from Nexus Thinking to Nexus Doing

REXUS

MANAGING RESILIENT NEXUS SYSTEMS THROUGH
PARTICIPATORY SYSTEMS DYNAMICS MODELLING

Deliverable 4.2 – Framework for PSDM implementation in REXUS case studies.

WP4 – Advancing Nexus Thinking

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Abstract

The present Deliverable includes details on the methodological approach (mainly based on 'Participatory System Dynamics Modelling' - PSDM) that has been proposed in the REXUS project to support an improved Nexus understanding and an effective Nexus operationalization. An interested reader will find full methodological details on how the PSDM activities have been planned at project level, with a thorough characterization of the multi-steps procedure that has been designed. Detailed information on how desk and participatory exercises (the latter directly in the LAA environment) are being integrated, is also provided. Additionally, insights from the implementation of PSDM in REXUS pilots are also given, with practical information on how the process for PSDM implementation is tackled, on the main evidence so far and on the key challenges and bottlenecks. Reflections and lessons learned from pilot areas are also included.

The present Deliverable deals with activities that are dynamically evolving in all pilot areas, and therefore it only provides a preliminary version of the PSDM framework as it has been designed. A revised version, updated and revised according to the experiences in pilot areas, will be prepared at M36.

1 Introduction

The present Deliverables describes the activities being performed in the Task 4.2 'Participatory System Dynamics Modelling' (PSDM in the following), led by IRSA with contributes mainly from UCAM and Pilot teams. Basically, Task 4.2 is oriented to support shifting from the individual or sectoral perspectives to the definition of a 'System' picture and is based on participatory activities performed in all pilots in order to explicitly account for the diversities in problem understanding and perception. The final objective is to support the long-term involvement of stakeholders in LAAs and a cross sectoral knowledge fertilization process.

The task mainly aims to develop a process for operationalizing Nexus in the pilot areas, based on the potential of different System Dynamics Modelling (SDM) tools and techniques through a strongly participatory approach deeply rooted into the LAAs. A key objective to be achieved through this process is the integration between scientific knowledge (provided by the available models and data) and local knowledge, collected within the LAAs and properly structured. The task also deals with crucial issues related to the effective involvement of stakeholders in modelling the Nexus structure, i.e.: i) how to guarantee the long-term involvement of stakeholders in the modelling activities? ii) how to account for the differences in problem framing among the engaged stakeholders? iii) how to guarantee equitable and inclusive participatory modelling processes? To this aim, state-of the-art methods for stakeholders' engagement in modelling exercise are being adopted. The present Deliverable mainly deals with the development of a common framework for implementing a participatory process supporting SDM development

The work is being developed in direct connection with the activities related to the Task 4.3 and detailed in the D4.4. The coupled-resource stock flow model developed by the UCAM team will be augmented explicitly including behaviors, perceptions and pilot-specific information described through the PSDM. The PSDM will also contribute to understand the decision-making behavior, and support what-if analyses.

The Deliverable is structured as follows. The Section 2 provides a review of relevant literature dealing with PSDM, providing both a very basic introduction to the methods and a summary of the main frameworks that have been already developed. Section 3 provides a summary of the proposed REXUS framework for PSDM implementation, with full details on the main methodological aspects. Section 4 deals with the most relevant modelling issues that emerged so far, discussing also the integration of PSDM with other sectoral models. The state of activities in the REXUS pilots is then discussed in the Section 5, where details from some relevant pilots are also discussed. A critical analysis of such experiences is then proposed in the Section 6, which also provides information on how the framework could be customized/adapted to pilot specificities. Lastly, section 7 includes some conclusions and details on future activities

It is worth mentioning that this Deliverable proposes a preliminary version of the PSDM framework as it has been designed, which is still being updated and revised according also to the experiences in pilot areas. It should be thus considered as a dynamic and living document, with a huge space for revisions and improvements. For this reason, we intend to submit an updated version of the PSDM framework in M36 (although not required in the GA) based on all the feedbacks received in the case studies. It is also worth underlining that some cross-fertilization is taking place also with the LENSES project (PRIMA Programme supported by the European Union GA n° [2041]), in which IRSA Team is directly involved in PSDM implementation for Nexus analysis.

2 State of the art

2.1 An introduction to PSDM

System Dynamics Modeling (SDM) creates explanatory models of system structures and simulates dynamic interplay between key variables to explore system behavior over time (Sterman, 2000). As already briefly introduced in the Section 2.4 of the REXUS D4.1 ('Report on PSM and SNA. Identification of DOs, NRQs and NIs), the method helps system conceptualization and problem identification in social-ecological systems where simulation is most useful for decision making (Kopainsky et al., 2017; Videira et al., 2010). Such models facilitate knowledge integration across many domains (Harwood, 2018), shedding light on interactions between social and natural systems and how these might be influenced by public policy (Gallagher et al., 2020; Ghaffarzadegan et al., 2011).

Both qualitative and quantitative approaches exist in SDM, whose use depends on analysis objectives, employed methodology and addressed audience (Brychkov et al., 2022). Basically, qualitative SDM allows the analysis of the system behavior with the help of a conceptual (mental) model, often based on Causal Loop Diagrams (CLDs) which capture how elements in the system are interrelated by depicting cause-and-effect linkages and feedback loops (Sterman, 2000). The need for qualitative forms of model-building is often dictated by the existence of a large number of 'soft' elements in a system and on 'textual' data that are obtained for example from interviews. Qualitative SDM provide often useful insights for decision-makers. Quantitative simulation model mainly derives from a stock-and-flow diagram and a set of simulation equations that quantify linkages between different types of variables. The main objectives of quantitative SDM include the elimination of inconsistencies in understanding of general behavior the system and the empirical testing of hypothesis about system behavior and all causal mechanisms (Brychkov et al., 2022).

The value of SDM (particularly in the 'qualitative' form) can be increased by the active involvement and empowerment of different stakeholders in extracting rich qualitative data about the system and its complexity. Stakeholders can help to analyze the system elements and their interactions, as well as to structure, categorize and debate these interacting elements. Storytelling and narratives can help better understanding specific loops as well as the whole system. Working in groups, they further socialize the originated stories and system maps in a multi-stakeholder environment to overcome possible mistakes and discrepancies of their system visualizations. These activities are iterative so the products they derive become dynamic tools rather than static objects of analysis.

The 'participatory' component to SDM is therefore not unusual, particularly in case complex systems are being modelled. PSDM enables a collective way of developing a system model, known as group model building (GMB), based on the idea that '*effective learning from models occurs best, and perhaps only, when the decision-makers participate actively in the development of the model*' (Brychkov et al., 2022; Sterman, 2000). Drawing Causal Loop Diagrams (CLDs) to map feedback dynamics is one of the options for GMB (Sterman, 2000). The essence of gathering stakeholder groups is to exchange mental models in order to unravel and communicate important problem-affecting feedback loops, which include key elements and causal links between these elements. The participants of these groups try, via shared understanding and available expertise, to obtain tangible representation of dependencies across various system dimensions.

Following (Freeman, 2000) two of the research challenges in addressing the "wickedness" of complex environmental problems (mainly water-related) are the challenge of becoming more interdisciplinary and the need for integrating two types of knowledge: scientific and local tacit knowledge. Within this context, PSDM is being considered as a best practice methodology in several fields (Rouwette et al., 2002; Vennix, 1996). Among the key advantages, the co-development of the SDM helps foster a feeling of ownership by the stakeholders, who will also be more likely to adopt and further recommend the model's policy solutions (Thompson et al., 2016). The model may be enriched by the stakeholders' local knowledge and the stakeholders involved will develop a more detailed understanding of how the system works and evolves (Scott et al., 2016) PSDM may also help define collectively and compare the expected impacts of selected strategies, with specific attention to those related to socio-institutional measures (Pluchinotta et al., 2021, 2022). Stakeholders can learn about system complexity and seek integrated approaches to achieve better outcomes. For example, they can use simulation to propose and 'test' single, multiple, or sequenced actions expected to achieve desired outcomes before. SD simulation modeling assists stakeholders to assess virtually a variety of different approaches to improve system outcomes, consider the benefits and drawbacks of each, and identify mechanisms likely to lead to or impede improvements in the analyzed system (Weeks et al., 2022).

2.2 PSDM and Nexus studies

Sustainable development requires the effective management of resources (mainly water, energy and land) which are increasingly under pressure due to socioeconomic development and climate change. In this direction the water-energy-food (WEF) security Nexus is oriented to reduce trade-offs, promote synergies, increase system efficiency, and seek strategies for sustainable development. Therefore, addressing WEF security challenges requires an understanding of the complex behavior of the WEF Nexus, which often integrates human systems (e.g., economy, energy, land use, etc.) and natural systems (e.g., hydrology, biology, etc.) in the same framework (Wu et al., 2021). A WEF Nexus model is based on interconnections (Wu et al., 2021) which integrate water, energy and food subsystems into a single system.

Using model building blocks and concepts, including stocks, flows, feedback, and delays SD modeling helps advance the understanding of the dynamical behavior of systems over time, and therefore, is powerful in investigating complex systems that are characterized by considerable dimensions, strong interactions, nonlinearity, unknown parameters, time delays, adaptive emergent behavior, and feedback loops (Eusgeld et al., 2011). In SDM all links are visual and explicit so that one can verify and ensure the processes in individual components are realistic (Elshorbagy et al., 2005) and easily identify important variables, some of which can be developed as strategies.

For such reasons, PSDM has been recently used in several studies to perform WEF Nexus analyses and for supporting policy development. One recent application, in the Mekong river basin, is a paradigmatic example for international nexus research (Gallagher et al., 2020). The authors combined participatory CLD processes, scenario modeling, and a new resilience analysis method to identify and test anticipated WEF risks. The proposed approach generated improved understanding of potential cross-sectoral and cross-level risks mainly from major hydropower development in the region. The results showed expected trade-offs between national level infrastructure programs and local level food security, but also some new insights into the effects local population increases may have on local food production and consumption even before hydropower development. The analysis shows the benefit of evaluating risks in the nexus at different system levels and over time depending on how SD and inflection points are considered. The case illustrates the contribution of participatory system-thinking processes to risk assessment procedures for complex systems transitions. Participants in the modeling procedures also found the experience powerful in terms of information sharing, rapid risk assessment, and personal learning.

An intervention protocol, based on PSDM, for supporting sustainability transformations relying on the WEF approach was proposed by (Kimmich et al., 2019). PSDM was used to describe and simulate the current livelihood and environmental condition in the region through explicit scenario modeling, using participants' knowledge and facilitating dialogue about future risks and potential actions to mitigate or adapt to these. The Authors employed a procedure based on the use of CLDs that involves stakeholders selecting essential variables, developing cause-effect connections between them, and then simulating development of these relationships into the future through scenario analysis. The work demonstrated that participatory CLD mapping and simulation is likely to be one effective implementation method for WEF nexus governance processes. The development of scripts that serve as replicable protocols has been also suggested.

