LEarning and action alliances for NexuS EnvironmentS in an uncertain future

LENSES

WP3

D3.1 Report on adequacy of pilot governance structure to manage Nexus interactions

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Executive summary

One of the key issues that need to be addressed to enable the sustainable Water-Ecosystem-Food (WEF) Nexus management concerns the overcoming of the institutional fragmentation. As already pointed put by several authors, quantitative approaches to the WEF nexus management would fail if not supported by interventions aiming at overcoming the policy fragmentation. Although efforts were carried out for detecting barriers hampering the collaboration among the different sectors involved/interested in the WEF nexus, still limitations need to be overcome. Specifically, most of the existing methodologies focuses exclusively on the interactions among the institutional actors. In this work, the production and provision of Ecosystem Services (ESs) are at the core of the analytical approach. Therefore, we assume that the institutional system is conducive if it facilitates the ESs production and provision. To this aim, a system-based approach was adopted in this work. Efforts were carried out to map the complex interactions within the Socio-ecological and technological (SET) system. Then, Graph Theory measures were implemented to detect and analyze vulnerable elements in the SET system, i.e. elements that, due to their position in the system, could hamper the ESs production and provision. The methodology was tested in two of the LENSES case studies. The lessons learned are used for improving the methodology and to transfer it to the other case studies.

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1. Introduction

The Water-Ecosystem-Food (WEF) Nexus framework was introduced to account for the complex interactions among these three sectors, to enhance synergies among the policies in the different sectors, avoid unintended trade-offs and inform cross-sector collaboration and policy coherence (Pahl-Wostl et al., 2018). Despite the benefits of the WEF Nexus approach, policy, planning and management decisions are often made without accounting for the impacts on the related sectors and the potential unintended consequences. Previous studies described several barriers hampering effective collaboration in Nexus management, such as power asymmetries, lack of trust, lack of communication, rigid sectoral planning approaches and regulations, and fragmented knowledge (Oberlack, 2017; Weitz et al., 2017).

A recurring criticism of the WEF Nexus thinking is that it adds little to the existing approaches aiming at achieving integration and coordination for efficient, equitable and sustainable management of natural resources - e.g. the Integrated Water Resources Management (IWRM) (UN-WATER, 2008). However, as pointed out by several authors (e.g. Bazilian et al., 2011; Stringer et al., 2018), the WEF Nexus' novelty stands in the need to adopt a holistic view - instead of the water-centred one, as in the IWRM. Moreover, the WEF Nexus focuses explicitly on the relationships and interdependencies across sectors, it is built around the awareness of the existing policy fragmentation across the different sectors. It puts at its core the need for a systematic and simultaneous dovetailing of governance approaches in the various sectors (Weitz et al., 2017; Pahl-Wostl, 2019) since technical and physical interconnections that ignore the need for coordinated policies are likely to fail (Pahl-Wostl, 2019).

WEF Nexus is based on the idea that failing to account for connections among the different sectors could worsen resource scarcity and induce trade-offs and conflicts. WEF Nexus security claims for enhancing the resilience of the human-environment-technology system as a whole, unpacking relations and interactions among the different elements of the system (Pahl-Wostl, 2019). Analytical approaches to identify the facilitating and hindering conditions for cross-sector coordination and collaboration, illuminate roles and relationships among the different actors involved in WEF Nexus management, diagnose trade-offs and security issues, and identify opportunities for transformations toward a more collaborative policy-making are required (Stringer et al., 2018; Pogue et al., 2020; Johns and White, 2021).

Starting from these premises, the main scope of this deliverable is to **develop a framework for assessing the capacity of the institutional contexts to enable the sustainable management of the WEF Nexus**. Besides, the framework will support the **identification of barriers** hampering the achievement of a satisfactory level of policy coherence. The results of this analysis will be then used to support **the development of policy scenarios**, in cooperation with WP4.

The literature review concerning the WEF Nexus policy-making shows that the vast majority of the work on collaborative environmental governance is entirely focused on the social and political processes, whereas the characteristics of the ecosystems, as the target of the governance efforts, are mainly disregarded. The numerous ways in which people and ecosystems interact could create complex patterns of socio-ecological interdependencies, where actions and outcomes in one component can lead to actions and outcomes in another, either intentionally or unintentionally (trade-offs) (Bodìn et al., 2019). In LENSES, we assume that collaborative processes for WEF Nexus should be devised accounting for the constraints posed by the biophysical characteristics of the ecosystem (Bodin & Tengo, 2012; Bodìn, 2017).

Ecological interdependencies are fundamental for the functioning of ecosystems. Compromising ecological connectivity could jeopardize the capability of the ecosystems to produce and provide the ecosystem services (ESs) that societies are relying on. Everything that humans derive from nature is produced by ecosystems, and not by one specific type of biophysical entity in isolation (Furst et al., 2017; Yuan & Lo, 2020). Considering the centrality of the ESs production for the WEF Nexus resilience - see D4.1 for more details on this - maintaining the ecological links is crucial and could become particularly challenging if two interdependent ecological components are managed/used by different actors who are not coordinating their activities. This could lead to unintended trade-offs hampering the production of ESs. Thus, protecting the ecosystems' ability to deliver contributions to people to support current and future generations demands a holistic understanding of human-environment relations (Stringer et al., 2018), accounting for the key ecological interdependencies that need to be captured in the analytical framework along with the socio-institutional structure. Holistic approaches that integrate social and ecological system perspectives can help unravel the complex linkages and feedback occurring across temporal and spatial scales, and between different levels, sectors and groups for the management and use of ecological resources. Moreover, adopting a socio-ecological approach for the WEF Nexus analysis helps in defining meaningful Nexus system boundaries, and identifying the right and relevant stakeholders and decision-makers to be involved in the system analysis (Furst et al., 2017). In doing this, LENSES contributes to the progress in measuring and theorizing complex patterns of social and ecological interdependencies for ESs production.

On the conceptual level, and in line with Bodìn (2017), we assume that socio-ecological fit implies that the structure of a collaborative network - i.e. the actors and their collaborative network - should be aligned with the structure of the ecological system being governed (Bodìn, 2017; Bodìn et al., 2019). A better socio-ecological fit is accomplished if the links in the ecological system are paired in the socio-institutional network (Bodìn, 2017).

In this work, we adopted a network-based approach for assessing the capability of the socio-institutional system to activate collaborative WEF Nexus policy-making. We considered the network approach as a perspective where a system is described and analysed as a set of nodes. The various types of relationships among them are described and analysed as links (Bodìn et al., 2019). Social network analysis (SNA) has become an important tool for analysing and understanding natural governance systems. In the context of the WEF Nexus, SNA has been implemented to understand the communication complexity present within the Nexus, and the functioning of the whole network. SNA can help to address patterns of actors' relationships and to identify potential power asymmetries. Finally, SNA has been adopted to highlight the multi-scalar nature of the Nexus governance system (Jones and White, 2021).

Contrarily to traditional socio-institutional network analysis, whose main scope is to detect governance gaps in the WEF Nexus by analysing the network of formal and informal interactions among the different actors, the socio-ecological network-based approach considers actors as being linked also through shared ecological resources, management of ecological processes and ESs production and use (Pahl-Wostl, 2018). Therefore, governance gaps in the WEF Nexus could be due to the fact that actors are linked via interactions in the biophysical system that have no appropriate correspondence in the network of socio-institutional interactions. The development of coherent WEF Nexus policies does not only require collaborative networks fitting the specifics of the collective action problem - i.e. cooperation vs. coordination. It should also fit the underlying characteristics of the biophysical system.

Misfits in the socio-ecological network can happen due to the misalignment of the social and ecological connectivity - e.g. if two non-collaborating actors manage two separate but interconnected ecological components - or when the landscape is divided into administrative, management, and categories that do not account for the coherence and continuity of the landscape and of the ecological resources and processes (Bodìn, 2017; Pahl-Wostl, 2018).

