LEarning and action alliances for NexuS EnvironmentS in an uncertain future

LENSES

WP4

D4.3 Guidelines for PSDM replication of LENSES approach

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Executive summary

Participatory System Dynamics Modelling (PSDM) is used in the LENSES project as one of the key methodological tools for supporting Water-Ecosystems-Food (WEF) Nexus analysis. In particular, the potential of PSDM is related to: i) support better understanding the WEF systems under investigation, integrating stakeholder perception and scientific knowledge; ii) help building a shared understanding of the main challenges for the study areas as well as a preliminary analysis of the most important dynamics that can affect those challenges; iii) help in the identification of leverage points and in the design of policies and actions for a sustainable Nexus management; iv) help understanding system state and potential evolution under different (future) conditions. These objectives have been achieved using either qualitative (Causal Loop Diagrams, CLDs) and quantitative (stock and flow models) SD tools. The strongly participatory nature of the approach, deeply rooted in the activities performed in the LENSES Learning and Action Alliances (LAAs), besides allowing the invaluable integration of local/stakeholder knowledge, also guarantees the long-term involvement of stakeholders in LAAs and enhance a cross-sectoral knowledge fertilization process. A summary of the methodological process developed and implemented in LENSES is available in the D4.2.

The present Deliverable specifically aims at providing a critical analysis of the process of PSDM development and use in the LAAs. Starting from a review of the main advantages and disadvantages of different PSDM techniques as discussed in the scientific literature, the Deliverable provides details on how the elements that represent a value added (e.g. the potential to visualize complex systems) have been exploited and on how the weak points (e.g. the limited potential for spatialization) have been partially or totally overcome in the LENSES pilots. A twofold perspective is provided: as analysts, we provided some methodological comments and 'hints' to best use PSDM tools and methods in participatory activities; pilot leaders were asked to provide (also reflecting stakeholders' point of view) comments on the main positive and negative aspects related to PSDM use, thus also suggesting what can/should be improved. Ultimately, we propose some methodological suggestions and opportunities for the replication of PSDM also beyond the LENSES project.

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List of abbreviations

CLD: Causal Loop Diagram

LAA: Learning and Action Alliance

NBS: Nature Based Solutions

PSDM: Participatory System Dynamics Modelling

SA: Sensitivity Analysis

SF: Stock and Flow model

UA: Uncertainty Analysis

WEF: Water-Ecosystems-Food

Guidelines for PSDM replication of LENSES approach

1. Purpose of the deliverable

The present deliverable is directly related to the activities performed within Task 4.2 (‘*Participatory System Dynamics Modelling – PSDM*’), and is mainly oriented to provide a critical analysis of the participatory processes implemented in LENSES pilots to support PSDM development and implementation. First, the deliverable includes a short review of the available literature on participatory modelling and, in particular, on participatory approaches for SDM (Section 2). This section aims to identify the peculiar positive and negative aspects of qualitative and qualitative SD methods, according to previous studies, summarizing some gaps and limitations, as well as some elements that provide a value added to the use of PSDM. Section 3 provides a summary of the participatory activities performed in all LENSES pilots, with reference to the framework on PSDM implementation detailed in the D4.2. It also refers to the Roadmap for the operationalization of the LAAs, and mainly aims at providing an overview of the sequence of the participatory activities that have been either directly or indirectly (through the support of pilot leaders) carried out in the LENSES pilots. Section 3 is the core of the deliverable, as it is focused on the analysis of the main strong and weak points of PSDM (as highlighted in the literature) through some critical reflections of how they have been tackled in the LENSES activities. In other words, the section is oriented to provide the analysts' perspective on the main methodological features of the participatory process for SDM building and validation, highlighting also some elements of innovation (e.g. the use of participatory mapping to support CLD building and the inclusion of spatial information in stock and flow models). Section 4 is, instead, mainly based on the feedbacks received by pilot leaders, and includes some of the main concerns highlighted by stakeholders involved with the PSDM as well as some of the main advantages. The analysis is still not complete, as the last round of workshops has not yet been completed in the LENSES pilots. Lastly, Section 5 provides a critical discussion and Section 6 the concluding remarks.

In summary, the present Deliverable aims to: i) identify the main positive features and potential limitations of the use of SDM in a participatory context; ii) provide a critical review of the use of PSDM in the LENSES project, focusing on the main methodological aspects; iii) summarize the perception of PSDM implementation from the LENSES pilots' stakeholders. The Deliverable also aims to provide methodological suggestions and guidelines for an effective replication of the proposed approach even beyond the project.

2. Background information

2.1. Participatory modelling and the role of PSDM

Over the past few decades, environmental governance has been shifting to include more public participation throughout the decision-making process, with an increasing attention for collaborative processes. Benefits of participation include increased public trust, transformation of adversarial relationships, social learning, and higher quality and more durable decisions. A large body of literature describes what successful participatory processes involve, but it also recounts the difficulties and problems that may arise from these efforts (e.g., groups of stakeholders may be over- or under-represented in participatory processes, and power imbalances may occur). Furthermore, the complexity of most environmental issues requires a coordinated decision-making across geographical scales, organizational boundaries, and policy fields, with proven difficulties (Hedelin et al. 2021).

There are many different roles that stakeholders may have in a planning and decision support process, depending on the goals of the specific process. It may also be necessary to involve different stakeholders at different levels of participation. Starting from the scientific literature, (Basco-Carrera et al. 2017) developed a revised 'ladder of participation', which includes one level of non-participation (i.e. ignorance), three levels of low participation (awareness, information and consultation) and three levels of high participation (discussion, co-design and co-decision making). This is summarized in the following Figure 1.

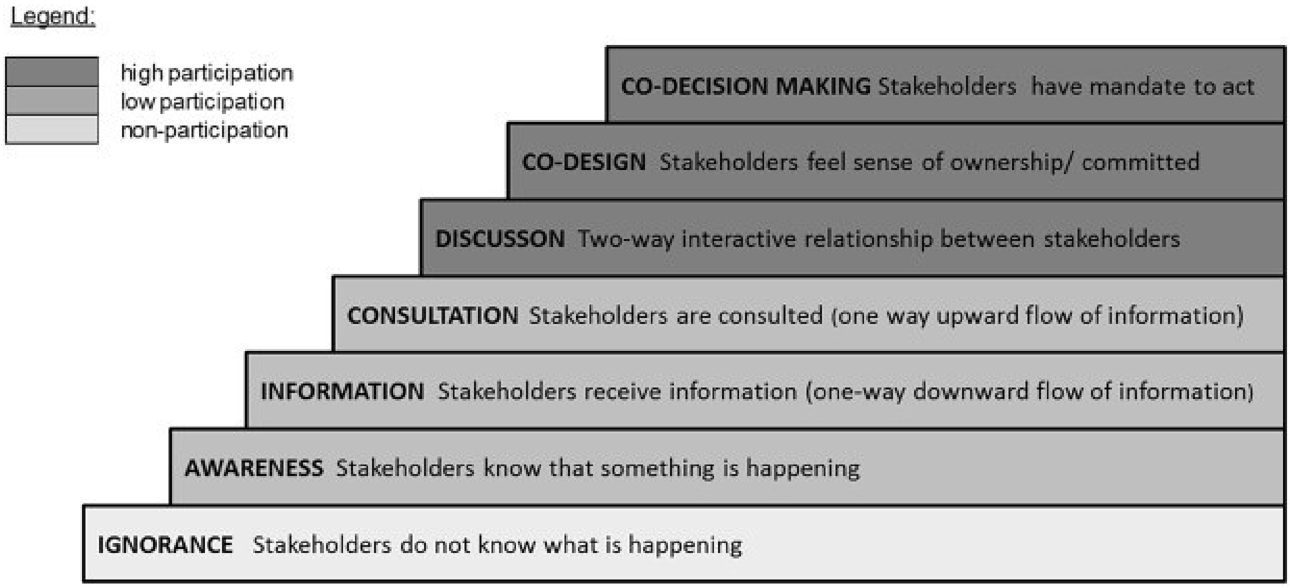

Figure 1 The participation ladder, from Basco-Carrera et al. (2017)

The key features of Participatory Modelling methods – as well as the selection of the most suitable tool for each case - should be considered in view of the modelling goals, which range from the analysis of knowledge diversity and the understanding of potential sources of conflict, to the creation of a model that allows predictions to be made and that supports the detailed exploration of the implications of different decisions or actions. The following Figure 2, taken from Voinov et al. (2018), summarizes the key goals of participatory modelling tools, attributing a specific role to *qualitative SDM* (i.e. CLDs) and *quantitative SDM* (i.e. stock and flows).

CLDs are mainly used for supporting a system conceptualization, and therefore mainly for the communication of different worldviews. They are not necessarily scientifically accepted representations of the real-world systems, and may not be consolidated into a single model. Rather, the aim is to provide a comprehensive system representation, bringing together multiple perspectives, and maximizing engagement and understanding. At this end of the continuum, ease of communication and interpretation might be the most important factors to consider in selecting methods. Conversely, stock and flow models are quantitative models able to describe system state and potential evolution, which may be validated against empirical data and expert knowledge.

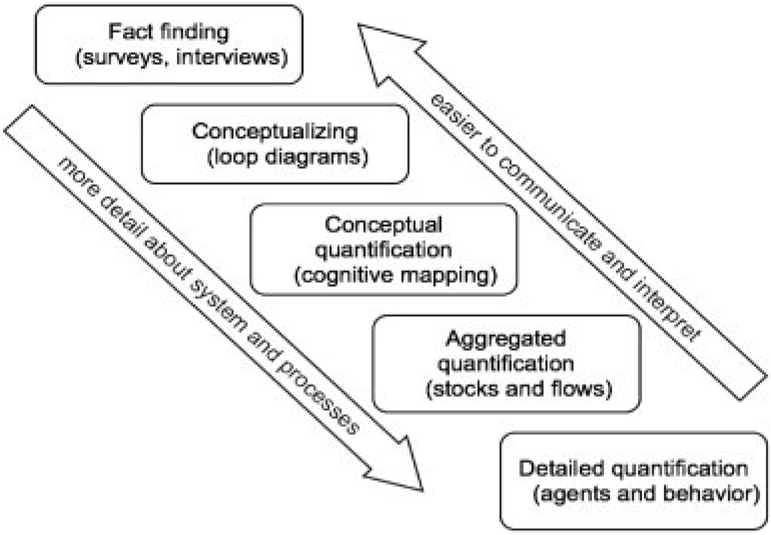

Figure 2 The modelling ladder: complexity versus communication, from Basco-Carrera et al. (2017)

Going further into details, the field of SDM began in the early 1960s to better understand complex human and industrial dynamics with the work of Jay Forrester (e.g. Forrester 1987, 1990). Today, SDM is used to inform decision- and policy-making in several fields including natural resource management (Stave 2010; Kopainsky et al. 2017; Rieder et al. 2021). In general, SDM offers a number of strengths in helping to understand the dynamic behavior of complex systems and test assumptions of different actions and policies with a focus on solving problems (Sterman 2000).

SDM is ideally used in participatory planning processes where it can support the negotiation of a shared understanding of a dynamic problem (Vennix 1996). It facilitates the exchange of ideas among participants and effectively integrates existing scientific research with local knowledge, ultimately supporting also mutual learning. This also encourages participant ownership of the model and greater support of outputs to address the problem. In addition to insights from the model, the model building process can increase the social capital of a group, strengthen relationships and improve communication (Rieder et al. 2021). Participatory SDM offers also other advantages since models built with stakeholders are based on the use of the language of people working on the chosen problem. The visual nature of the modelling software is also more accessible to a lay audience, and easy-to-use interfaces help minimize technical barriers between modelers and the modeling groups (Rieder et al. 2021).

Although PSDM has a proven potential in supporting decision making, some issues have been acknowledged in the literature. Primary concerns include lack of transparency regarding model-building and outputs and weak communication between modellers and practitioners. Furthermore, the time required from participants in the short term and the need for a competent modeller and facilitator to coordinate the process are major barriers to adoption (Stave 2010).

CLDs are commonly used in SDM to represent the key variables and relationships that are assumed to explain the dynamic behavior of a given system. CLDs need a relatively small number of conventions, making it simple to use, even for a non-technical audience. The CLD method has been credited for its simplicity and ability to give an aggregate or strategic view of the problem structure which helps to keep focus on feedback loops rather than on details. However, the method has been criticized **for not adhering to fundamental principles of accumulation which could lead to ambiguous and flawed inferences about problem dynamics**. Furthermore, in order to be effective, CLDs require that groups have an **agreed ontology about what**

variables mean and how the system works. Otherwise, there is a risk of producing shallow diagrams that hide both unexpected depths about given problems, and interesting insights in the differences between various stakeholders' mental models and views (Voinov et al. 2018).