SDM has been used by (Sušnik et al., 2018) to support a quantitative Nexus analysis, based on the qualitative description provided by a conceptual diagram on the major nexus components relevant for the Sardinia case study. The main focus of the SDM was the representation of the reservoir water balance for the island, accounting predominantly for water supply and for water demand related to agricultural, energy and domestic/tourist consumption. Energy generation and consumption were also taken into account, along with the mode of generation and sector of consumption, as was modelling the change in crop types (i.e., land use and food production changes) and the crop water requirements associated with potential crop and cropped area changes, as well as in response to change in the local climate. The model structure was consolidated in consultation with local stakeholders, and appropriate data were inputted into the model and the model outputs discussed with local case study experts to verify if the model was yielding sensible results.

One of the main research gaps in the literature is related to the need to better implement non-computational approaches for an improved understanding of the WEF security nexus also by local planners (Purwanto et al., 2019). In this direction, SDM is seen as a powerful approach, and Authors developed a qualitative CLD (map) of the water-energy-food security nexus a pilot area in Indonesia, with the aim of elucidating to local stakeholders the complexity of the system without recourse to a complicated modelling and data collection exercise. Such an exercise can highlight the complexity of such systems to stakeholders, and by thinking across traditional departments, can also help to break silo-thinking, moving towards systems thinking. GMB as part of stakeholder engagement was applied in the study area to improve problem understanding, raise consensus and build the spirit and commitment of stakeholders.

Qualitative and quantitative SDM was used with local stakeholders to validate model structure, data, results, and to gather information on Latvian policy objectives and implement them in the model as potential future policies by (Sušnik et al., 2021). Specific attention has been given to the potential role of cross-sectoral implications in the Nexus management. Basically, the process relies on three main steps of stakeholder participation, namely: i) one workshop for the identification of critical interlinkages among sectors, ii) one workshop for the validation of the conceptual model; iii) one workshop for the selection and discussion of suitable policy measures.

Alizadeh et al. (2022) used SDM for an integrated socio-economic and environmental analysis of a complex human-water system under different climate change scenarios. The model integrates the major characteristics of climate, hydrology, land use, agriculture, economy and society and is based on a coupled Physical/Group-Built System Dynamics Model. It is suitable for the analysis of complex socio-economic changes and serves in determining policy options for climate change mitigation and adaptation in the context of an integrated assessment. Among the most interesting and innovative aspects of the model, it is worth highlighting the policy analysis module which examines stakeholders' management and adaptation policy options during the participatory modeling phase, and the use of storytelling methods to establish a narrative scenario development process combining a multi-scale (top-down) and a co-production (bottom-up) approach.

2.3 Overview of frameworks for PSDM implementation

The present section focuses on the analysis of some relevant frameworks that have been developed in the recent scientific literature for supporting the implementation of PSDM approaches. These frameworks have, at least in some components/elements, inspired the PSDM framework proposed for the REXUS project.

A relevant framework for integrating sectoral models and stakeholder knowledge in Nexus management, with a focus on transboundary areas, has been detailed by (de Strasser et al., 2016). The methodology consists of six steps and is illustrated in Figure 1. In steps 1–3 a desk study of the basin is performed, and then used as basis for steps 4–6, where stakeholders are actively involved and a more in-depth analysis of nexus interlinkages is made. The diversity of the basins requires the methodology to be flexible enough to allow the analysts to consider a wide range of interlinkages and conditions, applying at the same time a simple and consistent framework.

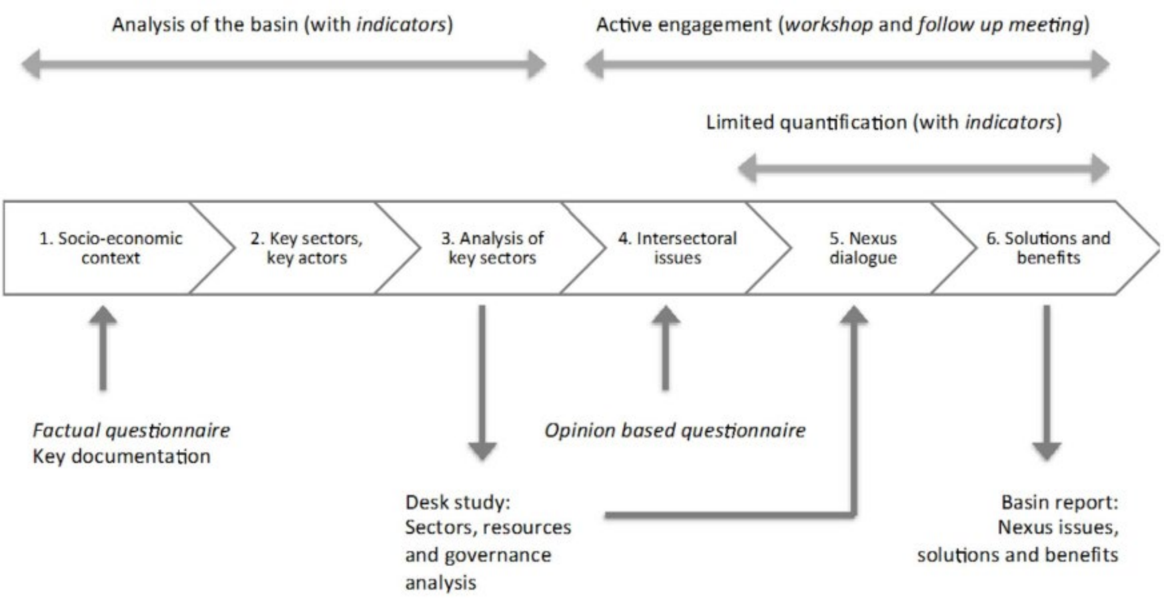

Figure 1: Graphical representation of the participatory process for Nexus analysis proposed by (de Strasser et al., 2016)

The key elements of the process are:

- Indicators—Steps 1,3,4,6: Three groups of indicators are used at different stages to substantiate the analysis of the basin, including spatial screening indicators, sectoral indicators and basin-specific indicators focused on interlinkages.
- Factual questionnaire—Step 1. Distributed to the participants to the workshop and local experts to collect basic information on the state and uses of resources as well as issues in the areas of water, energy, food/land and ecosystems.
- Workshop—Steps 4,5,6. It includes several sessions where participants engage in the nexus assessment process directly, by discussing intersectoral and transboundary issues. On top of

providing input to the assessment, this gives them ownership of the process and allows for direct confrontation of various sectors.

- Opinion based questionnaire—Step 4. Distributed, filled in and collected at the beginning of the participatory workshop to gather the opinions of stakeholders involved in the process and compare the different perspectives between sectors—water, energy, food/land and ecosystems—and countries on various issues. Issues that everyone agrees on and differences in perception are important nexus indicators.
- Follow-up meeting—Step 6. Discussion with authorities on how the findings and solutions included in the assessment relate to policies or programs in the countries, and what could be done to address the identified intersectoral issues. It is a mean of verifying the real relevance of the assessment for policy development.

Going further into details, the process includes the following steps:

- Step 1—Socio-Economic and Geographical Context Step, which aims at characterizing the basin conditions and its economic context and determining the level of dependency of countries on the basin's resources, mainly based on the assessment of resources security and on the identification of strategic goals, development policies and challenges.
- Step 2—Identification of Key Sectors and Key Actors, which aims at identifying the key sectors to be included in the nexus assessment and the key actors to be involved in the process (i.e., workshop and further consultation).
- Step 3—Analysis of Key Sectors. Understanding how the sectors use resources, their socio-economic value and what are the rules, plans and regulations associated with them is the objective of this step. The step comprises both a resource flows analysis and a governance analysis.

The outcomes of Steps 1–3 constitute the core of the desk study, which informs the discussion on interlinkages and feeds into Steps 4–6.

- Step 4— Intersectoral Issues Step. This mainly takes place in a participatory workshop, which defines how sectors interface in the nexus dialogue. Intersectoral issues are explored from sectoral perspectives as participants are divided into thematic groups—water, energy, food/land and ecosystems—according to their expertise or area of interest. Key policies, sectoral plans and data sources are presented and validated by local actors, who also provide expert judgment for prioritization of issues. An opinion based questionnaire is used to collect the different perceptions of sectors and countries.
- Step 5—Nexus Dialogue. This can be considered the core of the nexus assessment because it is the moment where intersectoral issues are discussed having all concerned sectors around the table. A shared understanding of the nexus is built and the interlinkages identified in Step 4 are jointly prioritized and combined into thematic "nexus storylines". Next, the relevant future tendencies (climate change, socio-economic trends) are identified jointly with participants and the effects that these will have on intersectoral issues are discussed.
- Step 6—Solutions and Benefits. Following the discussion on intersectoral issues, possible solutions are discussed. They can be of two kinds: (a) Synergetic: when two or more sectors actually cooperate on actions and projects that create multiple benefits. (b) Sectoral: when the action of one sector has side benefits on other sectors or at least minimizes the negative impact on other sectors. Technical solutions as well as policy interventions are considered.

Some key steps of this process (e.g. the development of questionnaires) have been considered as a reference for the REXUS activities, as detailed in the D4.1. Full details on the process (including a description of the workshop and the presentation of supporting materials) are available online (https://www.mdpi.com/2073-4441/8/2/59).

A valuable approach has been proposed by (Purwanto et al., 2019), although focused only on GMB exercises and, specifically, on the co-definition of CLDs. The process, which relies on the theoretical approach proposed by (Vennix, 1996) is graphically summarized in the following Figure 2:

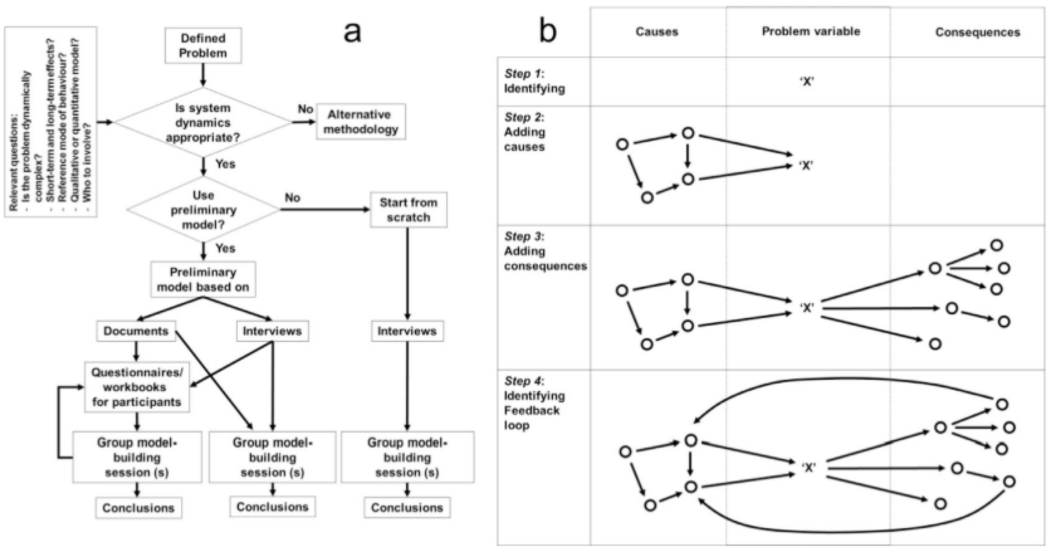

Fig. 1. The general stages in applying system dynamics GMB (a) and the process of causal loop diagram development (b)
Notes: 'X' problem-variable; O other variables. Source: adapted from Vennix (1996).