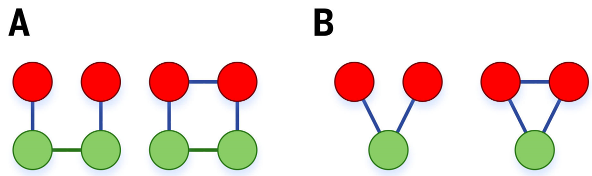

Figure 1. Horizontal fit in the socio-ecological network

As shown in figure 1, the alignment between the social and ecological networks requires that two separate entities (red) managing two interconnected ecological resources (green) should have a collaboration link (part A of the figure). A similar misalignment could happen if two entities are managing/using the same resource, without collaborating (part B of the figure).

The adoption of an integrated network for the ESs assessment was suggested by (Dell et al., 2017) as a way to better address this kind of misalignments. In the integrated network for ESs, nodes representing ESs can be connected to an ecological network (i.e. by specifying which ecological resource provides each ES) and to a socio-institutional network (i.e. establishing which actor uses the resources, benefit from the ES, manage the ecological resources, or produce pressures affecting the ecological processes for ES production) (Grizzetti et al., 2016; Dell et al., 2017; Stringer et al., 2018; Pogue et al., 2020). Although these network-based approaches can be particularly useful in unravelling the complex system of interactions affecting ESs production, there are some drawbacks that need to be overcome. Firstly, existing approaches seem to focus primarily on the elements and processes affecting the production of ESs and tend to ignore the other aspects related to the flow, distribution and use of the ESs by the final beneficiaries. ESs production capacity could be of a purely theoretical nature (Furst et al., 2017). Moving from the ESs capacity - i.e. the potential of an ecological resource to produce specific ESs (Pogue et al., 2020) - towards their mobilization and realization, requires the activation of key elements of the socio-ecological-technological system, such as users' perceptions, skills and management, technological innovation and infrastructures, and institutions (Andersson et al., 2021). Therefore, we need to introduce the technological component of the system, defining the Socio-Ecological-Technological (SET) system. Secondly, the developed network-based frameworks seem capable of analysing the current conditions and assessing the fitting of the socio-institutional network for enabling ES production and flow but have limited capabilities to detect the main causes of this misfitting and to suggest potential interventions. Finally, the ecological system should not be considered static since its components and connections evolve and change over time. Therefore, the socio-institutional network should be capable of adapting itself to the changing conditions, to keep in alignment with the ecological network (Bodìn et al., 2019).

Starting from these premises, this work describes an innovative ES- and network-based approach for:

i) mapping the complex web of interactions among actors, ecological resources and human assets (e.g. knowledge, infrastructures, etc.) affecting the production, the flow and the use of ES;

ii) detecting and analysing the barriers hampering the ES production due to lack of effective interactions; and

iii) defining networking interventions aiming at overcoming the detected barriers.

The adopted approach is based on the integration of scientific and stakeholders' knowledge for developing and analysing the SET network for WEF Nexus security. By implementing this approach, the work aims at demonstrating that policy interventions for enhancing the effectiveness of the interaction mechanisms within the WEF system are crucial for achieving WEF security.

2. Socio-ecological-technological (SET) network analysis or the WEF Nexus

As previously introduced, the key aim of this deliverable is to present a framework that allows the identification of key barriers for the WEF Nexus security and the assessment of the capacity of the institutional contexts to enable the WEF Nexus sustainable management. This approach is based on the construction and analysis of a socio-ecological-technological framework. The following table describes the different methodological steps included in this framework.

Table 1. Description of the methodological steps

Methodological step	**Objective**	**Adopted method/tool**
Mapping the SET system	Develop the socio-ecological-technological (SET) network referring to the stakeholders' perception and scientific/experts' knowledge.	Individual semi-structured interview Experts' knowledge elicitation and literature review Aggregation phase Causal Loop Diagram
Network analysis and barriers detection	Transforming the SET network in the meta-network for the network analysis. Identify and analyse the main barriers hampering the effective WEF Nexus management due to lack of effective interaction in the SET network	Organization Risk Analysis approach Graph theory measures
Networking interventions	CO-defining policies for overcoming the detected barriers and to enhance the capacity of the SET network to produce and provide the ESs for the WEF Nexus security	Scenario building and analysis

The first step in the adopted approach concerns the mapping of the complex and non-linear connections among the different elements affecting the production, provision and use of the ESs in the SET system. To this aim, different kinds of knowledge were elicited, structured and aggregated. Specifically, the map of the

SET system was developed referring to: i) the stakeholders' knowledge and perceptions about ESs to be produced, the key elements, resources and processes - both natural and human - affecting the production and provision of the ESs for the WEF Nexus security; ii) the existing literature concerning the management of ecological resources and process for the production of ESs; and iii) to the experts' knowledge concerning the existing and potential barriers to ESs production and provision. At the end of this phase, the SET network is defined, with specific reference to the non-linear web of connections among the different actors, resources, processes and infrastructures. Then, the subsequent phases aim at analysing the SET network and detecting barriers to ES production and provision for the WEF Nexus security due to ineffective interaction mechanisms in the SET network. To this aim, the Organization Network Analysis (ORA) (Carley & Pfeffer, 2012) was adopted. Finally, the results of the SET network analysis will be used to co-develop networking interventions, i.e. policies whose main scope is to overcome the detected barriers and enhance the effectiveness of the SET network in producing and providing the expected ESs (Valente, 2012) as part of the implementation plan of each of the pilots (e.g., collaborative actions integrated visioning and PSDM). The latter activity will be carried out in the coming months.

The following sections describe the details of the above-mentioned phases.

2.1. Mapping the Socio-Ecological-Technological system

This phase aimed at mapping the complex web of interactions among the different socio-ecological and technological elements influencing the production and provision of ESs for the WEF Nexus security. To this aim, two different sources of knowledge were accounted for. Firstly, existing scientific studies and institutional documentation concerning the ecological resources, ecological processes, infrastructures and human-induced pressures were considered. The institutional framework related to the management of ecological resources and the production and provision of ESs were analysed as well. This phase allowed us to start developing the causal connections among the different elements of the SET system.

Secondly, the stakeholders in the different case studies were involved in a participatory SET mapping exercise organized in cooperation with WP4. This phase aimed at collecting and structuring stakeholders' perceptions about the key ESs to be produced for the WEF Nexus security, and their understanding of the main elements, resources, processes and pressures affecting the ESs production and use. Moreover, the main actors interested/involved in the different phases of the ESs production were elicited and included in the SET mapping. In addition, the participants' understanding of the connections among the different elements was elicited as well. The knowledge collected in this phase was integrated into the draft of the SET network.

In order to represent the richness and diversity of the knowledge and perceptions about the functioning of the SET network, individual semi-structured interviews were carried out, and individuals' cognitive models were developed. Specifically, the interviews were meant to collect stakeholders' understanding concerning: i) the perceptions of WEF Nexus security; ii) the main ESs to be produced for achieving WEF Nexus security (i.e., water security, food security, maintaining delivery of ESs); iii) the most important ecological resources and processes to be activated; iv) the human resources, both physical (e.g. infrastructures) and non-physical (e.g. social capital, expertise, knowledge, etc.) contributing to the ES production and use; v) the main pressures due to human activities; vi) the main actors to be involved in the analysis - i.e. the ES beneficiaries, the managers of the ecological resources, the actors exerting the detected pressures-. The interviews aimed also at collecting stakeholders' understanding of the connections among the elements, resources and processes in the SET network.