The work from Voinov et al. (2018) summarized in the form of a figure the main capabilities of various participatory modelling methods – including qualitative SDM (i.e. CLDs) and quantitative SDM (i.e. stock and flow models), providing a rate from Low (L) to Medium (M) to High (H). A rating of "L" means that a method is less able to produce outputs that have the desired capability than is method rated "H" on the same capability. The following Figure 3, taken from Voinov et al. (2018), thus provide a summary of the key modelling issues that need to be considered for participatory tools. Similarly, an additional Figure is also provided (see Figure 4) with the main requirements for implementing various participatory modelling methods, including a rate from Low (L) to Medium (M) to High (H).

	Qualitative modeling methods					Semi-quantitative modeling methods				Quantitative modeling methods (aggregated)				Quantitative modeling methods (detailed)			
	Rich Pictures	Cultural Consensus	Role Playing Games	Causal Loop Diagrams and Cognitive/Concept Mapping	Decision Tree Analysis, Decision Focused Structuring	Social Network Analysis	Fuzzy Cognitive Mapping	Scenario Building	Analytic Hierarchy Process	Systems Dynamics	Empirical Modeling	Geographic Information Systems	Bayesian Modeling	Cost Benefit Analysis	Agent Based Modeling	Cellular Automata	Integrated Modeling
Spatial representation	M	L	L	L	L	L	L	L/M	L	L	L	H	L	L	H	H	H
Temporal representation (dynamic)	L	M	M	L	L/M	M	L	H	L	H	M	L	L	L/M	H	H	H
Qualitative forecast	L/M	M	M	L/M	L/M	M	M	H	L	H	M	L	M	L/M	H	H	H
Quantitative forecast	L	L	L	L	M	M	L	M	L	H	M	L	M	M	H	H	H
Ease of communicating results	H	H	M	M/H	M	H	M/H	H	M	M	M/H	H	L/M	M/H	M	L/M	L
Transparency	H	M	M/H	H	M/H	M/H	M/H	M/H	M	M	L	M	L/M	M/H	L	M	L
Ease of modification	H	M	H	H	H	L	H	H	L	M	L	H	M	M/H	M	M	L
Feedback loops supported	L	L	H	H	L	M	H	M	L	H	M	L	L	L	H	H	H
Handling uncertainty	L	M	M	L	L	L	L	H	L	H	H	L	M	L	H	M	M

Figure 3 Key features and capabilities of different participatory modelling techniques, from Voinov et al. (2018).

PRIMA PARTNERSHIP FOR RESEARCH AND INNOVATION IN THE MEDITERRANEAN AREA

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	Qualitative modeling methods					Semi-quantitative modeling methods				Quantitative modeling methods (aggregated)				Quantitative modeling methods (detailed)			
	Rich Pictures	Cultural Consensus	Role Playing Games	Causal Loop Diagrams and Cognitive/Concept Mapping	Decision Tree Analysis, Decision Focused Structuring	Social Network Analysis	Fuzzy Cognitive Mapping	Scenario Building	Analytic Hierarchy Process	Systems Dynamics	Empirical Modeling	Geographic Information Systems	Bayesian Modeling	Cost Benefit Analysis	Agent Based Modeling	Cellular Automata	Integrated Modeling
Time and cost	L	M	L/M	L	M	M	L	L/M	M/H	M/H	M	M	M/H	M	M/H	M/H	H
Data (Empirical)	L	M	L	L	M	H	L	L/M	L	L/M	H	H	M	M/H	L/M	M	H
Systems Knowledge (Conceptual)	L/M	M	L/M	L/M	M	M	M	M/H	M/H	H	L	L/M	M	L/M	H	H	H
Expertise of modelers	L	M	M	L	M	M	M	M	M	H	M/H	M	M/H	L/M	H	H	H
Methodological expertise of stakeholders	L	L	L	L	M	L	L/M	L/M	L	M	L/M	L	M	L	L/M	M	M
Computer resources	L	M	L	L	L	M/H	M	L/M	M	H	M/H	H	M	M	H	H	H

Figure 4 Key requirements of different participatory modelling techniques, from Voinov et al. (2018).

Lastly, Voinov et al. (2018) provide an evaluation of the appropriateness of participatory modelling methods based on the following main criteria:

- Effectiveness: how well can a specific method succeed given the focal problem of interest, and how well it meets the needs of the processes.
- Efficiency: whether the methods can achieve the goals in the needed time and with the appropriate use of the available human, financial, and technical resources.
- Social value added: how well the methods support the broader goals of the process, such as promoting gender, racial and income equality, learning and education, dialogue among diverse groups, and social capital of stakeholders (in line with the social network development mentioned below).

3. Overview of the activities in the LENSES pilots

The development of PSDM in the LENSES pilots followed (in general) the approach detailed in the D4.2 “Framework for PSDM implementation in LENSES case studies”, which basically proposes a series of participatory and desk activities oriented to build qualitative and quantitative models. The present section provides a basic summary of the activities involving the participation of relevant stakeholders in model building. In part of the case studies, the IRSA team joined in person project activities, directly supporting pilot leaders in the organization of the participatory exercises oriented to PSDM development and review. In other pilots, external support (including training) was provided to pilot leaders, and feedback was collected from them. Further details on the whole set of participatory activities performed in pilot areas, and related objectives, are available in the LENSES D2.2.

Pinios. Feedbacks were collected both through the interaction with pilot leaders and based on the direct participation in some of the participatory activities. The most relevant activities related to PSDM development are:

- Support to the preliminary round of semi-structured interviews, to identify the main sectoral issues and cross-sectoral interdependencies. Based on the identified challenges, the aim was to identify crucial areas, current state, barriers, and indicators as well as key interrelations between nexus challenges.
- Field visit in the study area (joint LENSES-REXUS activity), which helped better understand the key features of the area with the direct support of the pilot leaders.
- Support to the preparation of the 1st stakeholder workshop. The main objective of the WS is the final identification and prioritisation of challenges, problems, obstacles, strengths and opportunities (as well as relevant indicators). PSDM-related activities were also oriented to the development of sectoral qualitative models, mainly creating CLDs and the visioning of a Business as Usual (BAU) future.
- Support to the preparation of the 2nd stakeholder workshop. The focus of the WS is on developing what-if scenarios, trying to identify also the role of NBS. The integrated CLD of pilot areas is presented and discussed, and the stakeholders asked to participate in exercises to define specific targets for each defined goal/challenge, incorporating policy regulations.
- Ongoing: development of the stock and flow model, presentation of PSDM results and scenario analysis during the 3rd WS (22/02/2024).

Doñana. Feedbacks were collected both through the interaction with pilot leaders and based on the direct participation in some of the participatory activities. The most relevant activities related to PSDM development are:

- A field visit in the study area to have a general idea of the key challenges and issues that characterize the whole watershed, with a focus on the irrigated areas.
- Participation in the round of semi-structured interviews (11/2021), to identify the main sectoral issues and cross-sectoral interdependencies. Attention has been given to a better understanding of the perception of the local situation from specific groups of stakeholders (e.g., berry farmers) to describe the interconnections between irrigated agriculture and the state of the environment. The information collected was directly used in the development of a preliminary version of the CLD.
- Participation in the 1st stakeholder WS (October 2022). The results were collected and used to update the PSDM. The focus was the validation of the CLD and the discussion around potential solutions to the main challenges, through a participatory mapping exercise.

  - Support to the preparatory activities of the 2nd stakeholder WS and participation in the WS and focus groups (December 2023), to present the results of PSDM and to get information useful on the one hand for CLD validation and on the other hand for the development of the stock and flow model. Particular attention is given to the better understanding (and modelling) of specific behaviors of (classes of) agents.
  - *Ongoing*: development of the stock and flow model, presentation of PSDM results and scenario analysis during the 3rd WS (*tbd*). The stock and flow model is being also integrated with the results of sectoral models (in particular, hydrological models).

- Tarquinia. Feedbacks were collected both through the interaction with pilot leaders but also with the direct participation in the participatory activities and the direct interaction with local stakeholders. The most relevant activities related to PSDM development are:
  - A field visit in the study area to have a general idea of the key challenges and issues that characterize the whole watershed, with a focus on the irrigated areas.
  - Participation in the round of semi-structured interviews, to identify the main sectoral issues and cross-sectoral interdependencies. Attention has been given to a better understanding of the perception of the local situation from specific groups of stakeholders (e.g., farmers), with a direct focus on the role of irrigated agriculture for the sustainable development of the area.
  - Participation in the stakeholder workshop (May 2022), with the aim of discussing and finding an agreement on the main Nexus challenges for the area, as well as for a review/validation of the CLD through participatory mapping exercises. A specific exercise was also organized to better understand the interconnections among natural resources and agents involved in their use.
  - Participation in the stakeholder workshop (May 2023), mainly oriented to present the results produced and receive feedback on the preliminary evidence from modelling results, thus finalizing the identification of the main challenges for the area, the key objectives and the potential actions that can help improving system state.
  - *Ongoing:* Development of the stock and flow model, with integration of sectoral models (e.g. SWAT) and climate projections. Presentation of the results in a final workshop/dissemination event (tbd in April).

- Koiliaris. Feedbacks were collected both through the interaction with pilot leaders and based on the direct participation in some of the participatory activities. The role of the pilot leaders was particularly crucial in this case, as they have a long history of collaboration with local stakeholders. The most relevant activities related to PSDM development are:
  - A round of semi-structured interviews performed by the local team with relevant stakeholders.
  - Support to the preparation of two focus groups, that were organized with farmers. The activities were oriented to guarantee a better understanding of the impact of water resources management in the area and of innovation in agricultural practices, focusing also on the potential role of innovative crops (such as avocado) and the benefits of cooperatives.
  - Field visit over the area, to better understand the key features and characteristics.
  - CLD revision and validation with the support of the pilot leaders, also based on the outcomes of interviews and focus groups.

  - Support to the preparation of an additional focus group, performed with experts and oriented to support a further validation of the CLD.
  - Meetings with pilot leaders oriented to support the transition from the CLD to stock and flow models.
  - *Ongoing*: development of the stock and flow model, presentation of PSDM results and scenario analysis during the 3rd WS (*tbd*).

- Menemen Plain. Feedbacks were collected mainly through the interaction with pilot leaders, that were in direct contact with relevant stakeholders throughout the project. The most relevant activities related to PSDM development are:
  - Interviews and questionnaires, performed in parallel projects and analyzed to get relevant information for the development of CLDs.
  - The first stakeholder meeting, in order to better understand the main issues and challenges for the study area.
  - The second stakeholder meeting, where both farmers and policy makers developed and discussed their own view of the system building a Causal Loop Diagram (CLD), ultimately highlighting and discussing differences. A survey with farmers was also conducted.

- Deir Alla. Feedbacks were collected mainly through the interaction with pilot leaders, that were in direct contact with relevant stakeholders throughout the project. In particular, the most relevant activities related to the PSDM were the interviews and the first two workshops, as they allowed clarifying some key challenges such as the tight interconnection between community needs/well-being with agricultural activities, the impacts in terms of water availability and the potential role of innovative practices as points of intervention on the system.

- Hula Valley. Feedbacks were collected mainly through the interaction with case study leaders, that were in direct contact with relevant stakeholders throughout the project. In particular, the baseline version of the CLD has been improved to explicitly include the impact of APV projects, trying to describe their multiple impacts including, e.g. the potential increase of agricultural productivity along with the reduction of emissions and energy demand. In this direction, the results of the 1st Workshop were included in the CLD by the pilot leader. The results of CLD analysis, in particular as far as the potential benefits, impacts and barriers to APV implementation are concerned, are considered in the 2nd Workshop, which is oriented to start a dialogue at 'policy-makers level' that aims to explore the implications on Nexus management.