Figure 2: Overview of the stages of the process proposed for applying system dynamics GMB based on CLD (Purwanto et al., 2019)

Specifically, a one-day GMB workshop on WEF security nexus was conducted, preceded with a series of formal and informal meetings with all potential committees and participants in order to clarify the aims and objectives of the GMB exercise. The main session of GMB workshop focused on the development of the integrated WEF security CLDs in the local context.

PSDM (mainly through CLDs) has been used as for GMB also by (Herrera & Kopainsky, 2020) with the purpose of characterizing the issue of system resilience in terms of food security. The main steps of the proposed procedure are summarized in the following Figure 3, with details on the content and purpose of the participatory activities performed. A cycle of participatory and desk activities has been designed, in order to overcome one limit of the sectoral literature and of the SD practice, which is the need for a generic structure for designing replicable and comparable processes.

Step	Step 1	Step 2	Step 3	Step 4	Step 5
	Problem structuring process (resilience of what? and resilience for whom?)	Scenario analysis (resilience to what?)	A systems perspective (what are the alternatives for building resilience?)	Coping with change (how to build resilience?)	Performance management (how to monitor progress towards resilience?)
Purpose	To define what resilience means in operational terms. Answer the question "resilience of what?"	To identify what disturbances might disrupt or diminish the desired outcomes of the system (aka food security)	To produce a simulation model to analyse the dynamics of the system and identify thresholds, their nature, and potential leverage points for building resilience	To discuss potential policies or interventions in the system that might enhance the resilience of its outcomes	To identify and discuss the implications and challenges of implementing the proposed policies
Concrete activities	GMB workshop 1: Elicit variables (resources and drivers) Elicit causal links among resources, drivers and outcomes of the system Discuss how the variables affect the resilience of the desired outcomes	GMB workshop 1: Identify disturbances that might affect the system Discuss scenarios about the likelihood, magnitude and potential impacts of the identified disturbances in the system	Build and validate simulation model Validate model and document its caveats, limitations and purpose One-on-one interviews for validating the model and discussing about preliminary results with stakeholders	GMB workshops 2 and 3: Identify policy alternatives Discuss simulation results of alternatives proposed Discuss broader implications of policies proposed and trade-offs in other parts of the system One-on-one interviews for discussing policies included in the model and preliminary results	Develop a performance management system with government representatives Translate the model into an "instrumental" view of the system Discuss activities and process needed to implement the proposed policies Identify key performance indicators
Tangible outcomes	Causal loop diagram describing how resilience "works"	Graphs-over-time Scenarios	Simulation System Dynamics Model	Multicriteria policy assessment	Framework for a performance management system

Figure 3: Overview of the steps followed during the model-based analysis process of resilience (Herrera & Kopainsky, 2020).

A recent work by (Pluchinotta et al., 2022) related to the analysis of a urban regeneration process, used a novel type of thematic analysis of Causal Loop Diagrams (aforementioned as CLDs) constructed with each stakeholder group, based on their perceptions of the system, and oriented to better understand the potential effects on decision-making by systematically comparing different system maps around the same issue. The work also investigates how stakeholders can be supported through system modelling to create shared understanding of the system and adopt a systems perspective and solutions that fulfil a multitude of sustainability criteria. A framework for implementing a qualitative PSDM approach in the case study has been also proposed by the Authors. The key objectives, in this direction, were mainly to: (i) to bring together institutional stakeholders to jointly scope the focus of the work; (ii) to build different CLDs around the identified shared concern to capture the system boundaries for each group of stakeholders; (iii) to jointly understand differences in the stakeholders' perceptions and effects on decision-making; (iv) to reach consensus on the focus of the following activities. A summary of the framework is proposed in the following Figure 4.

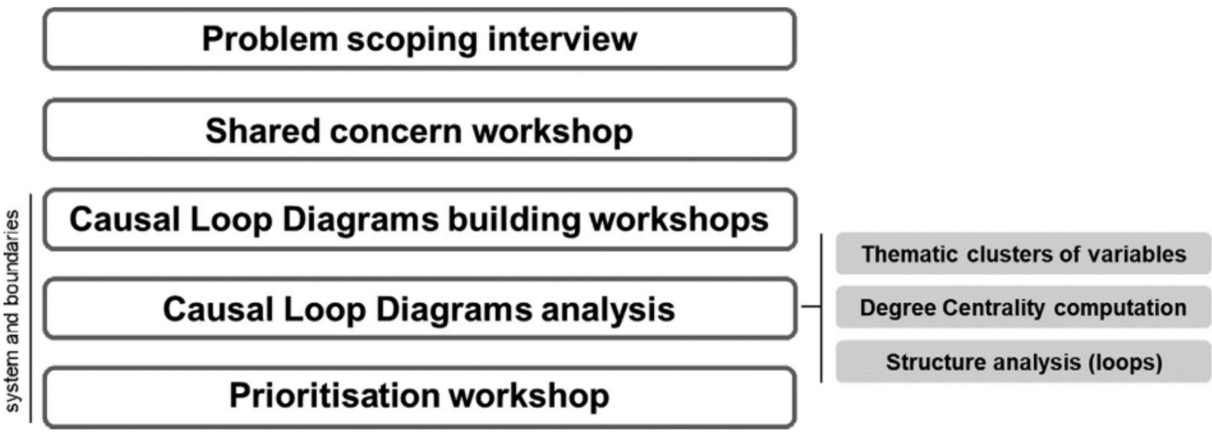

Figure 4: Overview of the PSDM process proposed by (Pluchinotta et al., 2022)

The authors highlighted also that PSDM allowed participants to see to which extent other stakeholders prioritized different issues and highlighted social and environmental factors, supporting also a successful discussion on how to overcome the differences and to collectively agree on the focus of the subsequent phases.

A participatory modeling procedure for SDM has been also proposed by (Gallagher et al., 2020) and is shown in Figure 5. An iterative process between stakeholder engagement activities (based on five participatory workshops, bilateral meetings and expert interviews) and desk research was performed to identify and quantify the mechanisms underlying trade-offs between national level energy security and economic growth and local level food security, the priority risks (scenarios), and potential actions (interventions).

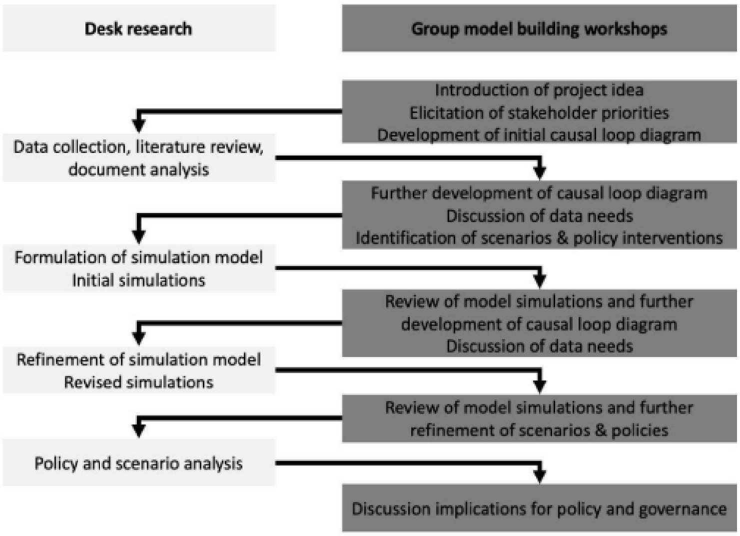

Figure 5. Overview of the PSDM process, including both desk and participatory activities, proposed by (Gallagher et al., 2020)

The proposed analysis approach comprises also three specific procedures:

1. Qualitative data analysis. A substantial amount of qualitative data was collected during the project and analyzed to support the choice of indicators to represent stakeholder priorities and identified risks of concern, scenario formulation, resilience analysis design, and in the discussion of results.
2. Scenario analysis. Framework conditions were changed, and different simulations compared. Particularly the authors identified two baseline scenarios (with and without a dam), and additional scenarios for adaptation (an alternative cropping scheme) and mitigation (environmental flow standards), identified by stakeholder groups.
3. Resilience analysis. Given uncertainties in stakeholder discussions and model calibration, the model-based scenario analysis was integrated with a resilience analysis. The impact of external disturbances (related to climate change impacts and population change) were measured through specific properties (hardness and elasticity).

A script for the whole process of stakeholders involvement in the discussion of a Nexus problem, including the development of CLDs has been developed by (Kimmich et al., 2019) and available online (https://agupubs.onlinelibrary.wiley.com/action/downloadSupplement?doi=10.1029%2F2019EF001311&file=eft2_607-sup-0001-2019EF001311-SI.pdf). The script includes, for each phase of the activity, timing, materials needed, a detailed description of the steps and the guiding questions to be used by the facilitators.

It is worth to mention here that the IRSA research Team involved in the REXUS WP4 already developed a framework for PSDM, fully detailed in (Pagano et al., 2019) and summarized in the following Figure 6. The mentioned framework has been proposed within the NAIAD project (H2020, Grant Agreement No 730497) and was basically oriented to define a structured participatory approach for Nature-Based Solutions co-design, co-evaluation and implementation.