The stakeholders' narratives collected during the interviews were translated into the causal diagram. Most of the connections in this diagram are cause-effects connections. These connections are characterised by a polarity. A positive link between elements A and B means that the increase of A would lead to an increase in B. A negative link means that the increase of A would lead to a decrease of B. The links in the SET map are also characterised by weight, representing the stakeholders' perception of the strength of the connection. To account for the role of actors in the SET system, different non-causal connections between actors and the other elements were added to the network. Specifically: i) an actor-resource link means that the actor owns and/or manages that specific resource; ii) an actor-process link means that the actor activates the process (e.g. water consumption); iii) an actor-actor connection means that there is either cooperation (i.e. positive link) or a conflict (i.e. negative link). Dashed lines were used in the map to differentiate these links from the causal connections.

At the end of each interview, an individual SET map was developed. The community SET map was, then, obtained by aggregating the inputs of all involved stakeholders. The aggregation method described by Giordano et al. (2020) was adopted in this work. A sequential aggregation process was carried out. Firstly, individual maps were aggregated into three sectorial maps, representing the different WEF Nexus security dimensions - i.e. water, ecosystems services and food securities. To this aim, the individual maps were translated into square adjacency matrices of the same size, added and divided by the total number of individual matrices. This operation results in a new matrix, the entries of which were the average of the weight assigned by the stakeholders. In this work, all respondents were equally considered; therefore a credibility weight was not introduced. The process of individual maps' aggregation stopped when all maps were aggregated. Then, these sectorial maps were aggregated to obtain the community SET system map. The aggregation of the sectoral SET maps was carried out by identifying elements and connections.

At the end of the aggregation phase, the map showing the stakeholders' perception of ESs for the WEF security, and their understanding of the complex web of interactions affecting the ESs production and provision was developed and ready for network analysis.

2.2. Developing the SET network

The main scope of this phase is to analyse the SET map by implementing the network analysis measures and, in doing so, detecting key barriers to the ESs production, provisioning and use due to ineffective SET network. Among the different methods available for carrying out network analysis, in this work, we adopted the Organizational Risk Analyser (ORA) (Carley & Pfeffer, 2012). Compared to other network analysis methods, ORA has several advantages making it more suitable for achieving the main goal of this work. Firstly, ORA does not aim exclusively to identify the most central element in the network. ORA is meant to combine computational organizational theory and network theory for describing, understanding and predicting the behaviour of complex and networked organizations, and assessing risk and network vulnerabilities. Network vulnerabilities refer to specific elements in the network whose failure, due to their position in the network, could provoke the failure of the whole network or a drastic reduction of its functionalities. In this work, a failure of the SET network would result in a reduction of the SET capabilities to produce and provide the key ESs and, consequently, affects the WEF Nexus resilience.

The basic assumption of the ORA approach is that the performances of a complex organization are not simply influenced by the structure of relationships among human actors. A complex organization depends also on how actors use and exchange knowledge, manage resources and cooperate to fulfil specific tasks. These entities and their relationships are represented by a collection of networks called meta-matrixes. The following table shows the different meta-matrixes.

Table 2. ORA meta-matrixes (Carley & Pfeffer, 2012).

	People	Knowledge	Resources	Tasks/Projects
People	Social Network *Who talks to, works with, and reports to whom*	Knowledge Network *Who knows what, has what expertise or skills*	Resource Network *Who has access to or can use which resource*	Assignment Network *Who is assigned to which task or project, who does what*
Knowledge		Information Network *Connections among types of knowledge, mental models*	Resource Usage Requirements *What type of knowledge is needed to use that resource*	Knowledge Requirements *What type of knowledge is needed for that task or project*
Resources			Inter-operability and Co-usage Requirements *Connections among resources, substitutions*	Resource Requirements *What type of resources are needed for that task or project*
Tasks/ Projects				Precedence and Dependencies *Which tasks are related to which*

Given that the ORA method was developed for analysing risk and vulnerabilities in human and virtual organizations, the use of the ORA methods for analysing the SET network requires some conceptual assumptions. In this work, the SET network was conceptualized as a hybrid and complex organisation composed of humans, ecological and technological elements. In this network, resources can be either human - e.g. infrastructures, knowledge, expertise, etc.-, technological or ecological. Ecological and anthropic processes were represented as tasks in the ORA analysis. The weights of the connections in the meta-matrixes were defined by accounting for the links in the SET system model. The ORA meta-matrixes were slightly changed to account for the SET network peculiarities, as reported in the following:

1. Agent X Agent. The entities of this network are all the actors involved/interested in the ESs production, provision and use: i.e. who benefits from the ESs, who owns or manages the ecological resources and/or the human resources (e.g. infrastructures), and who activates/influences a process affecting (either positively or negatively) the ESs production and provision. The links in this meta-matrix represent the connections among the different agents, i.e. collaboration and cooperation, information and knowledge exchange, and regulatory connections. Negative links in this network represent already existing conflicts between two agents.
2. Agent X Resources. A definition of the "resources" entities in this work is needed. Here we refer to both natural and human resources. The formers are all the natural resources that contribute to the production of the ESs - e.g. groundwater, rivers, forests, land, etc. The latter can be either physical - e.g. irrigation infrastructures - or cognitive - e.g. skills and knowledge. The connections in this meta-

matrix show who has access to specific resources, and who manages, owns and uses resources. Considering the scope of this meta-network, we do not account for the different nature of the links between agents and resources.

3. Resources X Tasks. This meta-matrix shows the resources that are needed in order to fulfil specific tasks. Given the nature of the SET network, we assume that a task could be either a human activity - e.g. irrigation - or a natural process - e.g. groundwater recharge - that needs to be activated to produce and provide the ESs. As already explained, "resources" could be either natural elements or human resources. Referring to the latter example, the resources that need to be activated to fulfil the task of "groundwater recharge" are the rainfall and the soil.
4. Tasks X Tasks. This meta-matrix shows the connections among the different tasks to be fulfilled, that is, the different processes that need to be activated in order to facilitate the production and provision of the ESs. Processes in the SET network can be connected either through positive or negative links. Negative connections are introduced in this meta-matrix to account for the existing trade-offs among competing processes (tasks). As an example, the human process of "groundwater use for irrigation" is negatively connected with the ecological process of "groundwater recharge". A positive connection means that the activation of a specific process is needed to activate the connected one.

The following table shows an example of an Agent X Task meta-matrix.

Table 3. Agent X Task meta-matrix

	T1	T2	Tm
A1	W11	W12	W1m
A2	W21	W22	W2m
An	W31	W32	W3m

The cells of this matrix represent the strength of the Agent X Task connections, that measure how important is a given task for a specific agent. Similarly, the cells in the Agent X Resource meta-matrix describe the degree of ownership or access to a specific resource by the agents. The Resource X Task meta-matrix cells show how important a specific resource is for carrying out the different tasks. Finally, the cells of the Task X Task meta-network describe how strong the impact - positive or negative - of a specific process over another one is.

2.3. Analysing the SET network and detecting the main barriers

The developed meta-matrixes describing the SET network were then analysed in order to detect the key barriers hampering ESs production and provision. To this aim, Graph Theory measures were used. Two families of measures were implemented in this work:

- Firstly, network-based measures aiming at analysing the structure of the whole SET network and assessing its capacity for enabling ESs production and provision.

- Secondly, nodes-based measures to identify the key vulnerable elements in the network, i.e. those elements that, due to their position in the network, could negatively affect the capability of the SET system to produce and provide the needed ESs.