4. Lessons learned from the LENSES pilots and guidelines for replication

4.1. Key features of participatory modelling: the analyst perspective on the use of PSDM in LENSES

The present section provides some details on the main lessons learned (so far) from the LENSES pilot areas, as far as the PSDM development and implementation process is concerned. Specific reference is made to the framework presented by Voinov et al. (2018) and proposed in Figure 3 and Figure 4. Specifically, the present section includes technical and methodological reflections made by the analysts with reference to the PSDM approach in LENSES, related to the following aspects: Spatial representation (Section 4.1.1), Temporal representation (dynamic) (Section 4.1.2), Qualitative and quantitative forecast (Section 4.1.3), Ease of communicating results (Section 4.1.4), Transparency (Section 4.1.5). Ease of modification (Section 4.1.6). Feedback Loops supported (Section 4.1.7), Handling uncertainty (Section 4.1.8), Modelling requirements and needs (Section 4.1.9).

4.1.1. Spatial representation (CLD Low, SF Low)

SD models have been initially developed to investigate the temporal dimension in non-spatial systems. This means that the lack of an explicit representation of spatial features is, still, one of the key limitations of SD models. Following (Voinov et al. 2018), both CLDs and stock and flow models have a relatively Low capability to deal with spatial information.

Analyzing the scientific literature on the topic, some efforts have been performed to extend the capability of systems dynamics to spatial modelling and to investigate the effects of spatial characteristics on the problem behavior over time. These efforts include: (1) breaking down the system into 'homogeneous' zones where each zone is represented by an individual system dynamics model; (2) coupling system dynamics models with GIS to exchange information between spatially distributed models over the simulation time (Voinov et al. 2018).

Within the LENSES project we acknowledged that the limited capability of SDM to represent spatial processes and information is a potential weak point of the approach. We used a tailored approach for including – in some pilots - spatial information both in qualitative and quantitative models (a cooperation between WP2, WP3 and WP4 supported in this direction).

The development of CLDs was supported, in some cases, by participatory mapping exercises, which were performed starting from a (printed) geographical map of the study area and providing stakeholders with a set of cards depicting main resources, socio-economic activities, pressures, impacts and potential interventions for the area. The items included in the cards mainly reflected the information gathered through the first round of interviews (and the baseline description). Basically, stakeholders were asked to locate the cards on the map, to get an overview of the spatial distribution of resources, activities and main challenges, while providing details on their interconnections. The same cards were then placed by the facilitator on a blank paper, and the information on the interconnections used to draw their cause-effect dependencies. Some blank cards were also given to stakeholders in case any relevant variable was missing. The analysis of the map was then used to support the revision of the CLD. Although this method cannot be considered as a 'spatial' version of the CLD or as a solution to the limited capability of SD tools to represent spatial problems, it proved to be a rather straightforward way to help stakeholders (and analysts) keeping track of the actual location of the main 'variables' and phenomena, and better understand the location of the key challenges in the area. In our experience, working together on a map also significantly helped stakeholders sharing a vision on the area and finding consensus on the main challenges, while giving everyone the opportunity to express her/his own vision of the system.

An example of the application of the proposed method is provided in the following Figure 5, with specific reference to the 1st stakeholder workshop in Tarquinia plain.

Figure 5 An example of participatory mapping to support CLD development from the Tarquinia case study. A participatory mapping exercise (left) is carried out in parallel with a conceptual modelling of the interconnections among variables (right).

Spatial information was also considered in the development of stock and flow models, mainly using a semi-distributed approach. Basically, we decided to identify 'homogeneous' zones, that were defined with the support of pilot leaders using a multiplicity of criteria which include e.g., shared challenges, dominant land uses, and similarities in hydrological characteristics. Specific meetings were organized with pilot leaders for the purpose of identifying such units for the pilot areas.

An example is proposed in the following for the Pinios river basin. The whole basin (considered as a case study in the sister project REXUS) has been preliminarily divided into 10 Areas of Interest. Two specific areas, i.e. the Delta and Agia are analysed in the LENSES project. For the purpose of building the stock and flow model, we used the 'subscripts' option (available in Vensim), which basically allows a single variable to represent more than one thing. In practice, we built a core structure of the model, allowing single variables (and equations) to have a different value (or structure) for the different AoI. This allows running the model in parallel on the selected AoI, providing also more detailed results in terms of spatial distribution. An example of inputs and outputs preparation and visualization referring to AoI is proposed in the following Figure 6, Figure 7 and Figure 8.

Spatial information can be also included – in a simplified form - through the coupling with hydrological models. In particular, this has been done in Tarquinia (mainly with reference to the results of modelling in SWAT), in the Doñana area and in the Koiliaris (including in both cases reference to the WEAP results). In these cases, reference was mainly made to the topological information included in the models which reflect a conceptualization of the main hydrological dynamics of the study area. This coupling with hydrological models can be particularly useful to include in the stock and flow model the results obtained by such models. An example is proposed in the Figure 9, where some variables are calculated using results from the WEAP modelling in the Koiliaris study area.

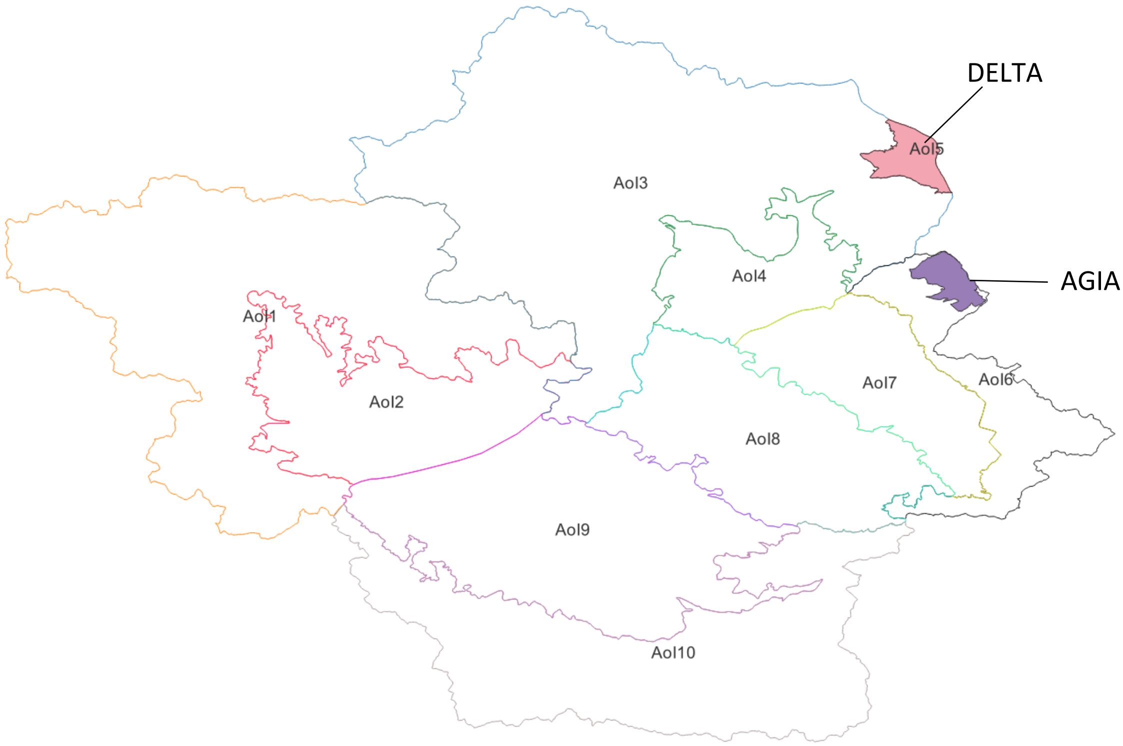

Figure 6 An example of spatialization of the stock and flow model using subscripts for the identification and use of different Areas of Interest: the Pinios case study.

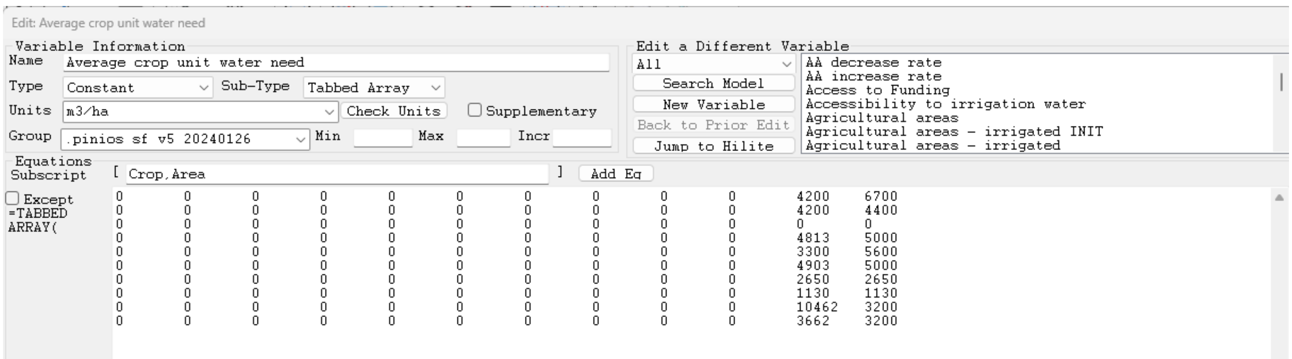

Figure 7 An example of spatialization of the stock and flow model using subscripts. A specific value of Average crop unit water need is assigned to each crop (rows) for each AoI (columns). Data are provided only for the Delta and Agia AoI.

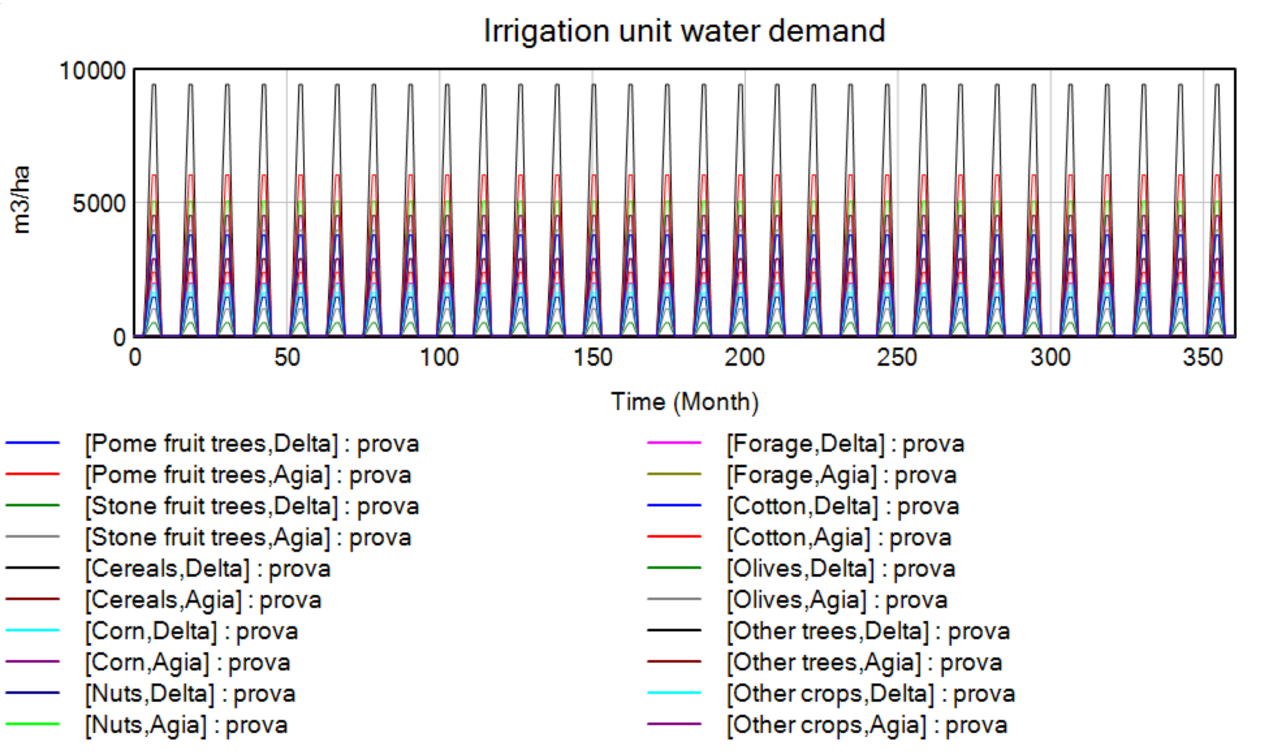

Figure 8 An example of spatialization of the stock and flow model using subscripts. Subscript are used to visualize different values of the same output variable (Irrigation unit water demand) for different Crops in different AoI.