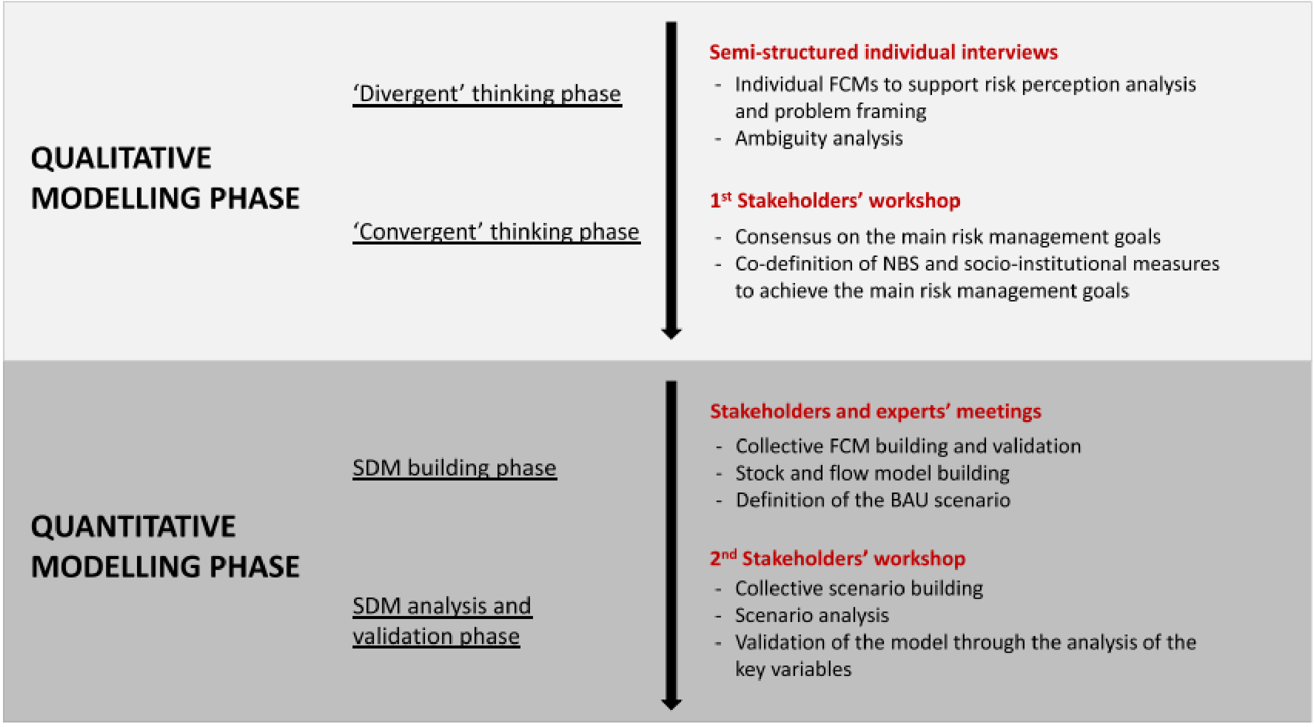

Figure 6. Overview of the PSDM process, including both desk and participatory activities, proposed by (Pagano et al., 2019)

The framework comprises two main phases, identified as 'qualitative' and 'quantitative' modelling phases. The 'qualitative modelling phase', described in detail in (Santoro et al., 2019), is based on the use of Fuzzy Cognitive Maps (FCM) to elicit and structure stakeholders' risk perception, knowledge, and problem framing. An Ambiguity Analysis is then carried out on individual FCMs in order to highlight similarities and differences among stakeholders' risk perceptions. The 'qualitative modelling phase' was closed with one stakeholder workshop, which was organized with a twofold objective: i) to identify the most important risk management goals, and the most suitable and effective measure(s) to achieve these goals; ii) to support building an aggregated version of the FCM. The 'quantitative modelling phase' mainly refers to the transition from a FCM to a stock and flow model, which requires a huge effort from the analysts. Targeted meetings and interviews are then used for the validation of specific parts of the model. Stakeholders are then involved in a second workshop, which is used for scenario analysis and validation.

This work clearly demonstrated the capability of PSDM to deal with multiple variables (both qualitative and quantitative) and multiple dimensions (e.g. technical, social, and environmental). It also allowed building a process that starts from the analysis of stakeholders' problem understanding and from the identification of individual priorities but aims gradually at reaching consensus on the key objectives and strategies. In general, hat the whole process helped breaking down some socio-institutional barriers related to the limited knowledge and helped bringing together different stakeholders in the discussion. Defining a shared problem frame and group model facilitates interdisciplinary and cross-sectoral communication and collaboration.

3 Description of the proposed framework

The present section provides a general description of the framework for PSDM that has been developed (and is being implemented) in the REXUS pilot areas, following the relevant literature summarized in the previous section. It directly responds to the need to have a structured and replicable procedure for project activities in pilot areas (and beyond) and aims to provide both theoretical and practical guidance to use PSDM approaches for Nexus studies. The proposed framework has been aligned with the general plan for the participatory activities developed in the REXUS project. Nevertheless, it is worth to remark that the framework is a general guidance which needs to be interpreted as flexible enough to be adapted to the needs and specificities of pilot areas and can be therefore modified and tailored. For this reason, the framework detailed in the present section should be interpreted as a preliminary version, which should be critically analyzed and revised throughout the project duration based on the feedbacks and evidence from the activities in pilot areas.

The proposed framework for PSDM implementation comprises multiple steps, and a series of participatory and desk activities. It basically describes a highly iterative process, as it involves constant iterations with other WPs (e.g. WP3) and needs to be adapted to the state of pilot activities. An overview of the proposed framework is provided in the following Figure 7, while further details on the different steps are provided afterwards. The framework is based on a series of 'desk' and 'participatory' activities (in blue and green boxes, respectively), and multiple interactions with the activities performed in other WPs (highlighted in the other boxes).

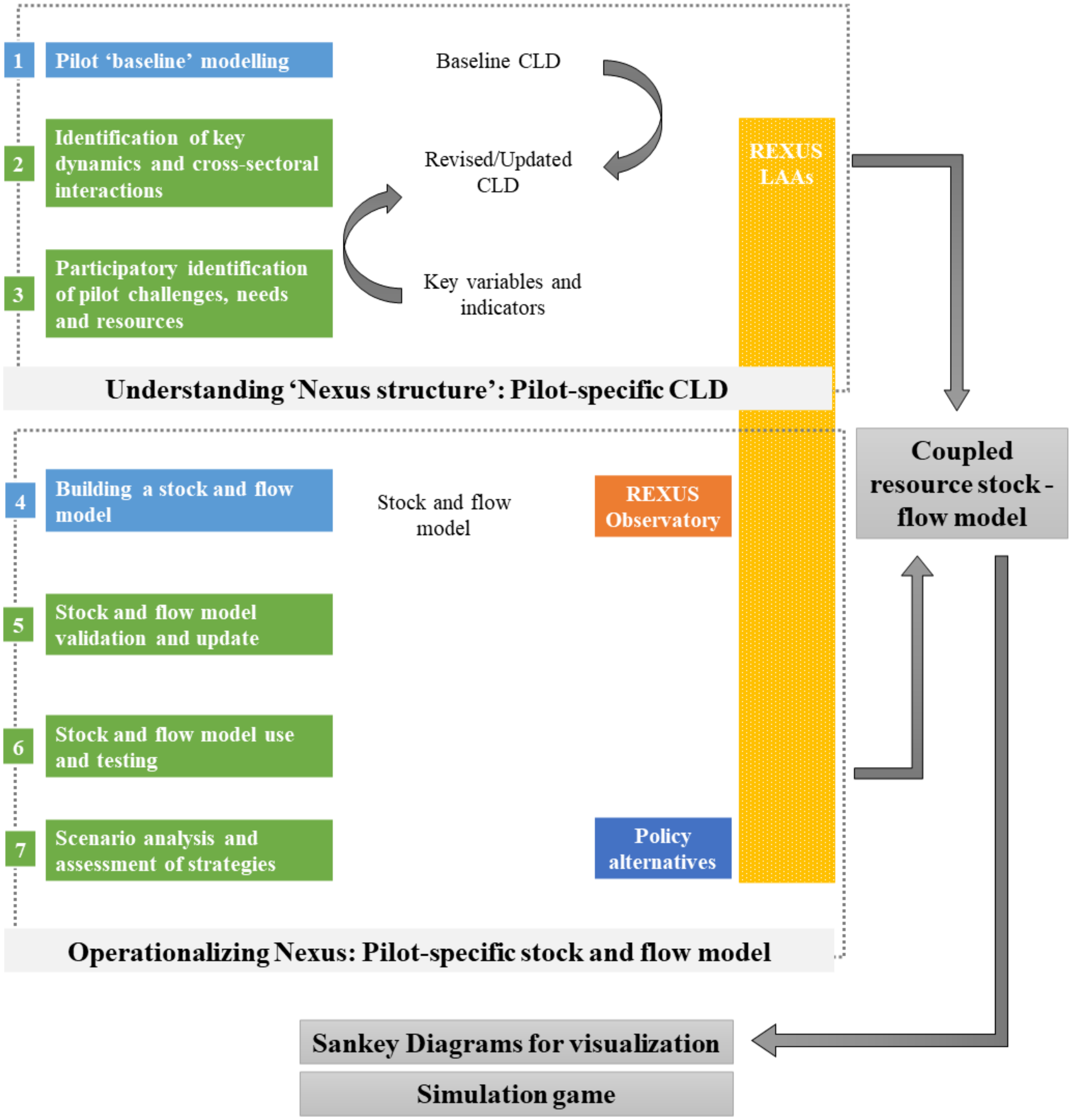

Figure 7. Overview of the steps of the REXUS PSDM implementation framework and of the key interactions with other activities

The framework basically comprises two major modelling phases. The first one (including steps 1-3) is more '*qualitative*' and oriented to provide an improved understanding of the 'Nexus structure'. This typically requires that a Causal Loop Diagram is built in each pilot area. The second one (steps 4-7) is more '*quantitative*' and oriented to produce a more operational approach to Nexus, based on the development of pilot-specific stock and flow models. Currently, the framework describes more into details the Steps 1-3 as those have been completed in several pilots and the methodological approach has been revised and consolidated. The activities related to Steps 4-7 have been in general designed and are currently being implemented in some pilot areas.

It is worth to highlight at this stage that the framework should be interpreted as flexible enough to be customized to specific pilot needs (in terms also of structure and evolution of the activities) and that it is meant to be implemented with a variable level of detail in each pilot area. Therefore, not all pilots will be involved in all steps of modelling, and not all pilots will be involved necessarily in the 'quantitative' modelling.

Step 1. Pilot 'Baseline' Modelling.

The first step of the framework aims at providing a basic understanding of each pilot area and is mainly based on the information included in the Baseline description. Bilateral meetings have been also performed at this stage with pilot leaders, in order to get further insights into the main Nexus challenges and strategic objectives for the area according to their knowledge. The specific target of PSDM for each pilot area has been also preliminarily shaped at this stage.

The main purpose of this step is to set the context of the analysis and to get a preliminary insight into the main challenges of the pilot, based on the retrospective analysis of the area, of the key policies (both implemented and planned) and of the evidence from previous projects and activities. During this step, the analysts identify the focus of pilot activities and define the modelling objective, building a preliminary SDM based on the use CLDs. As will be detailed in the following, the process of building and using a CLD is typically iterative and CLDs can be developed in a participatory workshop mode or based on data (typically qualitative) and evidence.

CLDs allow describing a system based on three elements: nodes, connections, and feedback loops. The nodes represent variables in the system and can be anything as long it makes sense to think of them going up or down over some scale. The connections (or edges) represent causal influence from one node to the other. Connections have a polarity which can be either positive (i.e. the variable they connect increase or decrease together) or negative (i.e. the variable they connect change in opposite directions). The third element is what makes CLDs unique compared to other modelling techniques (e.g. Fuzzy Cognitive Maps). The maps always show and focus on feedback loops, both in the construction phase and in its visualisation. Loops are made conspicuous by the use of curved arrows to create circles. The loops can be also color-coded to highlight them and annotated with small arrows and a specific '+' or '-' symbols (e.g. an 'R' or a 'B' respectively) to highlight if they are reinforcing (positive) or balancing (negative). In a reinforcing loop, change in one direction is compounded by more change. Balancing loops, in contrast, counter change in one direction with change in the opposite direction. A very basic method to determine if a loop is reinforcing or balancing is to count the number of '+'. If there are an even number of '+' (or none are present), the loop is reinforcing. If there are an odd number of '+' it is a balancing loop. Another way to double-check the expected type of loop is to draw the behavior of the system over time. A reinforcing loop shows exponential growth (or decay); a balancing loop tends to produce oscillation or movement toward equilibrium[1]. (Barbrook-Johnson & Penn, 2022; Sterman, 2000)

The feedback loops are usually focused around a 'core system engine', which is a set of nodes that are the core of the system, and strongly hint at dynamics in the system. CLDs are therefore typically useful to think at a slightly higher level, bringing together feedbacks and thinking about how these might play out together. The focus on feedbacks means the CLDs are a structured way of looking at a system, which can be performed at a different level of detail and complexity (Barbrook-Johnson & Penn, 2022).