According to previous works, examining the whole network structure can provide insights into the level of collaboration across the system. Bridging structures focus on the connections among different groups (Jones and White, 2021). Network centralisation can be used as a proxy measure of the communication level in the network. The value of this measure varies between 1 (this indicates a completely centralized network, that is, all connections pass through a single actor) and 0 (this indicates a perfectly distributed network). A second network-based measure is the E-I index. This measure provides an indication of the structure of the network and its orientation towards either within-sector or between-sector collaboration. This is a measure of the external versus internal ties, and it aims at measuring the level to which a group is oriented towards within-group embeddedness. External ties - also called bridging ties - connect different subgroups, while internal ties are those within the same subgroup. This measure provides insights into the level of collaboration within and between different subgroups (Jones and White, 2021). The value of this measure varies between -1 (this indicates a full closure network, where all actors only collaborate with those outside their own subgroup) and 1 (this indicates full bondedness, where actors only collaborate with those within their own subgroup). The capacity of the network to enable collaboration can be assessed also implementing the 'betweenness centrality'. Although this is a node-level measure, it allows for identifying the specific agents who most serve as bridges between different subgroups. Finally, the network density is a direct examination of the level of connectivity of the global network. The density measure examines whether or not the actors' connections are also connected to each other. A network has a high level of density if all actors are connected to all others - a rarely occurring situation. Jones and White (2021) suggested using this measure to assess the level of trust within the network.

However, most of the existing works implementing network measures focus exclusively on the institutional network and aim at assessing its capability of enabling collaborative policy-making. In this work, coherently with the work of Bodìn (2017), these measures were implemented to investigate to what extent the structure of the SET network enables the effective production and provision of the ESs needed to guarantee the WEF Nexus security. Therefore, the network analysis puts the ESs at its core and aims at assessing the complex web of connections among the different agents, resources and infrastructures. Potential trade-offs among the different ESs affecting the WEF Nexus security are detected. Therefore, we need to slightly change the meaning of the network measures that have been previously introduced. A highly centralized SET network means that there is a highly dominant ES, which is strictly connected to most of the other elements in the network. In this work, the E-I analysis is carried out by creating clusters around the ESs and accounting for the connection within and between the different clusters. Therefore, a high value of the E-I index means that the different ESs are strongly interconnected with each other. In a similar network, it becomes important to further investigate the connections among the ES-based clusters to verify whether these connections represent trade-offs or not. Finally, the density of the network shows how interconnected the different elements of the SET are.

The second group of network measures aims at identifying the key vulnerability in the SET network. That is, the elements that, due to their position in the network, could negatively affect the ESs production. To this aim, we adopted three different combinations of graph theory measures, as shown in the following table.

Table 4. Node-based measures for network vulnerabilities.

Graph theory measures	Meta-matrix	Definition	SET meaning
Individual congruence	Agent X Agent Agent X Task Task X Task	Individual Congruence represents the proportion of an individual's tasks whose collaboration requirements were satisfied through some type of actual collaboration activity carried out through some means of interaction by the agent.	If an agent is expected to carry out several tasks, but she/he is a rather isolated agent, she/he represents a risk for the SET effectiveness because there is limited cooperation in carrying out the tasks.
Resource-based access index	Agent X Agent Agent X Resources	It indicates if an agent has exclusive access to a specific resource and if she/he is well connected with the other agents.	If an agent is rather isolated but has access to key resources, she/he could represent a risk due to the limited capability to share the resource.
Agent Resource Needs Congruence	Agent X Resource Agent X Task Resource X Task	Agent Resource Needs compares the resource needs of the agent to do its assigned tasks with the actual resources of the agent. The measured value for an agent increases when it has the need for resources to which it is not assigned.	The incapability of specific agents to access the needed resources could negatively affect the fulfilment of key tasks for ES production and provision.

Figure 2 provides an overview of the methodological approach that is being applied for the mapping, development and analysis of the SET network towards the identification of key variables and meaningful information for the development of policy scenarios. Specific examples about the implementation of this approach in some of the LENSES pilots is provided in section 3.

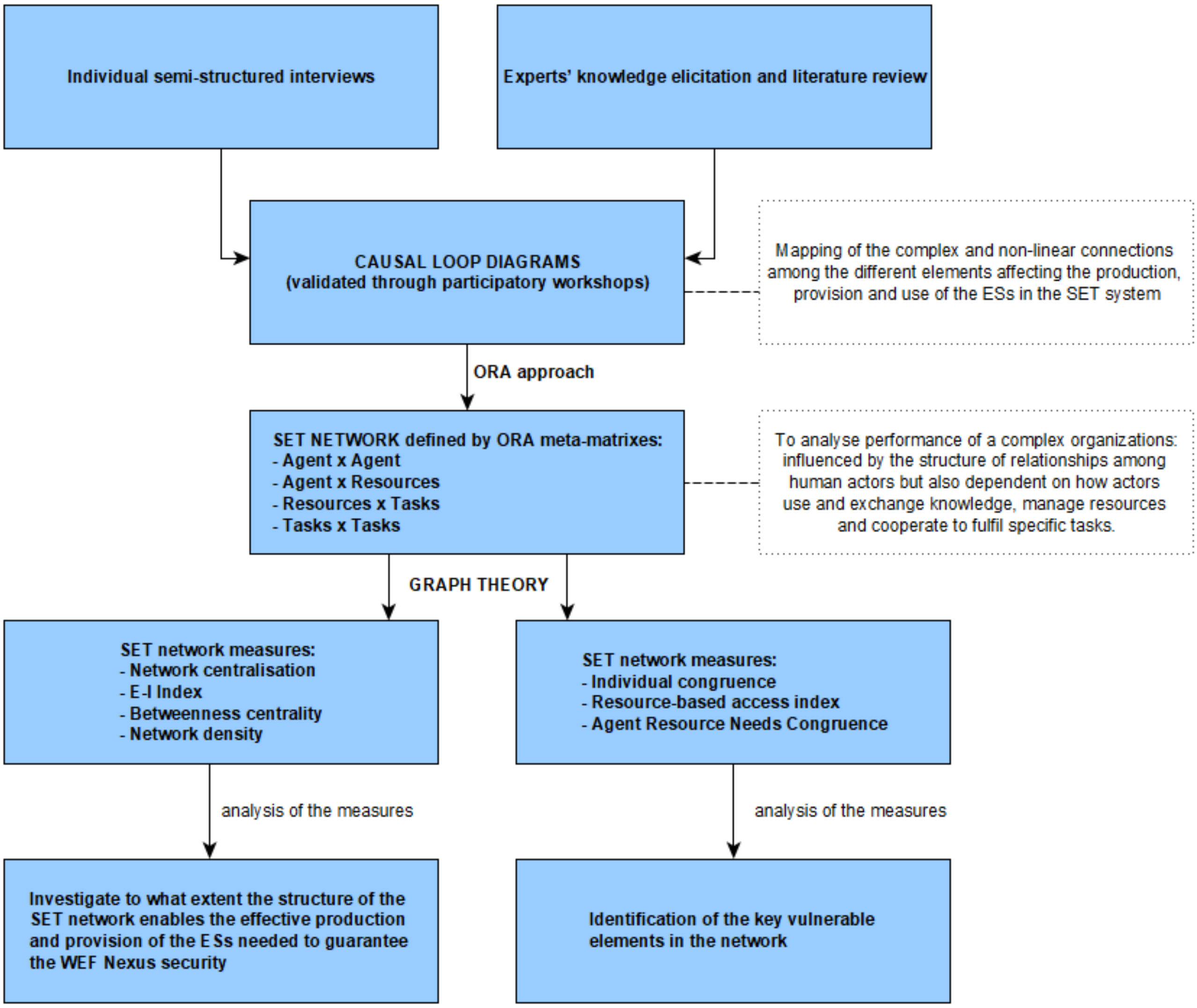

Figure 2: Overview of the methodological approach

3. SET network analysis in some of the LENSES case studies

As an initial step, the approach has been defined and developed for the pilot cases where the participatory System Dynamics Model (PSDM) is being fully implemented, namely the Doñana region and the Tarquinia plain. This decision was based on the possibility to adapt the participatory processes necessary for the development of the model for the collection of the information required for the SET analysis. However, we are currently collecting data and information from the other cases to extend the analysis over other LENSES pilots also interested in the adequacy of the governance structure for the Nexus management. The final results will be described in the deliverable D3.3.