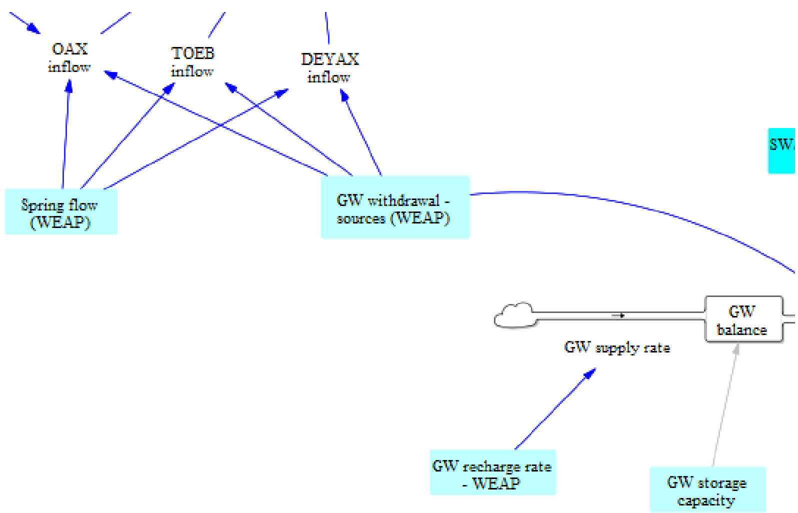

Figure 9 An example of conceptual spatialization of some variables of the stock and flow model through a coupling with hydrological models (e.g. WEAP).

4.1.2. Temporal representation (dynamic) (CLD Low, SF High)

As mentioned before, SD models have been typically developed to investigate the temporal dimension in non-spatial systems. This is particularly true for stock and flow models, which allow a thorough analysis of the temporal evolution of phenomena. CLDs, conversely, allow only a very limited representation of temporal dynamics.

One of the main reasons for the use of SDM in the LENSES project is related to the relevance of temporal dynamics in the analysis of the potential evolution of Nexus systems under a wide range of drivers and pressures. The temporal dimension is therefore considered as a central aspect of the developed models.

In the development and analysis of CLDs there is one feature that can help take into account time (yet in a simplified form), i.e. delays. Delays are critical in creating dynamics. They give systems inertia, can cause oscillations, and are often responsible for trade-offs between the short- and long-run effects of policies. CLDs should include delays that are important to the dynamics that are investigated or are significant relative to the time horizon relevant to the analysis.[1]

Figure 10 shows an example of the use of delays in CLDs with specific reference to the Menemen Plain pilot. An increase in the 'Water use for Irrigation' may cause a reduction of the 'GW level', but typically this process is not simultaneous, and rather occurs with a temporal delay. Highlighting delays can therefore help characterize some very basic temporal aspects that may condition the evolution of phenomena. This is particularly true when actions require some time to show impacts.

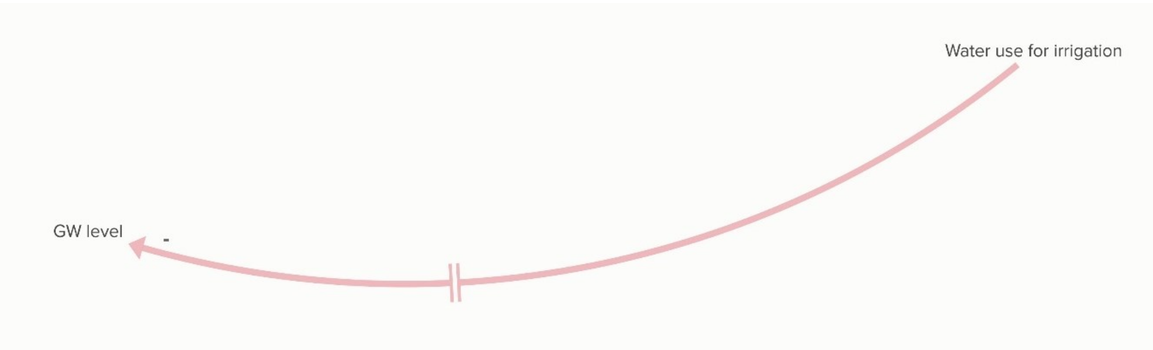

Figure 10 An example of use of delays for including simplified temporal information in a CLD (taken from the Menemen model)

Time dimension is, instead, inherent to the development of stock and flow models. In cooperation with pilot leaders, a relevant time step and duration of the simulations was identified. The stock and flow models have been designed to simulate 30 years with a monthly time step. The duration of the simulation depends on the identification of a significant time horizon to account for the main changes that may occur in the system (ranging from the impacts of climate change to the changes in agricultural areas, to the implementation of NBS), but can be easily modified. The time step has been selected considering its relevance to describe with enough detail some key phenomena (e.g. monthly variation of water demand) and the coherence with the time step used in other models (e.g. water allocation). Increasing the time step (e.g. seasonal or annual) would result in a potentially relevant loss of information at least for some dynamics, while reducing it (e.g.

[1] https://thesystemsthinker.com/fine-tuning-your-causal-loop-diagrams-part-ii/

daily) would add limited information in terms of quality of the outputs while potentially increase the computational burden.

4.1.3. Qualitative and quantitative forecast (CLD Low-Medium, SF High)

CLDs are typically used with the aim of promulgating or achieving greater system understanding. Therefore they have a rather limited capability to create forecasts, and produce qualitative or quantitative estimates of system state and evolution.

In the LENSES project, both a 'structural' and 'descriptive' analysis was performed on CLDs (details are included in the D4.2). The descriptive analysis is oriented to a better understanding of the interdependencies among relevant variables, also based on the identification and description of key feedback loops. The 'narrative' behind the analysis of key loops (or parts of the model involving selected variable) can help gaining a simplified qualitative forecast of potential system evolution. This aspect has been thoroughly detailed in the D4.2, and an example is reported in the following, with reference to the Tarquinia CLD.

The 'Water & Agriculture' feedback loop (balancing) in Figure 11, directly relates to the interplay between water resources demand (and use) for agriculture and the sustainability/profitability of agricultural practices. An increase in 'Irrigated areas' (as well as the transition to crops that typically require higher volumes of water) caused an increased 'Water demand for agriculture', with a cascading impact on the 'GW demand for agriculture' (and, similarly on 'SW demand for agriculture) and an increase in 'GW use for irrigation'. This causes an increased 'Water pumping' with a cascading effect on the 'Water cost (energy)', which ultimately causes a reduction of 'Farmers' income'. The analysis of the loop again suggests that attention should be given to the development of sustainable (yet profitable) agricultural development models.

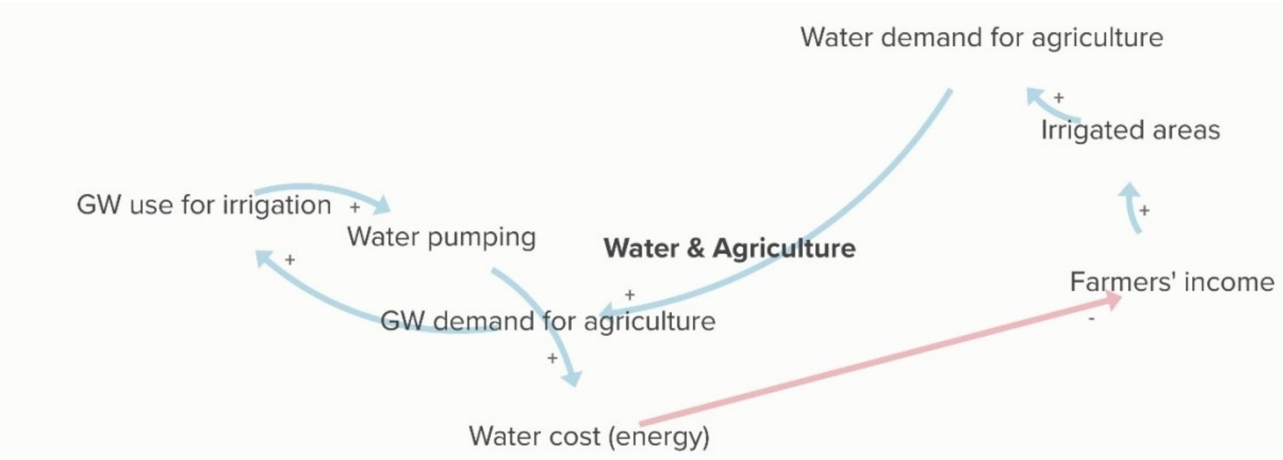

Figure 11 Focus on 'Water & agriculture' feedback loop in the Tarquinia Plain CLD (KUMU)

Conversely, one of the key features of stock and flow models is the capability to support scenario building (or planning, or exploration) dealing with uncertainties about the future. Scenario planning relies on a broad analysis of trends and policies to cover a range of plausible futures, while typically forecasting refers to the prediction of a specific future. Additionally, the stock and flow model can definitely support scenario analysis and forecasting, provided that quantitative information is available for the involved variables and dynamics.

However, the purpose and limitations of the stock and flow models should be carefully explained to stakeholders in order to avoid misunderstandings and the perception of SDM as a potential 'golden bullet' to easily describe and solve complex environmental problems. The experience suggests that stock and flow models should be rather limitedly used as predictive/forecasting tools, rather they should be proposed as straightforward tools to support scenario comparison even in a semi-quantitative form.

An interesting experience with the use stock and flow models for scenario generation and analysis has been recently completed in the Pinios pilot. In cooperation with the pilot leaders, we have been working on the preparation of relevant scenarios for the area. Those scenarios have been then presented and discussed with the stakeholders during the last WS. Clearly, the selection and construction of scenarios has been performed based on the evidence of the participatory activities already completed with the local stakeholders and was specifically oriented to show the potential impact of the selected NBS, along with other strategies that include ‘grey’ solutions (i.e. the activation of new reservoirs) and socio-institutional actions (e.g. training, activation of cooperatives, etc.).

The idea behind the proposed scenario analysis is to focus on a subset of relevant variables, selected among the indicators pre-selected by the stakeholders during the 1st and 2nd WS, able to cover all the Nexus domains. In this way we can provide sectoral information, focusing on the security of key resources, while also supporting a broader perspective that can help visualizing cross-sectoral implications of actions and strategies.

An example is proposed in the following Figure 12, which shows the expected impacts of CC (reference is made to the RCP 4.5) on the selected variables, which are ‘GW availability’ (related to water security), ‘Average agricultural sustainability’ (related to food security) and ‘Soil quality’ (related to ‘ecosystems security’). A comparison is made with the Business-As-Usual scenario (BAU), i.e. the current system conditions just projected in the future. The results show that the climate change could impact the state of GW considering a reduced recharge rate and an increased demand of water for crops. It may also cause a decay of soil quality and a reduction of agricultural sustainability.