[1] https://thesystemsthinker.com/causal-loop-construction-the-basics/

CLDs can be used in many ways. Most fundamentally, they are a way of visualising and exploring mental models. Exploration of the full map can be done in many ways, but typically with a qualitative analysis of the core engine and of the main feedbacks. It represents a hypothesis of the feedback structure of the system and also serves as a tool for the creation of a shared understanding of the system amongst members of a discussion group. CLDs are often an intuitive precursor to 'quantitative' System Dynamics models, used before the conversion to stock and flow diagrams and differential equations (Barbrook-Johnson & Penn, 2022).

As far as the Step 1 is concerned, the 'baseline' version of the CLD is mainly built on scientific knowledge (which is typically used for drawing well-known connections between e.g. biophysical variables) and on the evidence included in the D6.1 for each pilot area. At this stage it is crucial that the variables are clearly expressed as things that can go up or down and should be precise. 'Container concepts' such as 'Technology' which can mean many different things should be avoided and connections added (if needed) to make the diagram clearer or easier. This step is useful to make a hypothesis on the structure and content of the core system engine which can be either a variable at the centre, or a set of key variables which interact in ways that drive system behavior. The engine will be the focus of the map as a whole and will be one of the main focuses for exploring feedbacks. At this stage, it is useful to develop ideas about the variables might be connected (Barbrook-Johnson & Penn, 2022). In general, the structure of the CLD has been built trying to keep the different domains of analysis 'separated' (e.g. in sub-models), but also clearly highlighting interconnections and interdependencies.

Some relevant guidance, which can help dealing with CLD development, analysis and update, can be found at https://thesystemsthinker.com/.

In the REXUS project, this step was jointly performed by IRSA Team and UCAM-Engineering Team, and oriented to create CLDs in order to gain an understanding of pilot area problems with the objective of informing appropriate model development. The baseline document gave basic indication of relationships in the pilot area, but additional information was provided through interviews and conversations. CLDs supported identification of elements critical to stock flow models as well as policy instruments which may impact these stocks and flows. This is highly relevant to design scenarios for resource appraisal and policy analysis within any model developed. Overall, the CLDs and Sankey diagram provide an excellent insight into model development, as well as proving themselves to be useful standalone tools.

Step 2. Identification of key dynamics and cross-sectoral interactions.

Both Steps 2 and 3 of the proposed framework are based on participatory activities that can help revising/improving and complete the 'Baseline' CLD developed in the Step 1 and identifying the key variables for the analysis. Step 2 and 3 are tightly interconnected and the participatory activities required are performed at the same time (i.e. through the same interview and the same workshop). The Steps however are 'conceptually' separated as they have a rather different purpose and aim to provide a different contribution to the analysis, as detailed in the following.

Specifically, the second step aims at co-identifying the most important dynamics of the CLD for the pilot areas, according to the problem understanding of local stakeholders. The purpose is to elicit and structure stakeholders' understanding about current challenges (mainly sectoral, but also cross-sectoral, if possible), building the 'narrative of the present', ultimately creating a picture of the system that reflects stakeholders' perception and knowledge. The main result is the identification (and discussion) of cause-effect connections between key variables, with a few significant upgrades with respect to the Step 1: i) some additional arrows can be drawn, to reflect 'hidden' interconnections or perceived interdependencies according to the stakeholders; ii) some arrows might be removed, in case a cause-effect chain has been wrongly identified in Step 1; iii) new variables can be added, in case relevant elements have not been included into the picture; iv) variables can be removed, in case they are not perceived as relevant for describing system dynamics; v) relevant balancing or reinforcing loops are selected in the CLD; vi) different weights can be assigned to the cause-effect connections.

This step of the analysis is strongly participatory and based on two different activities:

A. Individual interviews with key stakeholders, for the identification of basic cause-effect chain affecting the main security dimensions (water, energy, food, ecosystems security). Full details are provided in the D4.1 along with the structure used for the interview.
B. Participatory exercises during the 1st Workshop, oriented to co-define Nexus interactions and sectoral interdependencies and causal connections. This phase can be completed with the support of geographical maps, and therefore used to provide also spatial information on the main issues and challenges.

The activity (A) has been performed referring to the sector (or domain) the interviewee was mostly related to. Basically, the rationale of the interview was to identify critical connections between the sectoral security level, and the level of satisfaction of the main needs expressed by the stakeholders, identifying all the most influential processes (both natural and anthropic), barriers and drivers. The adopted approach is theoretically centered around the role of Ecosystem Services (ESs). The analysis was mainly focused on the current system state ('Business-as-usual') and expected system evolution under current major drivers (e.g. climate change, economic conditions, etc.). A very simple graphical representation of the kind of insight that the interview aimed to provide, is available in the Figure 8.

Although the framework provides a general structure of the activities, there is full flexibility on how the activities A and B can be performed, depending on the context and on pilot-specific conditions and needs. For example, the information needed can be obtained directly with participatory exercises during the workshop (Phase B), without performing individual interviews (this was the case in two REXUS pilots).

Just to make an example, referring to the 'water' domain, one of the elements mentioned in connection to the 'water security' is the 'availability of surface water', and one of the related needs is the 'irrigation water demand'. In this regard, the key ecosystem resource bridging the need and the security objective can be a relevant surface water body (e.g. a river or a reservoir), with its capacity to produce a multiplicity of ESs (e.g. regulating – Hydrological cycle and water flow regulation; provisioning – water provisioning for agriculture). The capacity to produce such ESs depends on both natural (e.g. physical flows/recharge) and anthropic processes (e.g. management scheme or access to the same resource from different users). Furthermore, the capacity to produce ESs for achieving the needs related to the sectoral security can be also affected by other elements, that have been broadly classified as either 'barriers' (e.g. institutional fragmentation, sectoral regulation, etc.) or 'drivers' (e.g. climate change impacts).

Similarly, within the 'food' sector, a key element for guaranteeing 'food security' is the 'agricultural productivity' and one key related need is the 'profitability of agricultural practice'. Besides water, one of the main ecological resources for agriculture is 'agricultural land', which provides multiple ESs (e.g. provisioning - Cultivated terrestrial plants for nutritional purposes). The capacity to produce such ESs is conditioned by multiple natural and human processes (e.g. the agricultural practices used that may affect soil quality), as well as by barriers (e.g. lack of knowledge on innovative agricultural practices or poor spatial planning) and external drivers (e.g. market conditions).

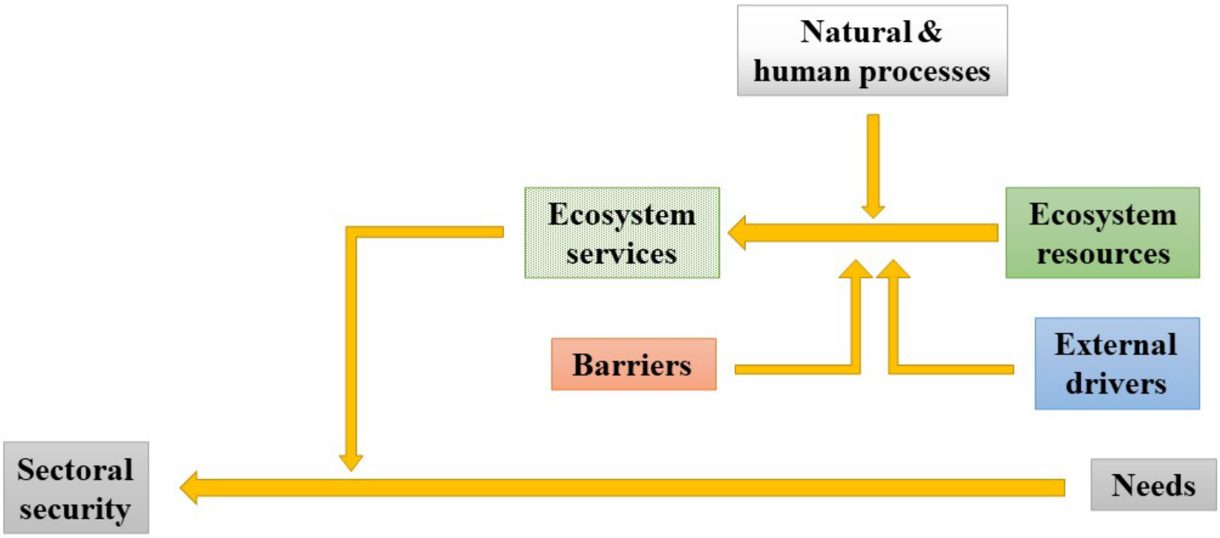

Figure 8. Graphical summary of the rationale of the semi-structured interviews performed with the stakeholders in REXUS pilot areas.

This step of the framework is useful for identifying the main dynamics to represent and analyze through the PSDM. The use of a semi-structured interview allows on one hand to have a structured and coherent approach to expert knowledge elicitation, but on the other to guarantee enough flexibility and simplicity also to 'non-technical' stakeholders.

Step 3. Participatory identification of pilot challenges, needs and resources

The third step of the proposed approach is oriented to identify the main challenges for the pilot areas, and to co-select the most important variables and 'measurable quantities' to be described by the model. This step is still focused mainly on 'sectoral' perspectives, but there is space also for starting the discussion on cross-sectoral issues. It is directly connected to the Step 2, as the selected variables/indicators should mainly contribute to describe elements included in the above Figure 8, including the level of achievement of the selected needs under different conditions (including selected scenarios) and the state of the key ecological resources.

This step of the analysis is strongly participatory and based on two different activities that, as already mentioned, are the same on which the Step 2 is based:

A. Individual interviews with stakeholders, for the identification of key 'measurable quantities', that are then translated in the form of scientific indicators by the analysts. The format of interviews does not make any reference to scientific indicators, thus allowing also stakeholders without a technical or scientific background, to contribute. Analysts are then required to perform a desk activity to 'translate' the measurable quantities identified by the stakeholders into the form of scientific indicators. Full details are provided in the D4.1 along with the structure used for the interview.
B. Participatory exercises during the 1st Workshop, oriented mainly to refine, select and prioritize the selected indicators. This phase is highly relevant to identify the main variables the model should be focused on.