3.1. The SET network in the Doñana case study

The following table shows the stakeholders engaged in the SET mapping.

Table 5. Stakeholders involved in the mapping exercise.

Stakeholder	Main sector(s)	Main Role(s)	Interview format
Spanish Geological Survey (IGME)	Water	Research	Online
Guadalquivir river basin authority (CHG)	Water	Water resources management	Online
Farmers Union – ASAJA	Food production	Providing technical support to farmers	In person
Doñana Nature	Ecosystem	SME organizing touristic trips in the Doñana protected area	In person
Farmers	Food production	Rice cultivation	In person
WWF	Ecosystem	Environmentalist NGO, with a specific working program in Doñana	In person
Optiriego	Food production	SME Providing technical support to farmers in irrigation optimisation	In person
Policy expert	Water / Ecosystem	Expert in water management and environmental protection	In person
Regional Authority – Agriculture Dept.	Food production	Land use policy and agriculture management	In person

The framework for the interview was implemented and the CLD was developed, as shown in the following figure.

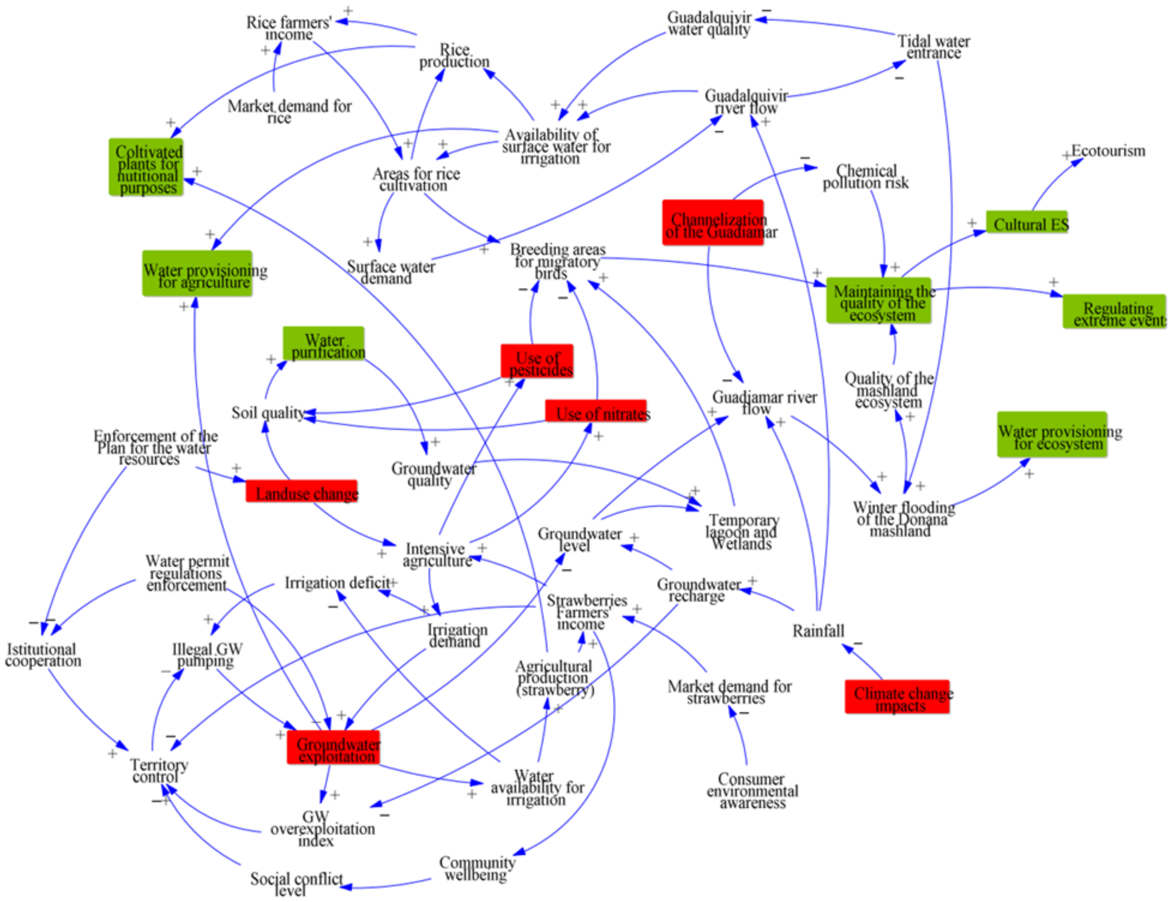

Figure 3: CLD developed for the Doñana case study

The next step concerned the development of the different meta-matrixes forming the SET network. The following tables show the different elements of the SET network. The methodology described in section 2 was implemented to develop the SER network starting from the CLD. Firstly, the main elements of the network were identified and grouped into three categories, as previously described, i.e. agents, resources (both human and natural), and tasks (i.e. both human and natural processes). The following table shows the list of the elements in the SET network.

Table 6. Human and natural resources in the SET

Resources	Type	Acronym
Irrigation network	Human	IRR
Wetlands	Natural	WET
Marshland	Natural	MAR
Groundwater	Natural	GW

Guadiamar river	Natural	GUAD
Guadalquivir river	Natural	GUAQ
Agricultural land	Natural	AGR
Soil	Natural	SOIL
Territory control capacity	Human	TERCCAP
Rainfall	Natural	RAIN
Agricultural production capacity	Human	AGRPR
Environmental awareness	Human	ENAW
Market accessibility	Human	MARK
Economic resources for eco-tourism	Human	ECTOU
Economic resources for agricultural production	Human	ECAGR
Plan for land use management	Human	PLAND

Table 7. Human and natural processes in the SET

Processes (tasks)	**Type**	**Acronym**
Groundwater exploitation	Human	GWEXP
Crop irrigation	Human	CRIRR
Agricultural production	Human	AGPROD
Eco-tourism development	Human	ECODEV
Biodiversity protection	Human	BIO
Use of chemical products in agriculture	Human	CHEM

Groundwater recharge	Natural	GWREC
Social conflict exacerbation	Human	CONFL
Water permit management	Human	WPERM
Water resources allocation	Human	WRALL
Territory control	Human	TERCON
Water provisioning for agriculture	Natural	WAGR
Water provisioning for biodiversity	Natural	WBIO
Water purification	Natural	WPUR
Production of cultural and aesthetic ES	Natural	CULT
Maintaining the quality of the ecosystem	Natural	ECQUAL

Table 8. Agents in the SET network

Agents	**Acronym**
River basin authority	CGB
Regional authority - agriculture	RAA
Big farmers	FARMB
Small farmers	FARMS
Municipalities	MUN
Local communities	COMM
Eco-tourists	ECOT
Economic agents in the touristic sector	ECECON

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Food market agents	MARK
Regional authority - environment	RAE
Regional authority - local development	RAD
National Park management authority	MPARK

As already explained in the previous sections, the SET network was developed starting from the ESs that need to be produced and provided to guarantee the sustainable management of the WEF Nexus. For the sake of clarity, the ESs are represented in green among the processes. Then, the resources and processes that need to be activated were added to the SET. Finally, the agents were included in the network. As described in section 2, the agents to be added were those managing/using a resource and/or activating/hampering a key process in the SET.

As a next step, the different meta-matrixes were created. As an example, the following table shows the Resources X Tasks meta-matrix. The numbers in the cells are the weight of the links and represent the strength of the connections between resources and tasks. That is, the weight of a link between a resource and a process (task) describes how important is a specific resource for the linked process.