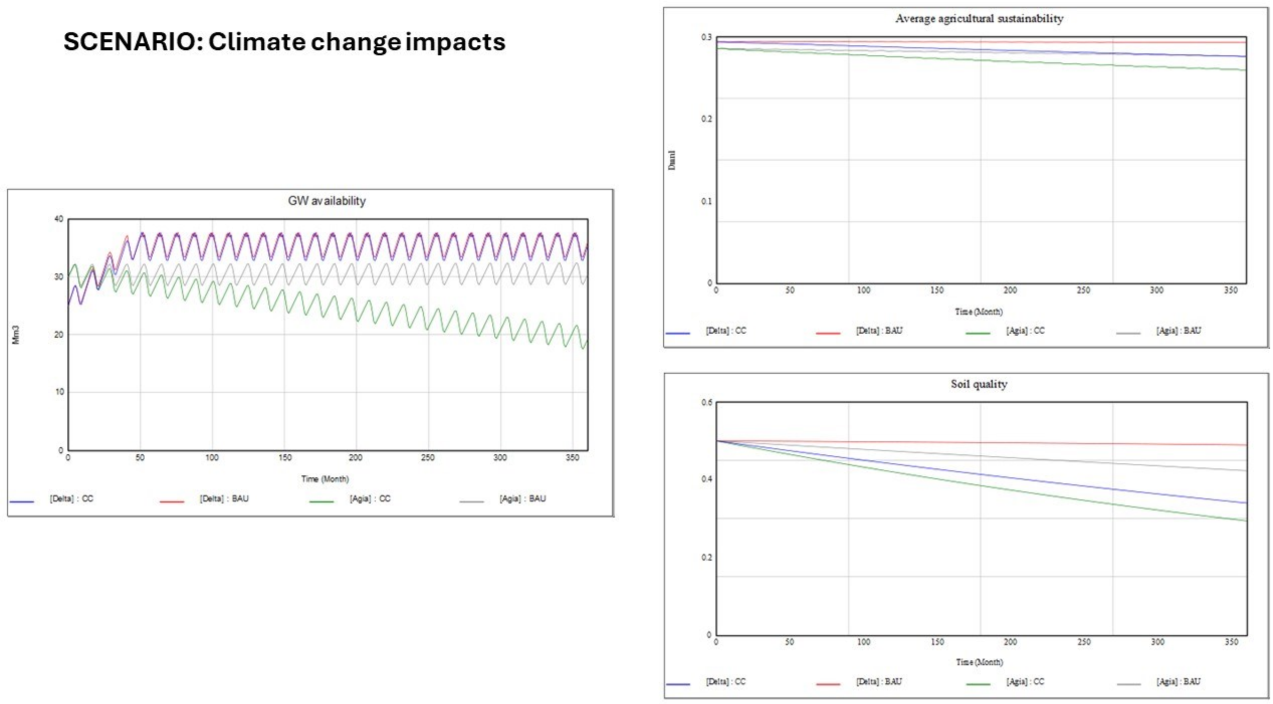

Figure 12 Results of the scenario analysis for the Pinios pilot (Climate Change scenario compared to BAU)

The following Figure 13, proposes another scenario, where the impacts of one of the suggested measures (i.e. the irrigation programming) is analyzed. Practically, it shows how the irrigation programming can positively impact the GW state (and this is particularly true for the Agia sub-basin). The positive effect on the average agricultural sustainability mainly relates to the reduced cost of production due to the reduced consumption of water.

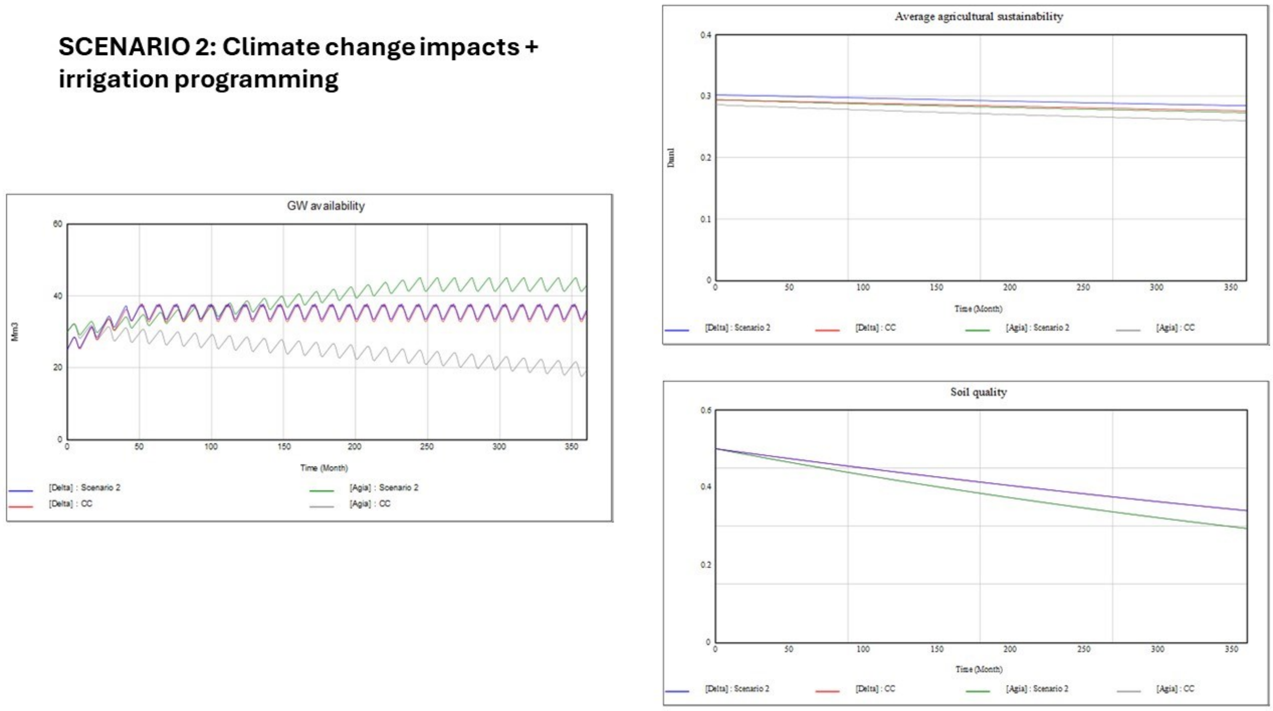

Figure 13 Results of the scenario analysis for the Pinios pilot (irrigation programming compared to Climate Change scenario)

One of the key lessons learned from this experience, as far as the 'forecast' issue is concerned, is that the use of a *comparative scenario analysis* is much more efficient and reliable for the stakeholders. It has been remarked a few times to stakeholders that PSDM does not aim to provide a precise estimate of the state of variables in the future under different circumstances. Rather, the value added of the approach is related to the comparative estimate of the state (and trend) of key variables in different conditions. Additionally, the impact (if any) of a specific action on the system state has been described isolating key variables in each sector, thus supporting the dialogue on how specific measures might increase the resilience of the Nexus (and not just of individual sectors).

Furthermore, it needs to be taken carefully into account that stock and flow models often rely on both qualitative and quantitative variables. In the example above, the 'GW availability' is a quantitative variable (units: [Mm3]) which represents in a rather detailed form the monthly water balance due to recharge phenomena and water uses. Conversely, both 'Soil quality' and 'Average agricultural sustainability' are qualitative variables (Dimensionless, ranging between 0 and 1) resulting from the aggregation of key influencing factors (selected starting from the 'causes' in the CLD). They therefore do not have a physical meaning, but still provide very valuable information in terms of trends (and related rationale). In this regard, it is crucial to carefully explain the meaning of variables to stakeholders. This has been done, in the Pinios, presenting some details on the model and on the main dependencies as in the following slide (presented to the stakeholders before the scenario analysis).

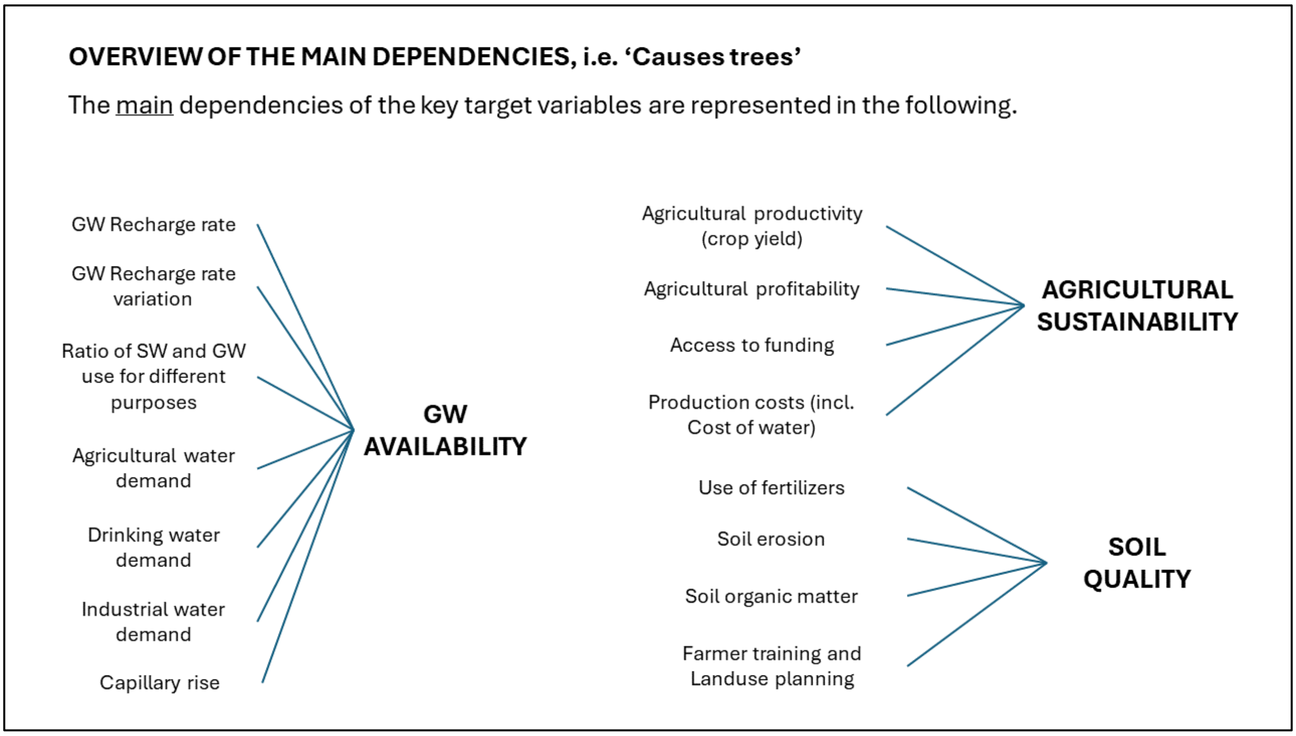

Figure 14 Description of the main target variables in terms of key dependencies (Pinios pilot)

4.1.4. Ease of communicating results (CLD-Medium/High, SF Medium)

It is well known that SDM results can be used to communicate essential findings to help understand the system's behavior. However, it needs to be considered that the use of SDM in Nexus studies mainly refers to highly complex systems. In fact, one key aspect in the development of SD models is that feedbacks, non-linearities and delays are ubiquitous, and therefore do not allow any intuitive judgement about the dynamic behaviour of systems.

The emphasis in drawing a CLD is on eliciting and representing feedback loops and delays that explain the problem behavior. The role of CLD changed in the scientific literature from a back-end tool to communicate the output behavior from the simulation model (i.e. expository mode) to a front-end model conceptualization tool. CLDs can be used as a standalone method for model conceptualization, credited for its simplicity and ability to give an aggregate or strategic view of the problem structure (Voinov et al. 2018).

In general, CLDs offer a rather easy and intuitive way of conceptualizing complex systems, which helps communicating the complexity of Nexus problems to stakeholders. The experience in the LENSES project is that stakeholders found that CLDs are rather straightforward to get a comprehensive system picture, to show and discuss the interconnections as well as the interdependencies among sectors. There are also, based on our experience, a few expedients that might be useful to facilitate communication with stakeholders:

- Finding a good balance between the need to provide a holistic picture and the opportunity of keeping the focus on sectoral sub-systems. In this direction, the use of 'shadow variables' (in Vensim, these variables are defined elsewhere in a view, in other views or in an equation and are useful in helping to reduce clutter and increase the clarity of a sketch) is particularly useful.

- Using colors for highlighting the polarity of the arrows, and/or for highlighting (or classifying) specific classes or types of variables. An example is provided in the following Figure 15 (the model is accessible here: https://kumu.io/alepag/lenses-koiliaris-nbs).

