the first crowd sourcing theme session.

Appendix B.2 Session B: Pinios River Basin Current Conditions

Q6: How can the management framework of the nexus system of Pinios River Basin be characterised? (select 1 out of 4 predefined answers).

A6: The vast majority of the stakeholders (90%) position the management framework of the PRB nexus system as a very complex spectrum, while only 10% of the stakeholders characterise it as moderately complex or simple. This fact reveals the limited effectiveness of previously implemented policies and poses higher expectations on the ongoing project. Only a small percentage (14%) of the food/agriculture-related stakeholders characterised the PRB's management framework as a simple one, believing that the promotion of new water transfer projects can simply address the relevant challenges.

Q7: Which sector of the nexus system faces the most crucial challenges? (select maximum 2 out of 4 predefined answers).

A7: Almost half (49%) of the participants consider the water sector as the PRB nexus sector that faces the most crucial challenges, followed by the ecosystems/climate (30%), food/agriculture (18%), and energy (3%) sectors. It should be highlighted that the water-related challenges are recognised as the most crucial ones by the stakeholders of all of the nexus sectors. The energy-related challenges are mostly recognised by the stakeholders related to the food/agriculture sector and are associated with the increased required energy amount and cost and thus agricultural production cost. Although the recognition of the high importance of the energy sector, the water, ecosystems/climate, and food/agriculture sectors seem to face most crucial challenges in the agricultural areas of the PRB in terms of the promotion of its socio-economic stability and development. The impulse response of the stakeholders may have been stimulated by the research teams' perception on the current challenges of the PRB, as expressed in a presentation that preceded the crowd sourcing meeting.

Q8: Which sector of the nexus system presents the highest complexity? (select maximum 2 out of 4 predefined answers).

A8: The water and ecosystems/climate sectors were suggested to present the highest level of complexity, according to the beliefs of 87% of the participating stakeholders.

Q9: How are the nexus sectors ranked according to their importance? (1-low to 4-high).

A9: The water sector (3.6 out of 4) was perceived as the most important sector in the PRB, followed by the food/agriculture (2.8 out of 4), ecosystems/climate (2.3 out of 4), and energy (1.5 out of 4) sectors. The water sector's high importance was unanimously recognised by stakeholders related to all PRB nexus sectors.

Q10: Which sector has already been investigated more thoroughly? (select maximum 2 out of 5 predefined answers).

A10: The food/agriculture sector (58%) was identified as the sector that has been the most extensively investigated, according to the perceptions of the participants, followed by the water (38%) and energy (4%) sectors, while none of the participants recognised the ecosystems/climate sector as the most studied one. This fact reveals that previous efforts and policies have mainly focused on the food/agriculture and water sectors, thus reflecting their importance for the PRB. Apparently, this approach denotes the "traditional" tendency to disregard, at least to an extent, the roles of the ecosystems/climate and energy sectors in sustaining the nexus system of a basin, despite the fact that large portions of the PRB's area have been included in one or more lists of environmental protection areas.

Appendix B.3 Session C: Management Practices

Q11: How do you characterise the efficiency of the management framework related to the challenges of your sector? (select 1 out of 5 predefined answers).

A11: Most (63%) of the stakeholders characterised the management framework efficiency of the sector they are involved in as moderate, followed by those who believe that the management context is low (25%), high (1%), or very low (1%). The moderate characterisation was found to be the most popular answer among the stakeholders from all the different nexus sectors. This fact reflects the efficiency of the previously implemented management policies in the PRB, which were deemed to have moderate impacts.

Q12: Which pairs of nexus sectors present the strongest interaction? (select maximum 2 out of 6 predefined answers).

A12: Half (50%) of the participants believe that the water–food/agriculture pair present the highest inter-dependency in the PRB, followed by the water–ecosystems/climate (30%), water–energy (7%), energy–ecosystems/climate (7%), food–ecosystems/climate (3%), and energy–food/agriculture (3%) pairs. It should be highlighted that the top three pairs with the strongest interaction in the PRB include the water nexus component, which denotes the importance attributed to the sector by all the different groups of stakeholders.

Q13: To what extent do the existing management practices consider more than one sectors? (select 1 out of 5 predefined answers).