Table 9. Resources X Tasks met-matrix

	GWEXP	CRIRR	AGPROD	ECODEV	BIO	CHEM	GWREC	CONFL	WAGR	WBIO	WPUR	CULT	ECQUAL
IRR	10	10	10	0	0	0	5	0	10	0	0	0	0
WET	0	0	0	10	10	0	5	0	0	10	0	10	10
MAR	0	0	0	10	10	0	0	0	0	10	0	10	10
GW	10	10	8	0	8	0	0	10	10	10	0	5	5
GUAD	0	0	0	0	10	0	0	0	0	10	0	8	8
GUAQ	0	8	8	0	0	0	8	0	10	0	0	0	0
AGR	0	5	10	0	0	0	0	0	5	0	0	0	0
SOIL	0	0	8	0	0	0	0	0	0	0	10	0	5
TERRC	0	0	0	5	8	0	0	10	0	0	0	0	10
RAIN	0	0	5	0	5	0	10	0	5	5	0	5	8
AGRPR	-2	-8	10	0	0	0	0	-3	-5	0	0	0	0
ENAW	-8	0	0	5	5	-5	0	-5	0	0	0	0	8
MARK	0	0	8	0	0	0	0	0	0	0	0	0	0
ECTOU	0	0	0	10	5	0	0	0	0	0	0	8	5
ECAGR	8	5	10	0	-5	0	0	0	0	-5	0	0	-8

Contrarily to most of the SNA methods, negative links have been introduced in this work to describe potential conflicts among the different elements in the SET. For example, the availability of economic resources for agricultural production has a negative impact on biodiversity protection due to the increase of groundwater exploitation for agricultural production.

Similarly, the other meta-matrixes were developed accounting for the stakeholders' knowledge as structured in the CLD.

The following figure shows the SET network developed for the Doñana case study.

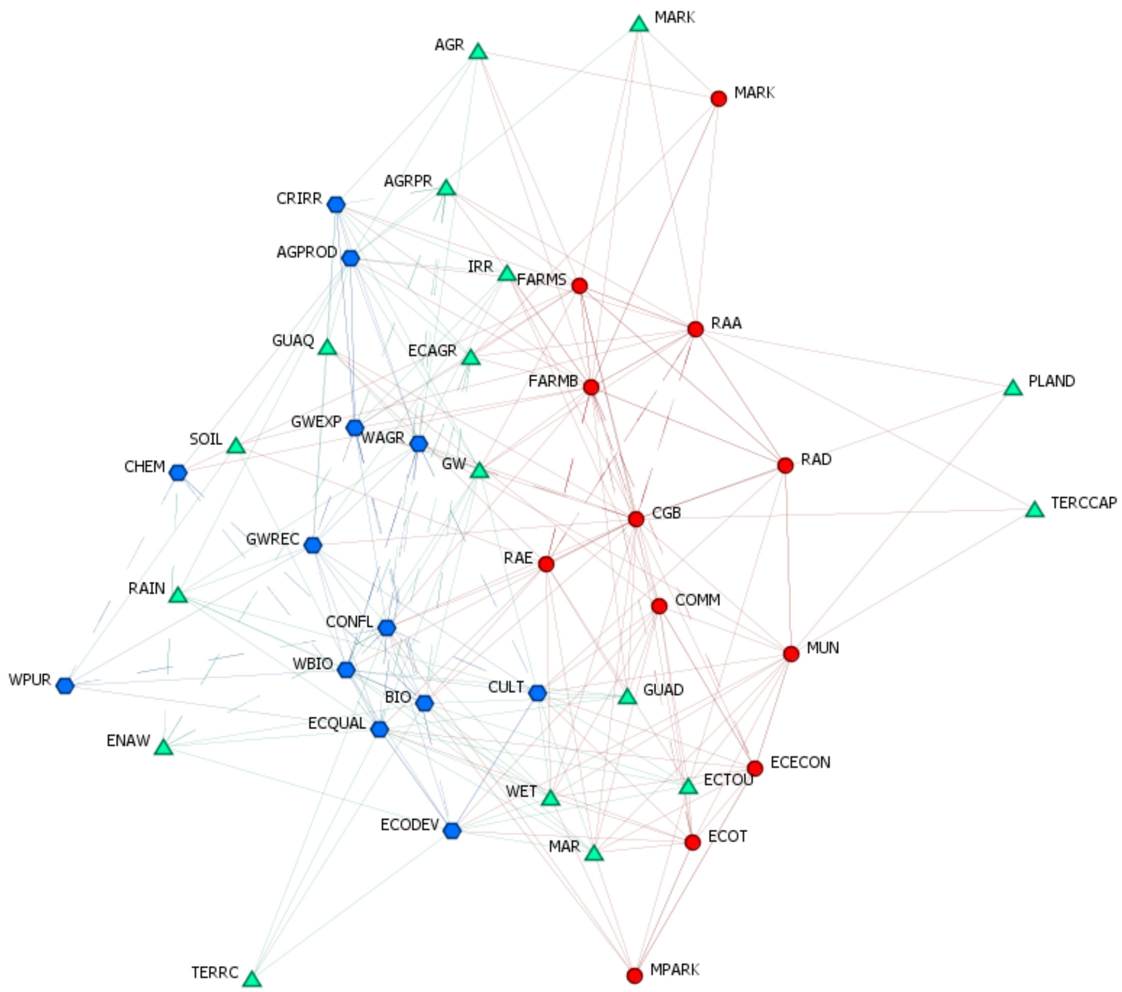

Figure 4: SET network for the Donana case study. The dotted lines represent negative links.

The network analysis measures were implemented in order to assess the capability of the SET network to enable the production and provision of ESs for the WEF Nexus resilience. Firstly, the measure at the scale of the whole network was implemented. The network is densely interconnected and has a high degree of centralization. The core of the network is represented by the water resources and the water-related ESs. The E-I index shows a relatively high interconnection among the different ES-based clusters. However, low connections exist between the groups related to biodiversity conservation and agricultural production. This lack of connection could lead to trade-offs among these ESs.

Secondly, the measures at the node scale were implemented to detect and analyse the existing and potential vulnerabilities of the SET network. The first measure is meant to identify the agents that, due to the importance of the tasks (processes) in which they are involved, could represent a risk for the SET, if not adequately integrated into the social network. We assume that an agent with a low level of individual congruence represents a vulnerability for the SET network. In this work, the main vulnerability due to the low level of individual congruence is the River Basin Authority. This agent is supposed to carry out several important tasks having a strong impact on the production and provision - i.e. water permit management, control of the territory, etc. However, it is rather isolated in the network. Specifically, it has conflicting relationships with both the big farmers and the Regional Authority. These relationships strongly affect its capacity to control the territory and, thus, to actually enforce the rules for water permit management and water resource allocation. The second measure that needs to be accounted for is the resource-based access index. It aims at detecting agents that are rather isolated in the network but have access to key resources for the ESs's production and provision. In this work, this vulnerability is represented by the National Park Management Authority. This actor seems to be completely isolated in the network of interactions, although it has access to key ecological resources needed to produce the ESs. It interacts neither with the River Basin Authority nor with the farmers. It seems to neglect the impacts of water management and uses on the quality of the ecosystem and ecological resources in the national park. This lack of cooperation is hampering the possibility to raise farmers' awareness concerning the impacts of their activities on ecological resources. Another key vulnerability according to this measure is the River Basin Authority. This is mainly because this agent has access to important resources - i.e. it has the responsibility to manage the water resources in the case study - but it is characterized by strong conflict with the Regional Authority, responsible for the implementation of the land use management plan. According to this plan, most of the areas currently irrigated - even if illegally - are officially considered 'irrigable' (i.e. which in practical terms means that can be legalized in the near future). However, the permits to use the groundwater for irrigation purposes should be issued by the River Basin Authority. In this situation, the lack of coordination among these two institutional actors reduces the capability of the River Basin Authority to effectively manage the key resources it has access. Therefore, the River Basin Authority is characterized by a rather low value of the resources-based access index.