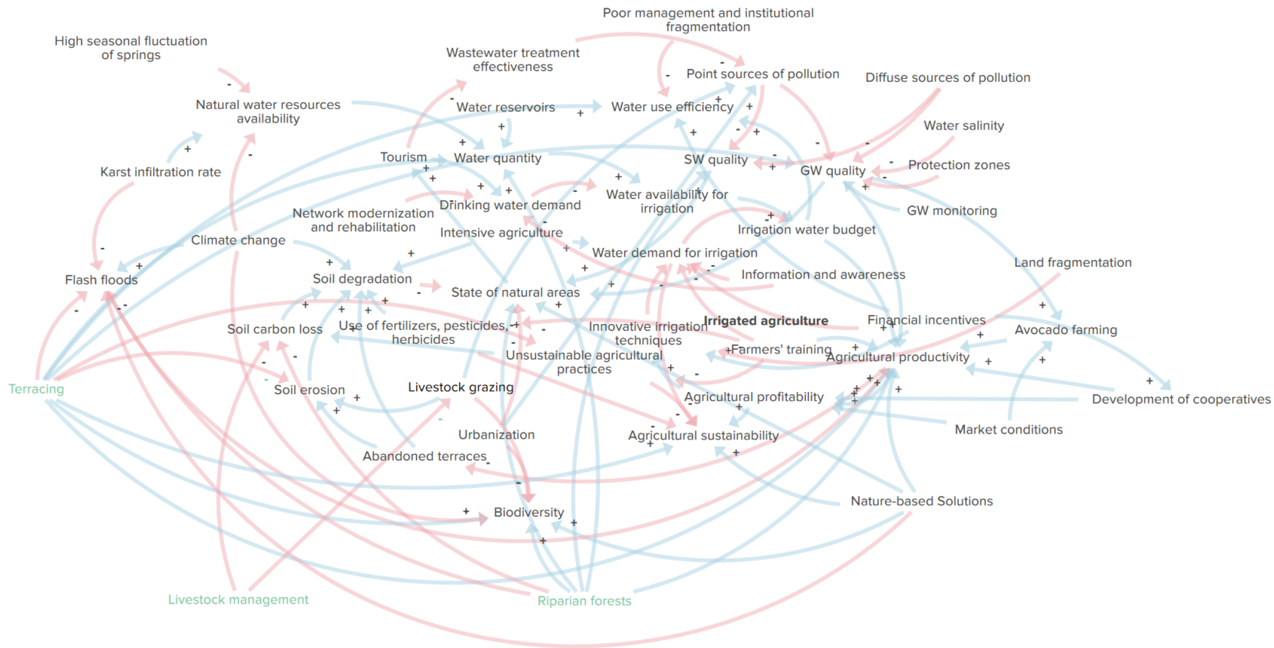

Figure 15 The CLD developed in Kumu for the Koiliaris case study. Blue arrows identify positive connections, red arrows identify negative ones. Variables in green are used to characterize Nature-based Solutions, while the bold is used to identify feedback loops in the CLD.

- Using a dynamic and interactive approach for presenting, analyzing and validating the CLD, identifying and highlighting feedback loops, and key dependencies of major variables (e.g. causes and uses trees). An example is provided in the following Figure 16.

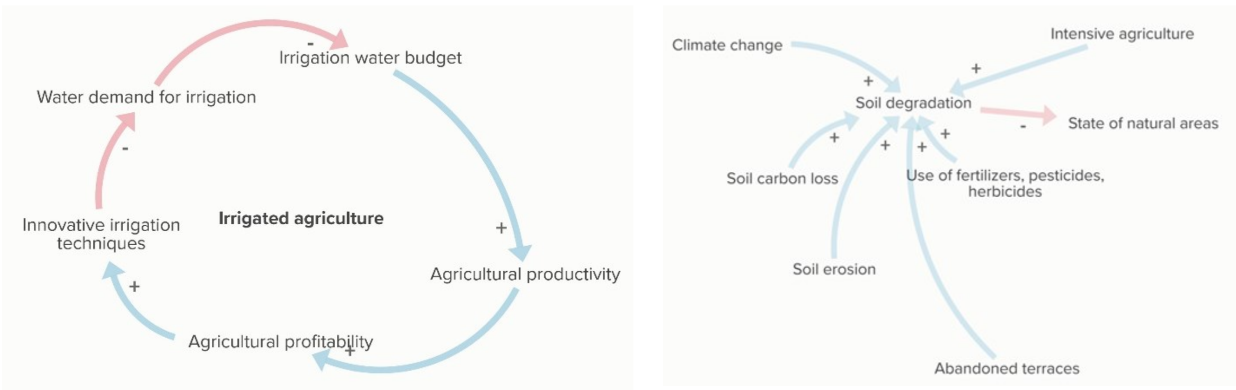

Figure 16 Referring to the CLD developed in Kumu for the Koiliaris case study, Figure a (left) shows how the interactive 'focus' can be used to isolate feedback loops; Figure b (right) shows how the 'focus' can be used to limit the view to the variables directly or indirectly connected to another variable (in this example, the variables directly connected to 'Soil degradation').

Similar expedients are also strongly recommended for building and visualizing the stock and flow models. In particular, the use of shadow variables – along with the use of sub-models – helped keeping the visualization easier, without losing the 'Nexus' perspective.

4.1.5. Transparency (CLD High, SF Medium)

The idea of model transparency mainly refers to the level of knowledge that is needed to understand a model and its underlying mechanisms. The extremes are often referred to as 'transparent' or 'black-box' models, but different levels (and methods) exist in between. There are interesting perspectives on the role of transparency in SDM (Alessi 2002; Kopainsky and Alessi 2015), including the idea that model transparency is not necessarily a positive (or necessary) condition of SDM, particularly when the focus is on learning/education purposes, but this depends on modelling goals.

For the purposes of the LENSES project, we feel that model transparency is essential. In line with the two main concepts underlying LAAs (i.e. 'Learning' and 'Action'), one of the key objectives of stakeholder involvement is 'learning', i.e. creating an environment that allows learners better understanding a system or problem. An improved system understanding allows, following (Alessi 2002), also a potentially better capability to control a system o problem.

The adopted approach, which values the direct participation of stakeholders (as much as possible) to model development, review and validation, requires a high level of model transparency.

As highlighted in the literature (Alessi 2002; Voinov et al. 2018), CLDs (frequently augmented with other visual techniques, such as graphs showing reference behavior or colorization to emphasize cause-effect relationships) allow making models transparent. They convey much more information than verbal descriptions. They especially make the variables and cause-effect relationships transparent, though they do not make the mathematics of the variables visible. They are good at making the big picture clear, but less valuable for the details.

The LENSES experience allowed highlighting a few aspects that can help improving CLDs transparency:

- **Visual/graphical techniques** directly contribute to model transparency. As shown in the previous subsection, the use of colors is particularly helpful to make some specific aspects of the model more transparent (e.g. key connections, loops, key variables). The use of colors and, more in general, of visual techniques, **facilitates the learning phase**, decreasing the initial cognitive load when a model is analyzed for the first time, ultimately helping to focus on key elements. Colors should be best used with other methods (e.g. numeric information) that can convey additional information.
- Provide **a simple yet effective description of (parts of) the CLD** helps stakeholders focusing on the 'meaning' of the model, rather than on its structure. Understanding the meaning of positive/negative connections as well as the relevance of reinforcing/balancing loops is not immediate, so the support of the analysts in a very **simple explanation of the meaning of some connections** can significantly support an improved model understanding. The following example (Figure 17) shows how one key issue (i.e. the role of irrigated agriculture) was presented to stakeholders in the 2nd Tarquinia plain workshop, following a general overview of the CLD, using the causes-uses trees.

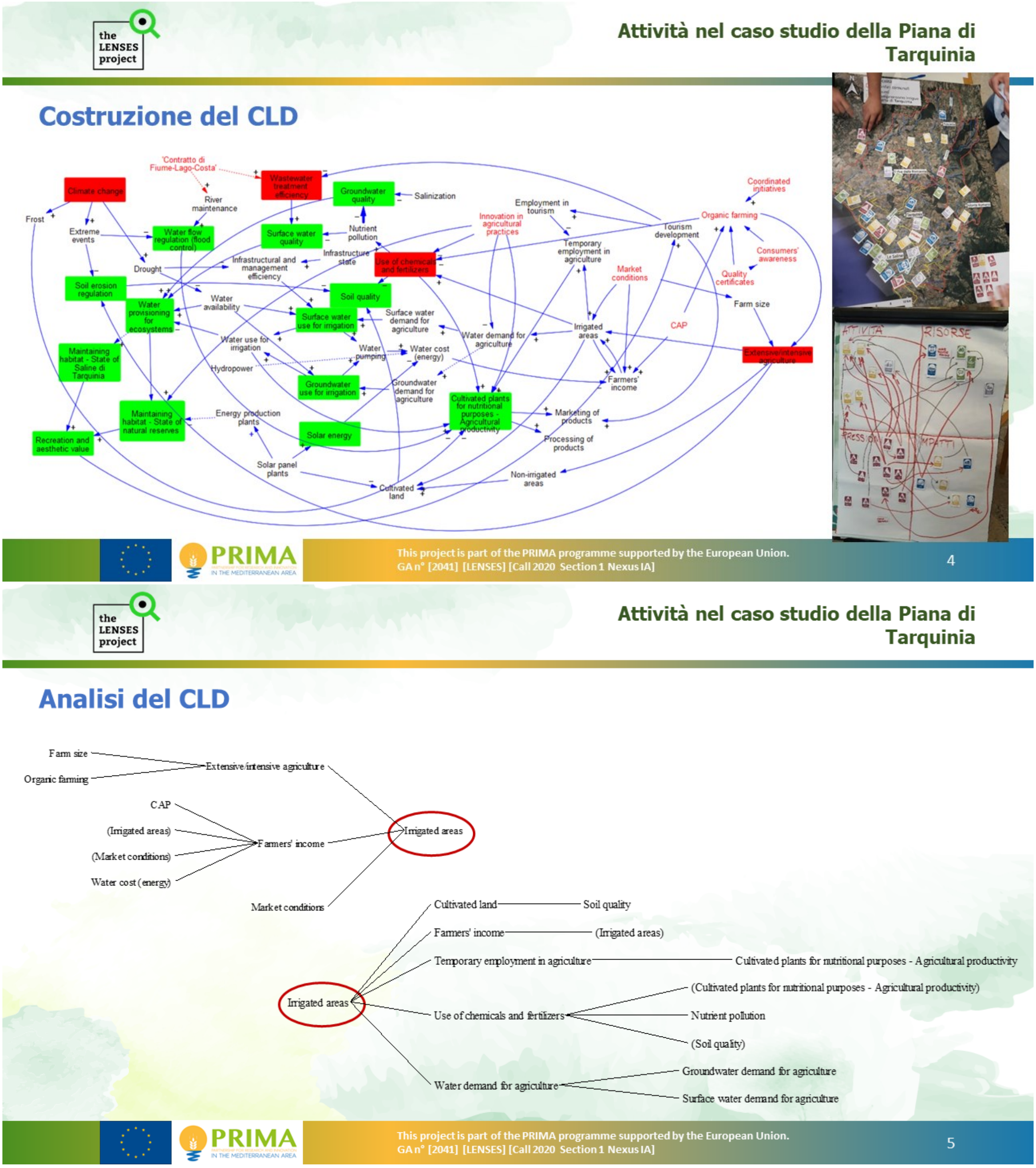

Figure 17 An example on how to improve model transparency, with reference to the Tarquinia CLD. The CLD is presented in general terms (Figure a), highlighting the complexity of the system under investigation, while the cause and uses trees area used (Figure b) to help stakeholders 'zooming' into one of the key issues for the study area.

- **Coupling the descriptive and structural analysis of the CLD**. The role of the analysts is also crucial in order to help stakeholders better understand the main outcomes of the model development phase.

In this direction, the use of simple but effective information (such as the results of the centrality analysis) help transferring some key messages to the stakeholders involved in model building and validation.

Stock-and-flow diagrams are inherently less transparent than CLDs, as they require at least a basic experience of learners with system dynamics notation. However, Stock-and-flow diagrams show much more information than CLDs, including equations. Their transparency can be improved as well improving graphical aspects, such as e.g. colorization or animation. Our experience in the LENSES project (partial, as the stock and flow models are still being presented and discussed during the last round of stakeholder workshop) is that a good level of transparency can be achieved only with the involvement of the analysts as facilitators (or narrators) describing the diagram and guiding the participants in a better understanding of model runs. Combining visual information with verbal explanations is key to support participants in the understanding (and effective use of) stock and flow models.

4.1.6. Ease of modification (CLD High, SF Medium)

CLDs are rather intuitive and easy to modify, by the analysts but even directly by the stakeholders at least once some key instructions and explanations are given. In the LENSES activities we considered all CLDs as highly dynamic and evolving models, open to updates and modifications throughout project duration. Taking advantage of the possibility of easily modifying and updating the structure of CLDs, we thus organized several participatory activities oriented to model revision. We used a specific approach in different case studies and, within the same case study, in different steps of the activities. Broadly speaking, there are the following options:

- The CLD is modified by the analyst, based on the information received from the stakeholders and or pilot leaders. This approach requires that a specific format is used for interviews and/or for running exercises during the workshop. The main advantage is that the model has 'control' on the modelling activities, with an increased coherence and consistency in the model. The main disadvantage is that there is a rather limited understanding (and ownership) of the model, and a more limited creativity from the stakeholders.
- The CLD is modified by the pilot leaders, provided that a basic training (1 hour online meeting) is done by the analysts. The main advantage of the approach is that pilot leaders can easily include a lot of information they get from stakeholders (including informal conversations). The main disadvantage is, again, a limited understanding of the model from the stakeholders.
- The CLD is modified directly by the stakeholders. This requires a basic training for the facilitators (in general, pilot leaders, considering that interviews and workshops are always in the local language), and an explanation of CLD basics to stakeholders. In our experience in the LENSES project, this is a rather effective way of involving stakeholders and stimulating dialogue, as emerged e.g. in the Pinios Workshop (see Figure 18) and refer to (Malamataris et al. 2023) for further details.