The main outcome of this phase is the identification with the stakeholders of a set of indicators, that can be relevant to describe both the current state of the pilot area and its potential evolution under different scenarios. Such indicators should be (ideally) computed through specific models under different scenarios, and feed the discussion with the stakeholders also during the 2nd and 3rd workshops.

Just to make an example, based on those proposed for the Step 2, the 'availability of surface water' can be described based on the 'water level (or volume) in reservoirs' and the 'Number, capacity and density of water reservoirs'; the related need 'irrigation water demand', e.g. through the variable 'Water use efficiency in agriculture: water volume pumped/used per unit area (or farmer)'. Similarly, the 'agricultural productivity' can be described through variables such as 'Agricultural yield per hectare' or 'Water use efficiency in agriculture: agricultural production per water volume pumped/used'; the related need 'profitability of agricultural practice' e.g. through the variable 'Economic efficiency per crop and cultivated area'.

Again, as already mentioned, there is full flexibility on how the activities A and B can be performed, depending on the context and on pilot-specific conditions and needs.

It also worth mentioning that all REXUS participatory activities will be performed in coherence with the Guidelines for stakeholder engagement (see D2.1) and with the REXUS Gender Action Plan (see D6.1).

Step 4. Building a stock and flow model.

The fourth step aims at translating the qualitative model (CLD) built in steps 1 to 3, into a quantitative model (stock and flow). This step is mainly based on desk activities and require a significant effort from the analysts, as the transition towards a quantitative model is not always straightforward.

A System Dynamics model is mainly made up of stocks and flows, plus the factors which affect flows. Stocks represent any entity which accumulates or depletes over time, and take numerical values. A flow is the rate of change in a stock, and is usually represented by a differential equation. These equations may be relatively simple and based on standard operations (e.g. addition, subtraction, multiplication, division, and sometimes exponents), or be more complex involving functions and parameters which moderate how variables interact. A simulation can be run by choosing a starting point (i.e. a set of stock values) and computing how stock values change through repeated time steps (Barbrook-Johnson & Penn, 2022).

One of the key advantages of using this kind of SD models is that various things can be represented in stocks and flows, which don't even have to be fully or precisely quantifiable, rather just provide a reasonable and meaningful trend over time. This is particularly true when 'soft' (unquantified) factors, such as social ones, are introduced into the models, which also require extra effort and care to be incorporated (Barbrook-Johnson & Penn, 2022).

In general, the stock and flow model should try to model the whole system, but focusing on specific sub-parts of a system or particular issues or problems, which may persist despite the presence of dynamics and interventions. It is also worth to highlight that the transition from CLDs to stock and flow models is not always needed, as the analyst can go straight into a stock and flow diagram. This clearly depends on the process that is being implemented and on the purpose of the modelling efforts (Barbrook-Johnson & Penn, 2022).

The transition from a CLD to a stock and flow model is not always straightforward, but is often useful to add order to an often 'chaotic' process by emphasizing the difference between information and material flows, and the importance of unit consistency throughout a diagram.

The conversion process includes the following steps (detailed at this website):

- Specify the Units of All CLD Variables

  Specifying the units of all CLD variables helps thinking about the causal loop in a more rigorous way, and this is an important step toward stock and flow thinking. Furthermore, it helps determine which variables are going to involve time and will therefore likely (but not necessarily) be flows, and it provides the basis for determining what variables are missing and will need to be added later in the conversion process.

- Identify and Create the Stocks

  The next step is to determine which CLD variables are stocks, which is facilitated by the definition of units helps facilitate this process by indicating which variables involve time and, therefore, are probably flows. Any additional stocks that might be needed can be also added at this stage.

- Identify and Create the Flows

  Once the stocks have been identified, the flows can be easily identified as they are simply the variables that add to or subtract from the stocks.

- Connect Flows to Stocks and Stocks to Flows (if Necessary)

  The first task in this step is to connect all flows to the stocks that they influence. If the flow has a negative effect on the stock (i.e. it is associated to a reduction of the stock), then it is an outflow; if it has a positive effect (i.e. it is associated to an increase of the stock), it is an inflow. Once all flows have been connected to their corresponding stocks, certain stocks might need to be connected to flows, in case they influence one or more flows through an information link.

- Add and Link Remaining CLD Variables

  In this step, any CLD variables that have not been previously identify as stocks or flows should be added. These "auxiliary" variables are of two types: 'constants' in case their value does not change at all over the time period considered, and variables that simply represent calculations based on stocks and flows. These variables should be then connected to the variables that they influence and to those that they are influenced by.

  Although the first version of the stock and flow diagram is done at this stage, the conversion process is iterative and further rounds of defining and creating variables are usually needed before the diagram can be considered complete.

- Define Stocks and Flows and Check Units

  Formally defining variables entails specifying the equation that allows calculating the value of a specific variable given its initial value and the values of the other variables in the diagram. A good practice is to start with the stocks, which are usually the easiest to define as they are calculated by adding the effects of the inflows and the outflows to the amount already in the stock. The next step is to define the flows and then check the units they use. Defining units for the flows may also lead you to discover other variables that need to be included in the diagram.

- Create and link any additional variable

  Once stocks and flows have been determined and associated to the proper units, other variables need to be examined. The process for defining the remaining variables and checking for unit consistency is the same as the one described above for defining the flows. Although the conversion can be considered complete at this stage, the model still is not calculable.

Step 5. Stock and flow model validation and update.

The process described at the previous Step 4 is mainly based on 'desk' activities, and on the translation made by the analyst of the CLD into the stock and flow model form. However, the proposed approach requires that a validation of the stock and flow model is performed with stakeholders/expert. However, this task could be challenging, as it might not be always easy for non-technical stakeholders to deal with the form (and the equations) included in a SDM. In this regard, the proposed framework suggests a 'simplified' model validation, to be performed focusing on a subset of key stocks and flows, which may have some uncertainty or ambiguity.

This step of the analysis should be based on two different activities:

- Individual interviews (optional) with selected stakeholders or with pilot leaders, for the analysis, validation and (potential) revision of sub-models or specific parts of the stock and flow model. This step will be performed, if needed, between the 1st and the 2nd WS, in case any element of the model needs further clarification.
- Participatory exercises during the 2nd Workshop, oriented mainly to discuss collectively specific parts of the model or sub-models. Specific attention should be given to: 1) the connections and influences between stocks and flows; 2) the cross-sectoral influences and interdependencies.

The expected output of this step is a revised version of the stock and flow model, particularly as far as the variables and connections are concerned.

Step 6. Stock and flow model use and testing.

This step of the analysis is, instead, more focused on the 'computational engine' of the stock and flow model. It should be strongly participatory and based on specific exercises to be performed during the 2nd Workshop, followed by desk activities.

An overview of the (potential) activities – and related objectives - foreseen for this Step follows:

- Identification of the Business-As-Usual (BAU) condition. The analysis of the outputs of the stock and flow model, for the key variables/indicators, should help ensuring that the model is able to describe the state of the system in the future assuming that no changes occur to input variables.
- Following the analysis of the BAU condition, stakeholders should be involved in the co-definition of potential scenarios. Multiple techniques could be used for the purpose, but the co-development and analysis of the Behaviour Over Time (BOT) graphs for key variables under different conditions has a proven effectiveness in actively engaging stakeholders (Calancie et al., 2018; Schoenberg et al., 2020). The creation of BOT graphs could provide insights and inform future modelling and data collection priorities, though an effective integration of multiple perspectives and a better

understanding of what the (intended or unintended) consequences of any action could be. Basically, during the 2nd WS the facilitator should ask stakeholders (individually or in groups) to draw the graph for each variable over time under different conditions, such as: 1) desired future, i.e. defining the evolution of the variables as the stakeholders would like; 2) most likely future, i.e. defining the evolution that the variables is expected to have according to stakeholders; 3) feared future, i.e. the 'worst-case' evolution of the variables. Such graphs should highlight - if possible - specific points and thresholds. In case the graphs drawn by the different groups on the same variables do not show great differences, they can be almost directly used to represent the variable's BOT. In the case of large differences, the different interpretations should be discussed with all stakeholders to reach a shared view.

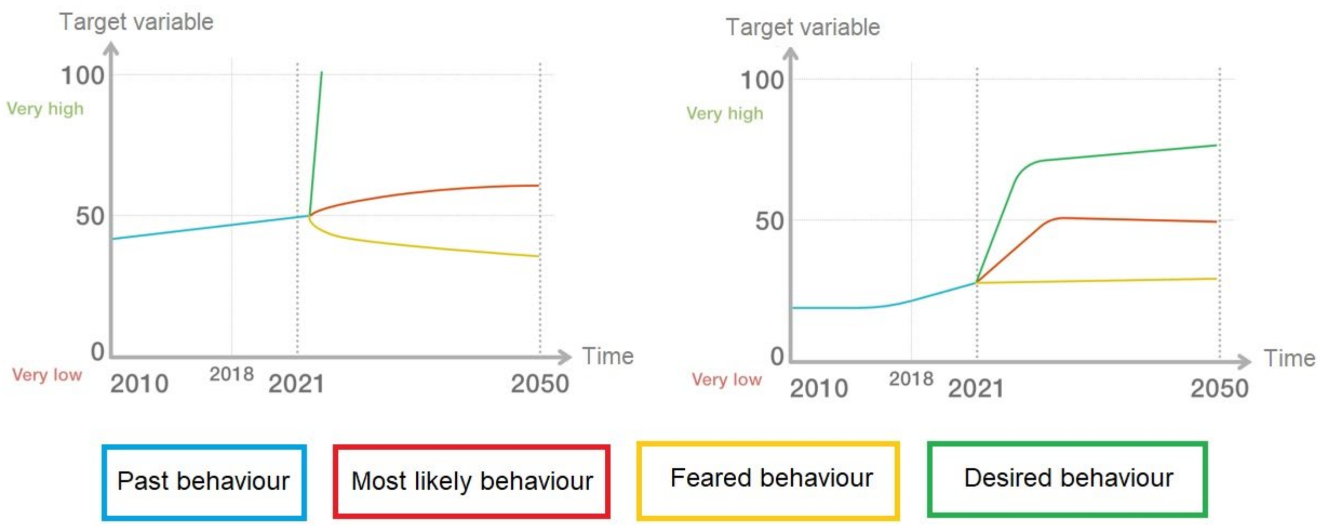

Figure 9. Graphical example of how the BOT can be drawn for key variables.

- One of the key aspect to consider in the participatory modelling exercises is the integration of the SDG targets into the modelling approach, which can be useful to make explicit the SDG implications linked to different scenarios (see also Step 7).

Some desk activities, based on the evidence of this step, will be needed to revise the model before it can be considered complete.

Step 7. Scenario analysis and assessment of strategies

The last step of the framework, to be performed during the last Workshop, is mainly based on the use of the stock and flow model to describe and analyse multiple different scenarios. Climate change scenarios can be taken into account, along with sectoral and cross-sectoral policies. The impacts of specific behaviors will be also taken into account.