Finally, the Agent-Resource Needs Congruence aims at identifying agents having limited access to important resources to fulfil their tasks. In our work, the analysis allowed us to detect two agents having a low level of Agent-Resource Needs Congruence, i.e. the big farmers and, once again, the River Basin Authority. The big farmers could represent a vulnerability because they have very limited access to environmental awareness, which is considered a key resource for activating processes (tasks) leading to the sustainable use of the resources and, consequently, to the protection of biodiversity and the ecosystem. The River basin Authority represents a vulnerability according to this measure due to its rather low access to the resource "territory control capacity". Due to this limitation, the River Basin Authority cannot fulfil its role as responsible for water permit allocation and management.

3.2. The SET network in the Tarquinia Plain case study

The methodological approach for the SET network development and analysis was implemented in the Tarquinia case as well. To this aim, the results of the participatory system dynamic modelling were used. For a detailed description of this process, please, refer to deliverable D4.1. The CLD was, then, used to develop the SET network. As already described in the previous section, firstly the SET elements were identified and, then, the connections were drawn. The following tables show the SET elements, grouped into three main categories.

Table 10. Human and natural resources in the SET

Resources	Type	Acronym
Irrigation network	Human	IRR
Agricultural land	Natural	AGRLAND

Surface water - Marta river	Natural	SW
Groundwater	Natural	GW
Forests	Natural	FOR
Pasture	Natural	PAST
Soil quality	Natural	SOIL
Natural areas	Natural	NATAR
Saltworks	Human	SALTW
Riparian areas	Natural	RIPAR
Coastal areas	Natural	COST
Economic resources for agricultural production	Human	ECONAGR
Economic investments for the touristic sector	Human	ECONTOU
Environmental awareness	Human	ENVAW
Touristic facilities	Human	TOURFAC
Wastewater treatment plants	Human	WWTP
Agricultural innovation knowledge	Human	AGRINN
Land use plan	Human	LANDPLAN

Table 11. Human and natural processes in the SET

Processes (tasks)	**Type**	**Acronym**
Groundwater exploitation	Human	GWEXP
Crop irrigation	Human	CRIRR

Agricultural production	Human	AGPROD
Eco-tourism development	Human	ECODEV
Biodiversity protection	Human	BIO
Use of chemical products in agriculture	Human	CHEM
Groundwater recharge	Natural	GWREC
Social conflict exacerbation	Human	CONFL
Groundwater exploitation permit management	Human	WPERM
Water resources allocation	Human	WRALL
Territory control	Human	TERCON
Wastewater treatment	Human	WWAT
Water provisioning for agriculture	Natural	WAGR
Water provisioning for biodiversity	Natural	WBIO
Water purification	Natural	WPUR
Production of cultural and aesthetic ES	Natural	CULT
Maintaining the quality of the ecosystem	Natural	ECQUAL
Water flow regulation	Natural	WFLOW

Table 12. Agents in the SET network

Agents	**Acronym**
River basin authority	RBA
Regional Authority	RA

Water utility	WATUT
Municipalities	MUN
Bio-district (eco-tourism)	BIOD
Farmers cooperatives	FARMC
Agriculture Innovation consultancy agencies	AGRINN
Environmental protection agency	EPA
Environmental associations	ENVASS
Farmers	FARM
Big market companies	MARK

Similarly to the work done for the Doñana case, the different meta-matrixes were developed accounting for the connections mentioned by the stakeholders during the participatory modelling exercise.

The following figure shows the Resources X Task meta-matrix for the Tarquinia case study.

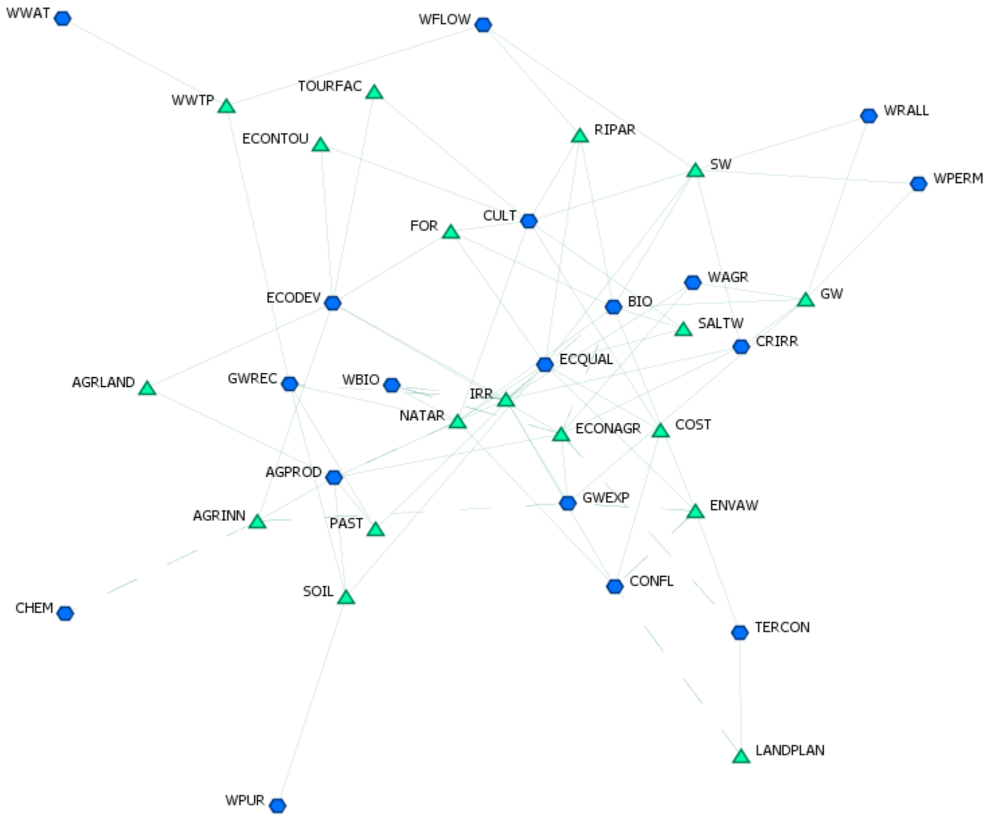

Figure 5: Resources X Tasks meta-matrix for the Tarquinia case study.

Then, the network measures were implemented. Firstly, the network-based measures allow us to define this SET network as a densely connected network. The different ESs are strongly connected to each other. Similarly to the Doñana case, this SET network has a rather high centralization. In this case, the network is built around the soil resource, which is crucial for the production and provision of the needed ESs. The E-I index shows a relatively high interconnection among the different ES-based clusters. However, low connections exist between the groups related to soil quality protection and biodiversity conservation and agricultural production. This lack of connection could lead to trade-offs among these ESs.

The node-based measures allowed us to identify the key vulnerabilities in the network. The first measure aims at identifying elements that, due to the large number and importance of the tasks to be fulfilled, claim cooperation. In this work, vulnerable elements due to their isolation are represented by the farmers' cooperatives. They are supposed to carry out several tasks aiming at supporting farmers in the adoption of innovative and sustainable practices. However, the rather low connection between these agents and the market companies is negatively affecting their capacity to carry out the task. Specifically, farmers perceived the cooperative as incapable of negotiating fair contracts with the market companies. This is leading to an ever-increasing competitive behaviour among farmers, reducing the farmers' social capital and, thus, negatively affecting the connection between the cooperatives and the farmers. This, in turn, is leading to increased agricultural production and, thus, increasing pressures on environmental resources, specifically on the soil. The incapability of the farmers' cooperatives to support the adoption of innovation is leading to unsustainable agricultural practices, such as abundant use of traditional fertilizers, overexploitation of land, and expansion of agricultural activities in natural areas.