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Figure 18 Stakeholders directly working on the CLD building. An example from the Pinios case study.

4.1.7. Feedback loops supported (CLD High, SF High)

Feedback loops are a crucial part of SDM, and are well represented both in CLDs and in stock and flow models. Simple models have a direct chain of ***causality***: input data affect some elements, which affect other elements, and so on, until eventually the elements which calculate the desired results of the model are reached. More realistic systems, however, contain elements whose output can, directly or indirectly, affect one of their own inputs. This creates a looping or circular system structure. CLDs are typically a visual tool to represent the feedback structure of systems.

There are two kinds of feedback loops: positive feedback loops and negative feedback loops.

- **Positive feedback loops** are self-reinforcing. Positive feedback loops Reinforcing loops produce both growth and decay. That is, they compound change in one direction with even more change.
- **Negative feedback loops** are self-correcting. Negative feedback loops drive systems toward equilibrium and balance.

The dynamics of most systems are driven by the interactions of many such loops, and that is the reason why the analysis (and discussion) of feedback loops is so relevant in the development of SDM. Different combinations of such loops (and delays) can be shown to produce various fundamental modes of dynamic behavior (e.g., exponential growth, goal-seeking, oscillation).

As SF models often reflect in a quantitative form the concepts described through a CLD, SF can directly represent feedback loops, and highlight the impact they have on the state and evolution of variables over time.

4.1.8. Handling uncertainty (CLD Low, SF High)

Following Voinov et al. (2018), making uncertainty explicit contributes to a much more transparent decision-making process. The opportunity to take into account uncertainty also relates to the model purpose, which also depends on how far into the future we need to look, and how precisely. In general, the capability to take explicitly into account (and to transfer to model users) uncertainty is much higher when the model becomes quantitative, and therefore is relatively low for CLDs compared to stock and flow models.

Following relevant SD literature (see e.g. Pruyt, 2013) a strong connection exists in SD between the multiple sources of uncertainty (related to 'natural' phenomena but also e.g. to social- economic-energetic uncertainties) and scenario analysis. All these uncertainties make any deterministic prediction worthless. Scenarios, simulation models, projections and ranges are therefore mostly developed in this domain, instead of deterministic optimization models and point predictions

A CLD can be used to understand phenomena and resolve issues about how the dynamics will play out, helping to explain the mechanics behind a complex system. However, they simply don't have enough information to resolve the uncertainties (Bridgeland and Zahavi 2009). A CLD developed around the scenarios may offer a complementary and slightly more sophisticated way of trying to identify key uncertainties. The focus is then on the so-called leverage points that emerge from the CLD. These leverage points are the factors in the CLD that jump out because of the high number of arrows going in and out. These key nodes in the CLDs densely woven network may prove to be suitable candidate critical uncertainties for a set of scenarios that is grafted on the same focal issue[2].

The stock and flow models have a significantly higher capability to deal with uncertainty. This can be done, for example, using the Sensitivity Analysis (SA), which helps analyzing the effect of (relatively) small changes to values of parameters and functions on the behavior of the whole system. This is particularly useful as it helps increasing the understanding of the relationships between inputs and outputs and, in the case of SDM, generate insights about the link between structure and behaviour (Pruyt 2013). This is particularly helpful when discussing and communicating results with the stakeholders, in particular for what concerns the identification of candidates for uncertainty reduction efforts (e.g. adding new knowledge) and the identification of inputs for which the output is insensitive because dynamic limits may have been reached or non-linear thresholds crossed.

An example of SA that helps clarifying the information that can be provided is reported in the following. Referring to the SF model developed for the Pinios, we tried to estimate and show the potential impact of a variable 'GW recharge rate' specifically for the Agia sub-basin. For this purpose, we assumed a variation of the 'GW recharge rate' in the range [0-1] with a random uniform distribution, and explored the results of 100

[2] https://blog.kumu.io/exploring-the-future-four-ways-to-combine-future-scenarios-with-causal-loop-diagrams-78a6869af05f

simulations. This analysis is rather simplified, as the software used (Vensim) allows running multivariate analyses and different shapes of the distributions of the selected parameters. The results of the analysis performed with reference to the 'GW availability' are reported in the following Figure 19. Results can be displayed either as individual traces (i.e. a thin line for every sensitivity simulation performed) or as confidence bounds (as in the Figure). These are computed at each point in time by ordering and sampling all the simulation runs. Thus, for example, for a confidence bound at 50, 1/4 of the runs will have a value bigger than the top of the confidence bound and 1/4 will have a value lower than the bottom.

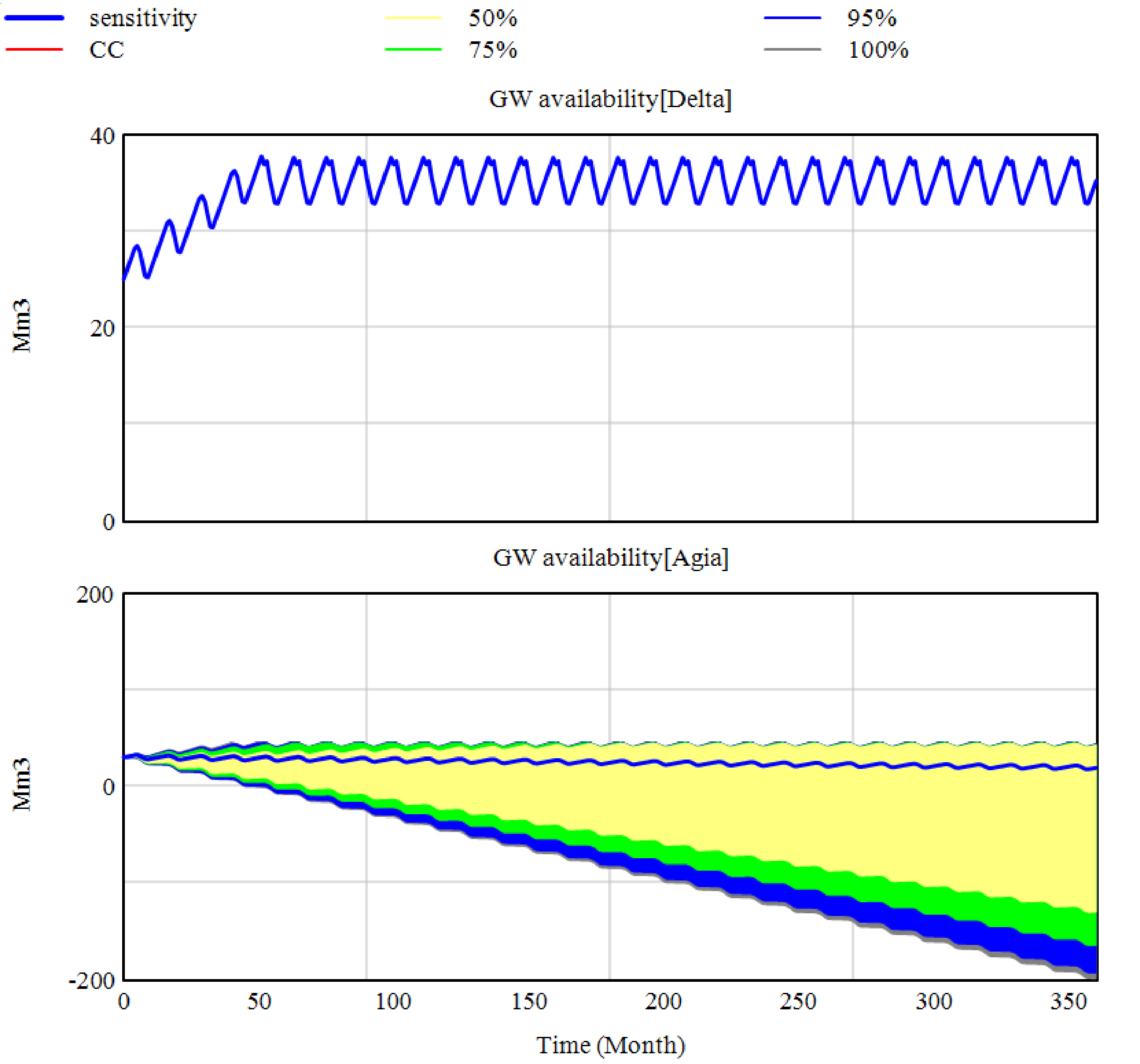

Figure 19 Sensitivity analysis (SA) for the variable 'GW availability' with respect to the variable 'GW recharge rate' (Pinios SF model).

The SA above shows that varying one relevant variable (the GW recharge rate) may have a direct and significant influence on the variable 'GW availability', but also impact other variables in the model (such as the 'Average agricultural sustainability', which is one of the other target variables, shown in Figure 20). It might be particularly useful to help systematically understand the influence of input variables and outputs.

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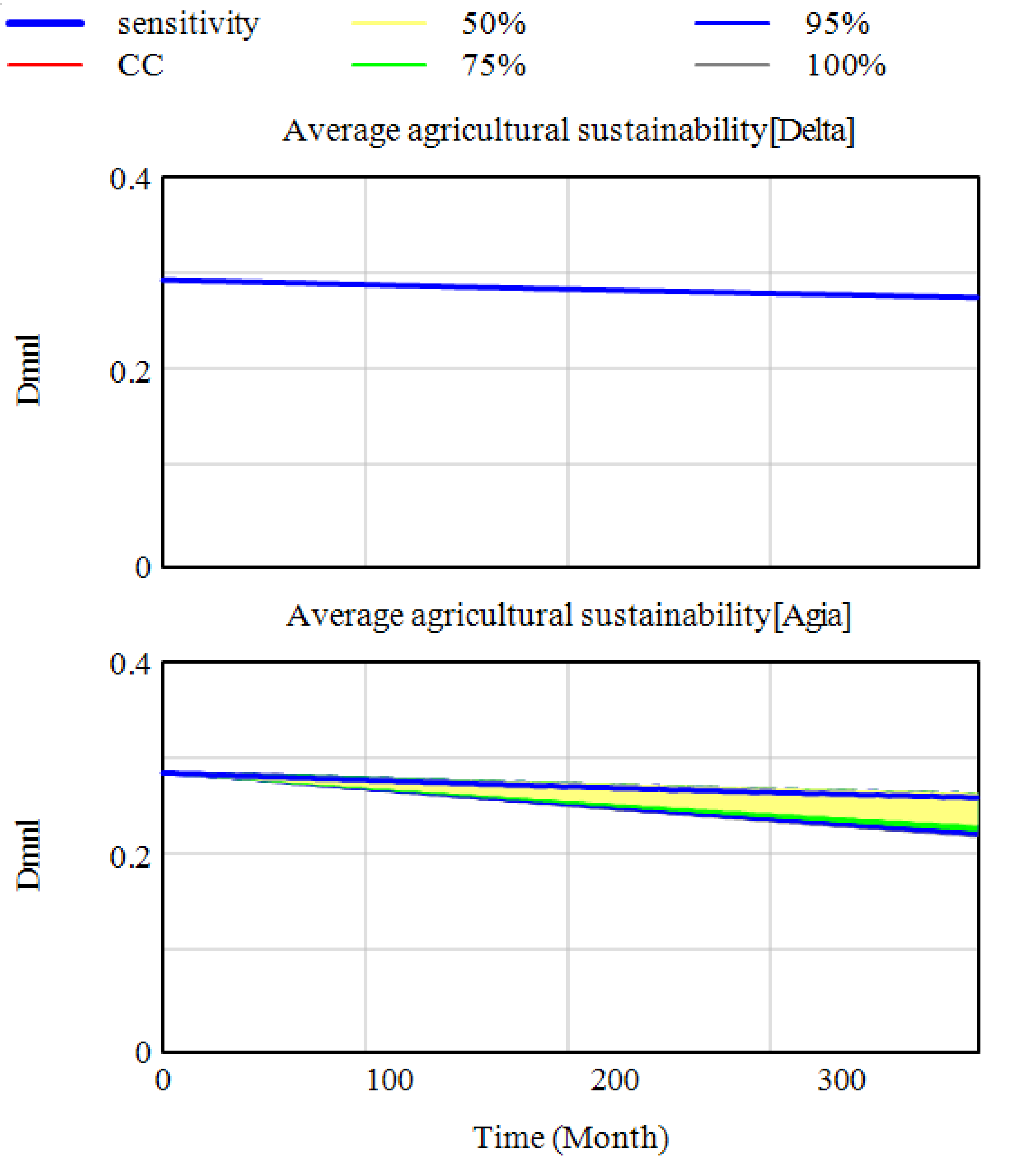

Figure 20 Sensitivity analysis (SA) for the variable 'Average agricultural sustainability' with respect to the variable 'GW recharge rate' (Pinios SF model).