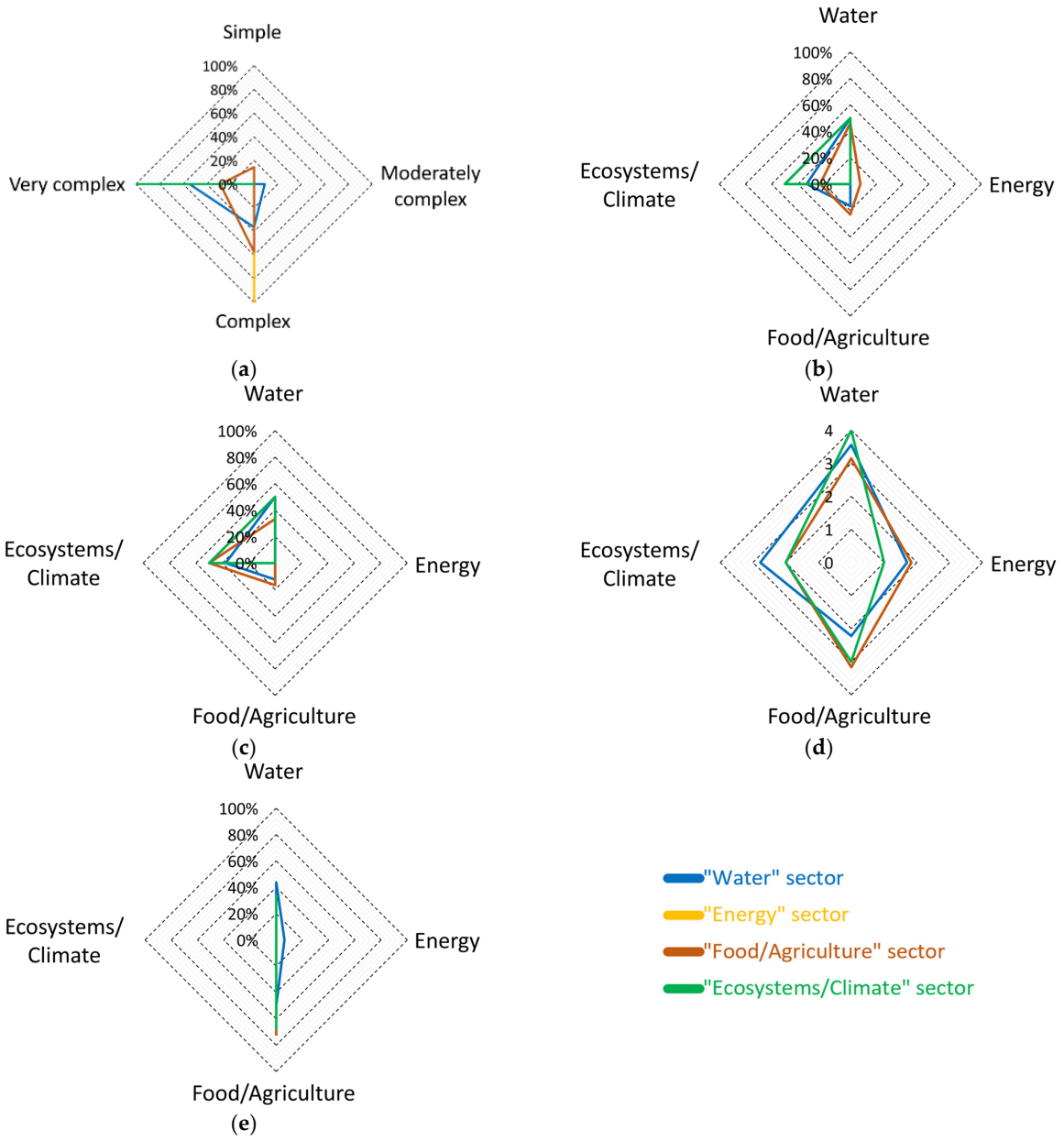

Figure A2. Responses of Pinios River Basin stakeholders to (**a**) Q6, (**b**) Q7, (**c**) Q8, (**d**) Q9, and (**e**) Q10 of the second crowd sourcing theme session.

A13: The vast majority (88%) of the stakeholders believe that the existing practices consider the other nexus sectors in the PRB to a moderate or low degree, followed by those who believe that other sectors are considered to a very low (6%) or high (6%) degree.

Q14: Which is/are the main basis/-es of management practices' selection? (select maximum 2 out of 5 predefined answers).

A14: The influential capacity of some stakeholders was recognised as the major factor affecting the selection of management practices by almost half of the stakeholders (44%), followed by the active stakeholder engagement (22%), non-active stakeholder engagement (15%), acceptance by local society (11%), and scientific evidence and sustainable development (8%), according to the perceptions of the participating stakeholders. The influential capacity of some stakeholders was found to be the most popular answer by the participants across all nexus sectors.

Q15: How is your sector affected or will be affected due to climate change? (select 1 out of 5 predefined answers).