The second node-based measure to be accounted for in the analysis is the resource-based access index. It aims at detecting agents with limited capability to share important resources. This measure indicates the Regional Authority as a vulnerable element in the SET network. This actor has access to a key resource for the WEF nexus management, i.e. the land use plan. The lack of interactions between the Regional authority and the other institutional (e.g. the municipalities) and non-institutional actors is hampering the cooperative implementation of the plan. There is a perceived lack of land-use planning effectiveness as e.g. some areas are being devoted to intensive almond/hazelnut trees growth and other highly productive areas are being instead used for installing solar panels.

Finally, the implementation of the Agent-Resource Needs Congruence measure indicates the farmers as a vulnerable element in the network. They are required to carry out a key task for the WEF nexus management, i.e. sustainable agricultural production. Reducing the impacts of the current agricultural practices on the ecosystem is a fundamental goal. However, the limited access to agricultural innovation knowledge (resource) is negatively affecting farmers' capacity to fulfil this task.

4. Discussion and concluding remarks

This section is dedicated to describing the lessons learned due to the implementation of the developed methodology in the two selected case studies. We refer to two main kinds of lessons. Firstly, some preliminary conclusions concerning the complexity of the SET network for the WEF nexus management will be drawn by comparing the experiences in the two case studies. Secondly, the suitability of the developed methodology for enabling collaborative policy-making for the WEF nexus management will be discussed.

Concerning the first point, we can state that both SET setworks – i.e. the Donana and the Tarquinia SET system – are characterized by a densely interconnected network. This is mainly due to the adoption of the ESs as the core of the network development process. ESs cannot be considered as isolated, since they are produced by ecosystems, whose processes and resources are interconnected. The implementation of node-scale graph measures allowed us to detect the key vulnerabilities in the SET network. Interestingly to notice that, in both case, non-institutional actors – e.g. farmers and local communities – play a key role in the SET network. This is particularly true for the Tarquinia case study. Whereas the main vulnerabilities in the Donana are due to the lack of interactions among key institutional actors.

Concerning the suitability of the adopted approach, the results from the case studies demonstrate some innovations compared with the existing approaches. The results of the literature review showed some limitations. Specifically, the previous works focused exclusively on the structure of the institutional framework. The activities described in this work showed the importance of adopting an integrated approach in the analysis of the institutional framework for WEF management. Assessing its capability to enable collaborative policymaking allows only partially to address the WEF-related issues - i.e. policy fragmentation. The WEF perspective has at its core the production and provision of ESs. Therefore, analytical methods for supporting the WEF Nexus management should be capable of assessing the capacity of the institutional system to enable the production and provision of ESs. ESs production relies on the complex web of interactions of an ecosystem, and not on one specific type of biophysical entity in isolation. In the adopted approach, an institutional system is considered conducive for the WEF Nexus management not only if it allows cooperation. The complexity of the interconnections characterizing the ecological system to be managed is accounted for in the SET network analysis.

Moreover, we learned that ecological resources have the potential for producing ESs. Other elements have to be considered in order to actually provide the ESs to the beneficiaries. In this work, we referred to the three main “filters” introduced by Andersson et al., (2021) i.e. institutions, perceptions and infrastructures. The introduction of these elements allowed us to better define the actors that need to be considered in the analysis, e.g. we accounted for the role played by the local community and the impacts of its perception of the ESs on their production and provision.

Finally, compared to the existing methods, the adopted approach demonstrates its potential in supporting the detection of the main elements negatively affecting the SET network effectiveness for the WEF Nexus management. The results of this analysis will be used in LENSES to support the development of policy scenarios.

5. References

Andersson, E., S. Borgström, D. Haase, J. Langemeyer, M. Wolff, and T. McPhearson. 2021. Urban resilience thinking in practice: ensuring flows of benefit from green and blue infrastructure. Ecology and Society 26(4):39. https://doi.org/10.5751/ES-12691-260439

Morgan Bazilian, M., Rogner, H., Howells, M., Hermann, S., Arent, D., Gielen, D., Steduto, P, Mueller, A., Komor, P., Tol, R.S.J., Yumkella, K.K. (2011). Considering the energy, water and food nexus: Towards an integrated modelling approach. Energy Policy, 39, 786-7906.

Bodin, O & Tengo, M. (2012). Disentangling intangible social-ecological systems. Global Environmental Change, 22, 430-439.

Bodìn, O. (2017). Collaborative environmental governance: Achieving collective action in social-ecological systems. Science, 357.

Ö. Bodin , S. M. Alexander , J. Baggio, M. L. Barnes, R. Berardo, G. S. Cumming , L. E. Dee , A. P. Fischer, M. Fischer, M. Mancilla Garcia, A. M. Guerrero, J. Hileman, K. Ingold, P. Matous, T. H. Morrison, D. Nohrstedt, J. Pittman, G. Robins and J. S. Sayles. (2019). Improving network approaches to the study of complex social–ecological interdependencies. Nature Sustainability, 2, 551-559.

Carley, K. & Pfeffer, J. (2012). Dynamic Network Analysis (DNA) and ORA. In: D. D. Schmorrow, D.M. Nicholson (Eds.), Advances in Design for Cross-Cultural Activities Part I, CRC Press, pp. 265-274. Reprinted from: Kathleen M. Carley and Juergen Pfeffer, 2012, "Dynamic Network Analysis (DNA) and ORA," In Proceedings of the 2nd International Conference on Cross-Cultural Decision Making: Focus 2012, San Francisco, CA, July 21-25, 2012.

Laura E. Dee, L.E., Allesina, S., Bonn, A. Eklöf, A. Gaines, S.D., Hines, J. Jacob, U., McDonald-Madden, E., Possingham, H., Schröter, M., Thompson, R.M. (2017). Operationalizing Network Theory for Ecosystem Services Assessment. Trends in Ecology & Evaluation, 32(2).

Fürst, C., Luque, S. & Geneletti, D. (2017) Nexus thinking – how ecosystem services can contribute to enhancing the cross-scale and cross-sectoral coherence between land use, spatial planning and policy-making, International Journal of Biodiversity Science, Ecosystem Services & Management, 13:1, 412-421, DOI: 10.1080/21513732.2017.1396257

Jones, J.L. & White, D.O. (2021). A social network analysis of collaborative governance for the food-energy-water nexus in Phoenix, AZ, USA. J Environ Stud Sci, 11, 671–681.

Oberlack, C. 2017. Diagnosing institutional barriers and opportunities for adaptation to climate change. Mitig Adapt Strateg Glob Change (2017) 22:805–838

Pahl-Wostl, C. (2019). Governance of the water-energy-food security nexus: A multi-level coordination challenge. Environmental Science & Policy, 92, 356-367. https://doi.org/10.1016/j.envsci.2017.07.017

Stringer, L.C., Quinn, C. H., Le, H. T. V., Msuya, F., Pezzuti, J.,Dallimer, M., Afionis, S., Berman, R., Orchard, S. E., Rijal, M. L. (2018). A New Framework to Enable Equitable Outcomes: Resilience and Nexus Approaches Combined. Earth's Future, 6(6), 902-918.

UN-WATER (2008). Status Report on Integrated Water Resources Management and Water Efficiency Plans.

Valente, T. W. (2012). Network Interventions. Science, 337(6090), 49–53. https://doi.org/10.1126/science.1217330

Yuan, M-H, Lo, S-L. (2020). Ecosystem services and sustainable development: Perspectives from the food-energy-water Nexus. Ecosystem Services, 46.

Weitz, N., Strambo, C., Kemp-Benedict, E., & Nilsson, M. (2017). Closing the governance gaps in the water-energy-food nexus: Insights from integrative governance. *Global Environmental Change*, *45*, 165-173. https://doi.org/10.1016/j.gloenvcha.2017.06.006

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