Stock and flow models allow also an Uncertainty Analysis (UA), i.e. is the computation of the total uncertainty induced in the output by quantified uncertainty in the inputs and models, and refers to the exploration of the influence of the full range of uncertainty deemed plausible. Following Pruyt et al. (2013), UA could be used for:

• evaluating plausible effects of uncertainties in parameters, lookups, functions, structures, sub-models, models, boundaries, methods, and possibly controversial/disputable perspectives

• generating many plausible scenarios / behavior patterns

• exploring and analyzing ensembles of scenarios/runs and uncertainty spaces

• evaluating the appropriateness of models under uncertainty similar to testing models under extreme conditions

• directly searching the uncertainty space for limits, tipping points, best fits, implausible results, or high leverage points using optimization techniques

• searching the uncertainty space for particular behaviors and densely concentrated regions thereof, identifying joint root causes of behaviors with particular characteristics (un/desirable dynamics, un/desirable end-states, or undesirable side-effects) with dynamic scenario discovery

A major difference between SA and UA is that SA necessarily starts from a base run/scenario, which is not the case for UA. In addition, SA is a means to explore the sensitivity of a model to small perturbations whereas UA is a means to virtually explore plausible real world effects of assumptions over their plausible uncertainty sets/ranges.

4.1.9. Modelling requirements and needs

A few additional reflections need to be done with specific reference to the key technical and methodological requirements of the participatory modelling tools discussed in (Voinov et al. 2018).

The **modelling requirements** for building PSDM are highly variable. In general the **time and cost needed** is relatively low for CLDs, although the process of model revision and validation might be long (as in the LENSES experience) in case multiple interactions with the stakeholders take place. The definition of a baseline CLD is rather immediate, provided that a good background knowledge of the study area exist, but obtaining a shared and robust version of the CLD is a longer process. In general, no deep **methodological knowledge and expertise** is needed to come up with a solid and reliable CLD. However, it needs to be considered that the process of CLD analysis (e.g. analysis and description of loops, centrality analysis) takes some time and requires a good technical expertise. The definition of a CLD does not need **empirical data**, and this probably represents the main value added of the approach. A fair conceptualization of the system under investigation can be achieved even without ‘hard data’, and relying on expert/local knowledge only. Similarly, a limited **conceptual knowledge of the system** is needed, and CLDs can be used exactly for the purpose of better understanding system state and potential evolution. The other resources (**computer resources**) needed for CLD building are also very limited, and currently several open source options (including Kumu) exist for the purpose.

Conversely, the process of SF models building is **time consuming and a strong technical expertise is needed**. Building a SF includes several phases of model review, formal analysis and validation. In this regard, the availability of **empirical data** is crucial to support validating the quantitative variables. Specific activities can be performed with the stakeholders (e.g. the discussion on the Behavior-Over-Time graphs) for validating even the qualitative variables. SF model building requires **methodological knowledge and expertise**, and – in general – a very good **understanding of the system**, which is often provided by the CLD.

4.2. Key features of participatory modelling: the pilot leaders (and stakeholders) perspective on the use of PSDM in LENSES

The present section provides a summary of the main strong and weak points related to PSDM implementation in LENSES pilots, through the 'lenses' of the pilot leaders. They were asked, through both personal communications and a more structured survey, to give feedback on the main positive and negative aspects related to PSDM implementation, focusing on the criticalities and value added of each phase.

A summary of the feedback received is provided in the following Table 1.

Table 1 A summary of the pilot leaders (and stakeholders) perspective on PSDM implementation in LENSES pilot areas.

Objectives (relevant to PSDM)	Related activity with the stakeholders	Main issues/problems faced with stakeholders	Value added in the interaction with stakeholders
Support to the identification of challenges for the pilot area	*- Semi-structured interviews (both preliminary and in-depth)* *-1st and 2nd Stakeholder WS*	*-Low interest of some stakeholders which did not show up at the meetings, thus not provided needed contribution from their side.* *- Some stakeholders were not willing to participate in meetings because of conflicts within and outside the sector.* *- High number of variables /cards used*	*- Rising awareness in different stakeholder groups* *- Talking and thinking together about specific challenges and issues* *- Visualising the challenges in the area (through mapping exercises) helped several stakeholders to recognise problems and identify solutions.* *- Knowledge exchange and dissemination* *- Support to consensus building*
Identification of interdependencies and conflicts between sectors	*- Semi-structured interviews (both preliminary and in-depth)* *-1st and 2nd Stakeholder WS*	*- High complexity of the structure of sectors* *- Distance between stakeholders at different level* *- Ensure a balance between sectors and stakeholders in order to limit potential bias.* *- Difficulties in fully understanding interconnections among variables* *- Highly conflicting views on resources uses*	*- Enhancing interactions between stakeholders* *- Consensus building around the need of a different model for socioeconomic development and identification of a common goal*

Identification of central elements and/or indicators	*- Use of CLDs with stakeholders during the WS*	*- Difficulty on the identification of 'shared' central elements because each stakeholder tends to focus on individual challenges - Too much emphasis is given to barriers rather than opportunities*	*-Pilot challenges evaluated from different perspectives - Clear idea of what, who and how needs to be involved to act on the system*
Understanding and visualizing the complex connections among sectors through Causal Loop Diagrams	*- Use of CLDs with stakeholders during the WS, including CLD analysis*	*-Limited participation of stakeholders without a technical background -Difficulty of getting a full understanding due to the complexity of CLD, which requires explanation (or the guide from a facilitator/analyst) - Need to better take into account short, medium and long term dynamics*	*-Improving vision development of stakeholders, specifically local authorities. - Raise awareness on the efficiency in resources use - Setting a common understanding of the direction to be taken / setting a baseline for dialogue among stakeholders (common goals) with different (individual) priorities*
Analysis of the Causal Loop Diagrams to identify issues and points of intervention	*- Use of CLDs with stakeholders during the WS, including CLD analysis*	*-Limited participation of stakeholders without a technical background -Difficulty of getting a full understanding due to the complexity of CLD - Tendency to focus on traditional solutions*	*-Better understanding of challenges and interactions. - Policymakers were very interested in the use of this tool for understanding the territory and for planning reasons.*
Understanding potential actions' impacts on the WEFE system using the CLD	*- Use of CLDs with stakeholders during the WS, including CLD analysis*	*-Conflicting interests from stakeholders*	*-Understanding and structuring of WEFE system*
Analysis of the stock and flow model and scenario analysis	*- Discussion of results during the 3rd WS*	*- Limited incorporation of 'local' quantitative information in the stock and flow model - Understanding the meaning of variables (and the implications of state changes in different scenarios) can be challenging*	*- Provides a comprehensive understanding of WEFE Nexus systems - Focusing on a subset of key sectoral variables is easier and effective (rather than focusing on the whole model)*

			- Helps understanding and visualizing the impact of different actions, supporting dialogue with policy- and decision- makers

5. Discussion

The present section provides some general remarks and reflections on the implementation of PSDM, although the process has not been completed yet (particularly as far as the development of stock and flow models is concerned). The evidence from pilot areas, mainly in terms of barriers encountered and opportunities emerged, is highly relevant for a replication of the approach beyond the LENSES project.

First, the correct identification of key stakeholders is crucial, as it guarantees that the process is well-balanced, equitable and that all different objectives and points of view are adequately taken into account. Furthermore, the wider and diverse the stakeholder group is, the richer is the knowledge that can be elicited and included in all phases of model building and development. However, this has a drawback, that is the potentially high level of conflict among stakeholders, and the multiplicity of points of view to be taken into account. From the methodological point of view, this implies that **the approach should be flexible and adaptable, depending on the main purpose of the activity (e.g. raising awareness or support to policy design), but also on the background and profile of the stakeholders involved**.

In this regard, two actions were taken: i) some activities were 'tailored' according to the stakeholders involved; ii) the whole approach - detailed in the D4.2 – was built considering a sequence of desk and participatory activities that can be (to some extent) modified without compromising the outcomes of the process. Regarding the point (i), for example, two different formats for the individual interviews were prepared (including a different number of technical details and a different complexity) and used depending on the background of the stakeholders. Regarding the point (ii) each pilot area customized the participatory activities (and exercises) according to the specificities of the stakeholders involved. Similar objectives, such as the CLD building and validation, were performed either through workshops (e.g. Pinios, Doñana) or focus groups (e.g. Koiliaris).

Second, the experience in LENSES highlighted also a twofold role of PSDM. On the one hand, it can be used for an in depth analysis of each sector, that helps identify objectives, challenges and needs. This is particularly useful for a 'diagnosis' of each sector on isolation, clarifying **the needs of individual stakeholders, and guaranteeing that the stakes and interests of everyone are correctly recognized**, that all voices are heard and that everyone is represented. In this direction the use of sectoral sub-models is valuable and facilitates model building and validation. On the other hand, PSDM can be used for facilitating **'Nexus dialogue'**, as both CLDs and stock and flow models allow a comprehensive representation of the interconnections among sectors, ultimately facilitating the definition of a collective (shared) view of system state and potential evolution. Building consensus among stakeholders on the goals and needs for an area is definitely one of the main objectives that can be achieved using PSDM.

Third, there has been a very positive feedback from stakeholders and pilot leaders on the use of PSDM for supporting Nexus analysis and management. CLDs provide a very valuable representation of the Nexus complexity and of the high level of interconnection and interdependency among different sectors, and has a remarkable capacity to visualize complex causal dependencies. Stakeholders are typically impressed by the **visualization of the actual complexity of the system they are dealing with, and by the understanding of the potential impacts, side-effects and unintended consequences of actions and decisions**. This is particularly true when strategic decisions related to the medium-long term planning and to the ‘vision’ for the study area have to be taken. Analyzing the structure of such a complex system (both with a descriptive analysis and with a structural analysis) helps raise awareness on the trade-offs associated with any decision, and identifying potential leverage points where actions could be more suitable or effective.

However, it is worth noting that PSDM in general is **not always a straightforward tool to manage for stakeholders, even for those with a technical backgroun**d. From the methodological point of view, it is not immediate to understand the basic notation (e.g. the meaning of polarities and how to interpret reinforcing or balancing feedback loops) and the key features of the method. In this regard, it is important to introduce at least the key basic features of CLDs and stock and flows to the stakeholders before presenting the results and, particularly, before discussing the main findings and asking for any feedback or validation exercise. The direct involvement of the analysts as facilitators or the proper training to facilitators is crucial for achieving this objective.

Lastly, the **continuous involvement of stakeholders** throughout the project duration and the regular presentation of project results is crucial, in particular as it helps in highlighting and valuing the benefits of participation, increasing the willingness to participate and guaranteeing the development of a sense of ownership of modelling outcomes.

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6. Conclusions

The work described in the present deliverable is directly related to WP4 activities, and focuses on the implementation of PSDM in the LENSES project. Specifically, the focus is on the lessons learned from the implementation of participatory exercises for SDM building in the LENSES pilots, in order to support a successful replication of the approach.

As detailed in the D4.2, PSDM implementation is mainly based on two phases, namely a 'qualitative' modelling phase based on CLD development, and a 'quantitative' modelling phase based on the development of stock and flow models. It comprises a series of desk activities (where the role of the analysis is central for building or validating models) and participatory exercises (needed to include explicitly stakeholders' knowledge into the picture and to co-design scenarios and solutions).

Starting from the literature, the key features that characterize participatory models are analyzed and discussed in detail with direct reference to the use of PSDM within LENSES. Methodological hints and suggestions are provided to deal with some key issues (e.g. spatial analysis, uncertainty management), and some feedbacks are collected from stakeholders to highlight the value added and potential limitations of PSDM.

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