A15: The vast majority (93%) of stakeholders believed their associated sector is already or will be highly or immensely affected by the climate crisis. Only 7% of the stakeholders believed that their sector is or will be moderately affected by climate change, while none of them assumed that climate change will not affect their related sector at all or minimally. It is also worth mentioning that most of the stakeholders related to the water and food/agriculture sectors believed that climate change is already having or expected to have a very high impact on their sectors. This perception is probably influenced by the intense and prolonged drought periods and the extreme precipitation events that recently occurred in the PRB, including the tropical-like cyclone named Ianos, which impacted the wider area in September 2020. The Ianos cyclone was the most intense medicane ever recorded in the Mediterranean region [94], causing casualties, severe floods, extensive infrastructure destruction, and heavy agricultural damage.

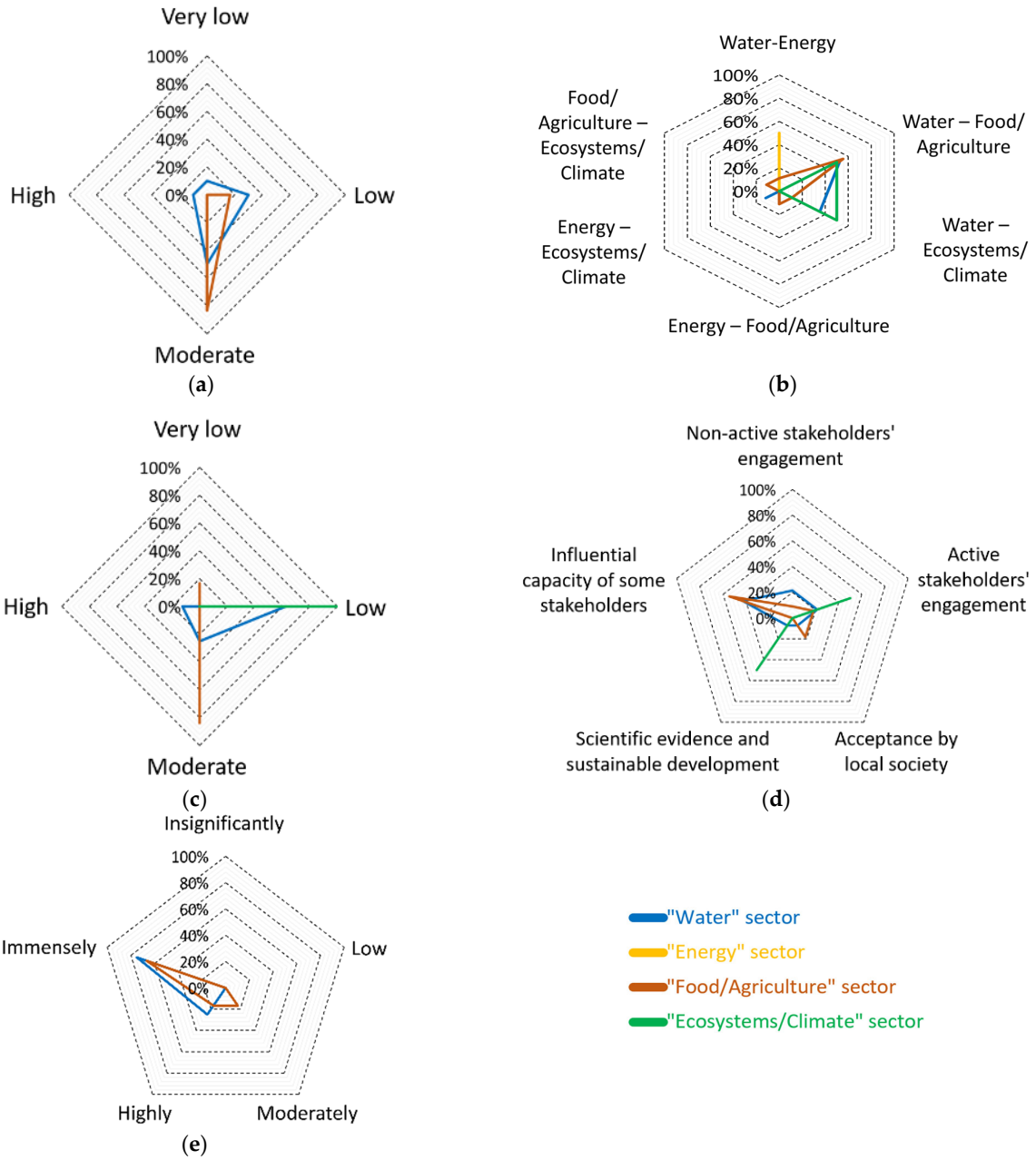

Figure A3. Responses of Pinios River Basin stakeholders to (**a**) Q11, (**b**) Q12, (**c**) Q13, (**d**) Q14, and (**e**) Q15 of the third crowd sourcing theme session.

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