A scenario represents a change in the model, which should be mainly performed changing the state of input variables, but also potentially modifying the structure of the model (i.e. with a connection added or removed). The purpose is to represent some intervention or difference in the system, mainly related to different policy options. Model outputs should be therefore considered as hypothetical futures, or qualitative forecasts of the types of patterns and dynamics we might see.

4 Discussion on key modelling issues

4.1 Spatial information and PSDM

Managing spatial information with (P)SDM is not a straightforward task, as System Dynamics tools are not inherently able to manage spatial data. Typically SDM allows a limited spatial representation since it works mainly with lumped regions, although recent research has explored the coupling between SDM to GIS to account for spatially explicit system dynamics (Terzi et al., 2021). The interplay between SDM and spatially explicit models or tools (e.g. GIS) in different case studies has been discussed in a work by (Elsawah et al., 2017). Basically, the spatial dimension can be incorporated into SD models through lumped modelling, coupling the SD model with GIS, and using modelling environments that support the development of spatially explicit SD models. Selecting the appropriate approach involves trade-offs between model purpose, software flexibility, and familiarity of the modeler with particular software.

For the purposes of the REXUS project, the technical management of spatial data will be customized according to pilot needs and information/data availability, with the general intention of implementing a 'lumped' approach rather than a spatially 'distributed' one. This is in line with the main value added of using PSDM in pilots, as it is mainly oriented to facilitate stakeholders' dialogue and to provide a decision support tool mainly useful at a strategic/planning level, rather than detailed information distributed over the study area.

However, an element of innovation will be introduced in the REXUS approach. Working in close cooperation with the WP2, the analysis of spatial information has become a central element for dealing with the 'participatory' component of SDM and directly introduced starting from the onset of LAAs. A map of the pilot area is introduced in the 1st pilot workshop, along with a set of cards defining the main drivers/resources/pressures for the area. The stakeholders are asked to identify cause-effect connections among such variables, while locating the corresponding card on the map. This allows immediately providing a spatial characterization of the main issues, also highlighting some potentially hidden interconnections (e.g. some phenomena that occur in a specific area but manifest impacts in a completely different one). Further details and a some examples are provided in the Section 5.

4.2 Integration with coupled resource-flow model

The activities described in the framework are tightly interconnected with those that are being performed by the UCAM-Engineering Team for the development of a coupled resource stock-flow model. As detailed in the D4.4, the model is based around the structure of a dynamic Sankey diagram, visualised as a series of sector-bound Sankey diagrams, showing changes to stocks and flows at a strategic level. The value added of the model lies in its ability to show how interactions between resource sectors influence overall and sectoral security. The integration with PSDM and the information collected through the participatory exercises performed within the LAAs can provide valuable insight into the specificities and criticalities of pilot areas, ultimately helping the development of the coupled resource stock-flow model and an effective visual representation of physical flows.

The expected interactions between the PSDM and the coupled resource stock-flow analysis are manifold, and can be summarized as follows:

- PSDM, through both the qualitative and quantitative components, should provide an improved understanding of the perception of a Nexus system from policy- and decision-makers, ultimately allowing the modelling of the impact of their 'behaviour' on the whole system. This objective can be achieved supporting extensions to the model, such as e.g. the integration of decision-making constraints as well as agent liaisons.

- Both interviews and participatory exercises that feed the PSDM are oriented to enhance understanding of the stakeholders' perspectives in pilot areas, supporting a clear identification of sectoral and cross-sectoral objectives for domain security. This task, which is also related to the identification of pilot-specific indicators (DOs, NIs and NRQs as detailed in the D4.1), should help identifying critical variables to model and to include in the visualization tool.
- The PSDM activities are strictly connected with the introduction of the concept of Ecosystem Services (ESs, as detailed in the D4.1). Introducing ESs into pilot areas and highlighting the role of 'nature-based solutions' is central also for the extension of the coupled resource stock-flow model.
- Several exercises during the workshops will be oriented to perform scenario analyses, both to describe the Business-As-Usual (BAU) conditions and 'what if?' scenarios. This should help better understanding and anticipating the system impacts of changes to Water, Energy, Food and Climate (WEFC) sectors, including e.g. sectoral and cross-sectoral policy actions. Information on the most relevant SDGs and on their level of achievement in different conditions can be also provided and used to feed the Game being developed.
- The participatory exercises performed in support of the PSDM building and validation, will also help understanding and prioritize the needs of decision-makers, ultimately helping to 'shape' the model in a for that adhere to their requirements.

The developed modelling approach supports the transition from science to policy by integrating quantitative data (mainly related to resources at a strategic level) and qualitative data (stakeholders' perceptions, priorities and behavior) within an environment where connections are clear and interactions can be analyzed. The model building is supported by participatory exercises and pilot activities, so that the model can answer questions relevant to strategic stakeholder concerns and at a suitable operational scale.

4.3 Integration with sectoral models

Another key aspect to consider is the integration of PSDM with sectoral models. This issue has not been discussed into full details yet, as the modelling has been mainly developed on the qualitative side, but will be central for the Steps 4-7. In this direction the role of PSDM is twofold:

- Use of sectoral data and models within the stock and flow diagram, for modelling e.g. bio-physical dynamics and quantitative issues;
- Provision of data and information that can be used by other tools or models (e.g. information that can be visualized through the Sankey Diagrams or the Metamodel).

The role of the REXUS Observatory as data/information provider will be central for this purpose, along with the dialogue with all WPs providing information from sectoral models, and with pilot team leaders.

5 Implementation of the framework in the REXUS pilots

5.1 Overview

The aim of REXUS is to contribute with PSDM (although to a different extent) to all pilot areas. The present section provides a summary of the current state of pilot activities in the REXUS pilot areas, along with an overview of the 'target' level of PSDM implementation by the end of the project. This reflects the estimated relevance of the approach for the challenges identified so far in the pilot areas, and might change by the end of the project. A summary is provided in the following Table 1.

Table 1. Current state of the PSDM-related activities in the REXUS pilot areas and expected level of implementation by the end of the project. The number in the Table identify the specific phases proposed in the Figure 7 and detailed in the Section 3.

Pilot area	Current phase of PSDM framework implementation	Target level of PSDM implementation
Spain - National	1	Qualitative
Spain – Jucar	2-3	Qualitative
Isonzo – Soča	3	Quantitative
Lower Danube	4	Quantitative
Pinios	2-3	Qualitative
Nima- Cauca	3	Quantitative

Ideally, the PSDM approach will be developed in a 'quantitative' form in at least 3 pilot areas (Lower Danube, Nima Cauca and Isonzo-Soča) but will not necessarily be limited to those. It should be also considered that the activities in the Pinios pilot area are slightly different from the others and characterized by the highest level of interaction/integration among modelling tools, as the Metamodel will be also implemented in the area by the DELTARES Team. The Metamodel will allow the evaluation of indicators (defined by experts and stakeholders) and used also with the purpose of aggregating results from other thematic models and tools, ultimately helping to assess several strategies/solutions in combination with climate scenarios.

Some of the potential criticalities that may affect the implementation of the PSDM framework in pilot areas are:

- Evolution of the pandemic, as the participatory activities are extremely more effective in case the interaction with stakeholders is based on physical meetings.
- Limited participation of stakeholders, as may occur in every participatory process. Additionally, approaching a SD model with stakeholders is often not straightforward.
- Language 'barrier'. The interaction with stakeholders should preferably be performed in the local language, as this allows a broader participation also from non-technical ones. This implies that the participatory exercises need to be performed by the pilot leaders, after a 'training' phase and – where possible – with the external support of WP4 Team. This barrier might be responsible for delays in modelling activities and for a potential loss of information.
- Integration with other models and data. The integration of the scientific information available in the different pilots is a critical task, as different sources of information might be available (with variable spatial and temporal resolution) and a specific processing (and typically, aggregation) need to be performed.

The present section provides, in the following, details on the current state of implementation of the proposed framework in some of the REXUS pilots, with a discussion on key methodological issues that might be relevant for the replication and wider uptake of the approach.

5.2 Nima-Cauca pilot area

The preliminary version of the model for the Nima-Cauca pilot area has been already described in full details into the D4.1 ('Report on PSM and SNA. Identification of DOs, NRQs and NIs'). A short summary is provided in the following, mainly highlighting some key methodological aspects related to the use of the PSDM framework.

A first version of the CLD has been prepared based on the information provided in the baseline description and on the interaction with the Pilot leader (CIAT) (Step 1) and is proposed in the Figure 10. Basically, this model allowed building a very simple and clear understanding of the main challenges of the area, in terms of resources security, and highlighting the main cross-sectoral issues and interdependencies. The model was built trying to keep the sectoral sub-models 'isolated', while also highlighting cross-sectoral interconnections. Some elements that potentially needed further clarification were also highlighted (with a ?).

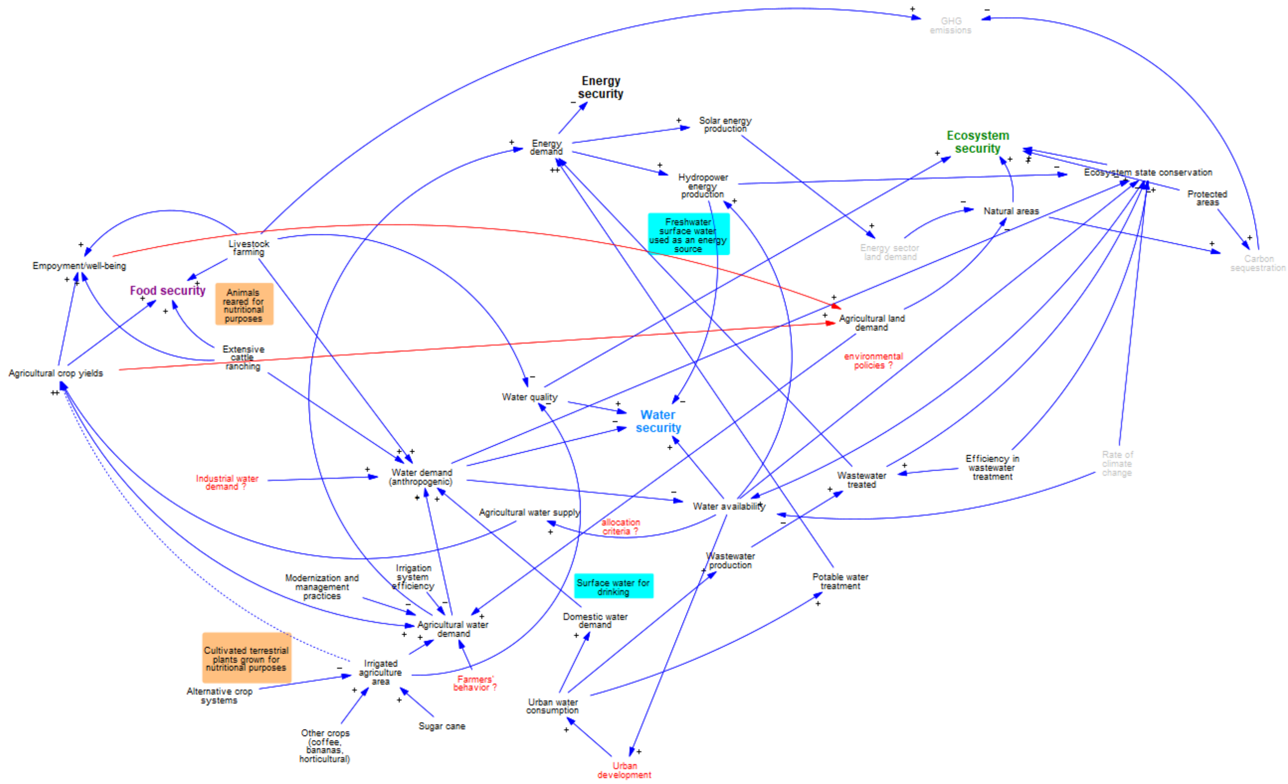

Figure 10. 'Baseline' CLD developed for the Nima-Cauca pilot.

The resulting model is rather simple, but basically highly useful to preliminarily identify the main issues to consider for analyzing the state of the pilot, such as the state of fragile ecosystems, the role of irrigated agriculture (and the importance of specific crops such as the sugar cane), the issue of wastewater treatment efficiency, etc.

A first round of interviews has been then completed in the period Feb 2022 – May 2022 with key stakeholders. These interviews (Step 2 and 3 of the framework) significantly helped revising the model, integrating the local knowledge with the information derived from the baseline description. As a result, a new version of the model was produced and is proposed in the following Figure 11. In this phase, some variables were named differently (e.g. making explicit reference to the corresponding ES, now highlighted in green), new variables were included (those in orange) and new connections were drawn.

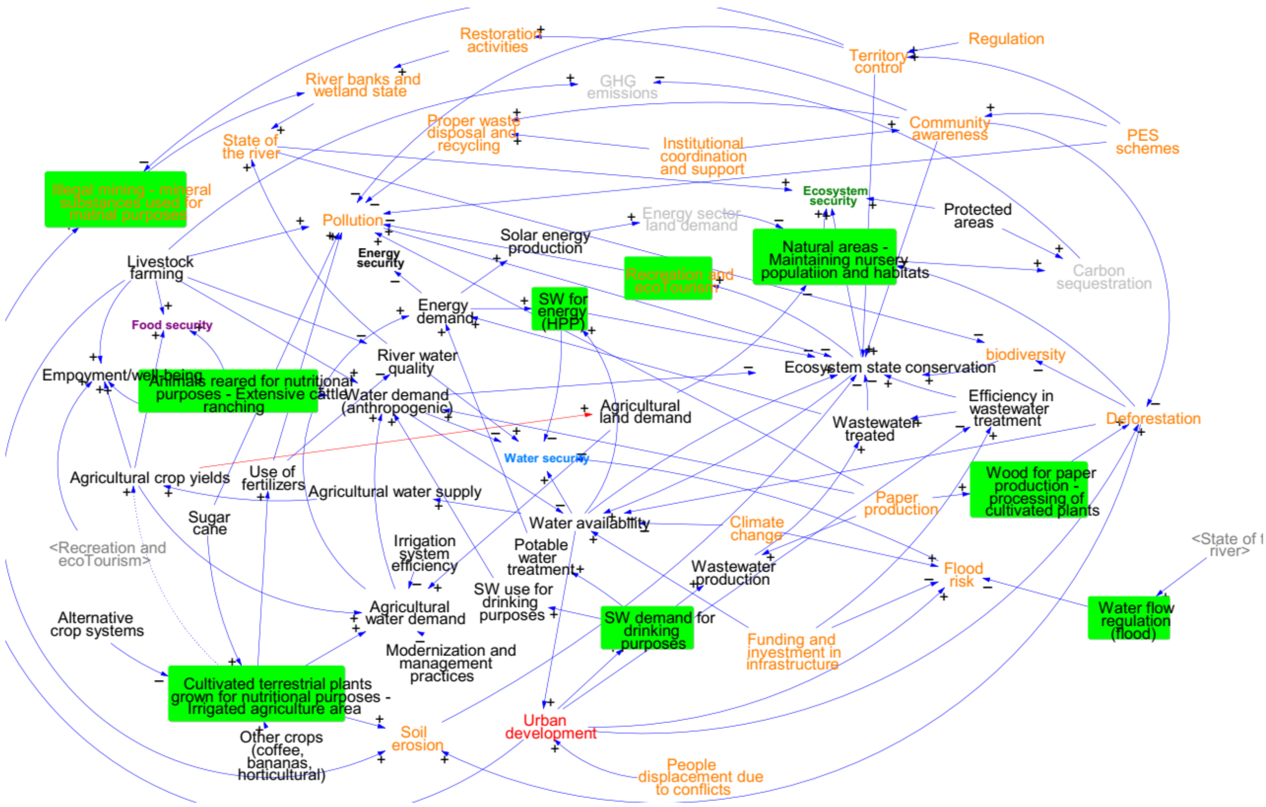

Figure 11: Revised CLD developed for the Nima-Cauca pilot, including evidence from the interviews

The interviews, for example, highlighted that agricultural activities are highly relevant for the well-being of local communities, although some practices are not considered as sustainable over the long term. This is the case of sugarcane production, which is essential for the development of the area since colonial times, but associated with a high water demand and to significant impacts, such as the increase of pollution over the area (with increasing concerns for the health of local population). Furthermore, a severe impact of agricultural activities is the increase of the soil erosion rate, which is an additional factor affecting the state and quality of the ecosystem, was highlighted. The stakeholders also mentioned the importance of the dynamics associated with the deforestation (identifying a direct dependency on paper production activities), which have multiple impacts over the system ranging from the state of natural areas to the biodiversity and the water availability and regulation. The increasing deforestation has also an impact on the intensity of soil erosion phenomena.

Starting from the issue of the limited availability of drinking water and the very low quality of service, the stakeholders also referred to the need for additional investments on the infrastructural systems by the government, also in view of the potential effects of climate change. Specifically, several interviews highlighted the potential role of increasing flood risk as a new concern induced by the climate change.

One of the main contributions provided the interviews was also related to a better understanding of the key socio-institutional dynamics affecting system state and evolution. Two elements were discussed: i) the influence of the low community awareness on the main environmental issues that the area is currently facing (poor efficiency of waste disposal, deforestation, state of ecosystems); ii) the poor territorial planning and control, related also to the limits and fragmentation of the current regulation, which have a negative influence e.g. on the soil and water pollution as well as on the spread of dangerous activities, such as the illegal mining which are causing increasing challenges to the state of the river banks and wetlands. Local stakeholders perceive a conflict between local communities (which take care of the forest and are also promoting processes of restoration of riverine areas) and big companies (which pursue economic profit but are involved in programs for restoring the environment and promoting ecotourism). In this direction, the lack of presence and control by public authorities is perceived as a significant barrier, although an opportunity already exists, represented by the presence of PES schemes (Payment for Ecosystem Services) which are currently implemented in the livestock sector.

The 1st workshop in the Nima-Cauca pilot area was then organized on the 3rd of August 2022 in Palmira, with the participation of 18 stakeholders (no representatives from the productive sector joined the workshop). A preliminary activity was oriented to provide background information to participants, and to present and discuss the main evidence from the activities already performed within the REXUS project. In order to facilitate the discussion and to focus on a suitable spatial scale, two groups were identified for the discussion. Following the interviews, a distinction was made between the 'upstream' and the 'downstream' area of the watershed, identifying (with the pilot leader team) a key challenge for both:

- Upstream area: it is the most 'natural' area, with a relevant conflict related to water and land use (forest plantation in vulnerable ecosystems) and the lack of primary sanitation conditions, which severely affects the state of the ecosystem.
- Downstream area: it is the most 'productive' area, mainly dealing with the issue of water pollution from agro-industrial crops and agricultural waste dumping.

A participatory mapping exercise was then performed for properly locating different classes of variables in the sub-basin (resources, socio-economic activities, technologies and pressures, each one characterized by a different color). A discussion on the reasons for the specific location of cards was also performed, followed by an analysis of the main cause-effect connections among variables (e.g. what pressures is exerted by economic activities and technologies on resources, what pressures economic activities receive and what are additional pressures that may impact resources). These interconnections between variables were also reported on a blank paper on the wall, where four quadrants (dedicated to the specific classes of variables) were drawn. An example of the outcome of process is represented from Figure 12 to Figure 15.

Water is central for the area, and used for multiple purposes, including consumption, ecosystem functions, and agricultural practices. The forest has also a crucial role, both for water security (regulation of extreme floods and contribution to the hydrological cycle). Some specificities of the two 'parts' of the river basin also emerged during the exercise. In the upper area of the Nima river sub-basin, the communities obtain water from the micro-basins that supply the Nima river through community aqueducts. Although the communities are efficiently organized to manage the aqueducts, the lack of adequate infrastructure causes system inefficiency when extreme weather events such as heavy rainfall occur. In the upper area there is also no sewage system, so all domestic waste is directly discharged into the river with a huge impact on water quality. In addition, the urbanization in this area are increasing, with a subsequent increase in water demand, increasing deforestation and contamination of the river. Another major threat is related to the use of water from forest plantations for paper production, as it limits the flows to the micro-basins. Very rarely, in dry periods, the availability of water is limited, with a significant impact on the hydroelectric power production plant. In this case, priority is always given to drinking water supply. Soil erosion and heavy rainfall in the upper part of the sub-basin are generating abundant sediments in the river, which may affects the operation of the hydroelectric plant, increasing the requirements for maintenance, cleaning and interventions in the river.

In the downstream area of the Nima River sub-basin, some districts (e.g. Amaime) lack an aqueduct with adequate infrastructure, which causes issues with water rationing. Although sewage systems are available in this area (yet not always fully efficient), the contamination of the river is still present mainly due to livestock farms (mainly pig and chicken farms) and to lower awareness of people, which throw garbage directly in the river. Local flora and fauna, for example fish species, are therefore heavily impacted. In addition, in recent years migrant communities have been settling next to the river, which on the one hand increases its contamination level, and on the other hand increase population risk level due to possible floods and health issues.

The river lacks riparian forests in some areas, which increases the risk of flooding. In addition, there are 'uncontrolled' mining activities from the river (such as stone, granite and gravel), which modify the river course, increasing the risk of flooding.

In the downstream area, the sugarcane companies use water for irrigation, with a potential conflict with the communities in the dry season. However, some of these companies are working to improve irrigation systems and the efficiency of industrial water use (including water reuse). However, additional concerns are related to the burning activities of cane, that generates health problems in the local population, and the use of agrochemicals that affects the state of the water and the soil. It is important to highlight that the cane production, paper production and energy companies in the area perform activities with a social and environmental impact in close cooperation with the local communities. For example, the paper production company promotes sustainable tourism in the Nima River corridor also through birdwatching, ecological trails, flower crops and restoration activities that benefit part of the community. In addition, this company has a native forest protection area. The energy company and the cane production companies support environmental groups in river cleanup processes, recycling and training activities in waste management. They also support the fund 'Agua por la vida', an initiative for basin restoration and biodiversity conservation.

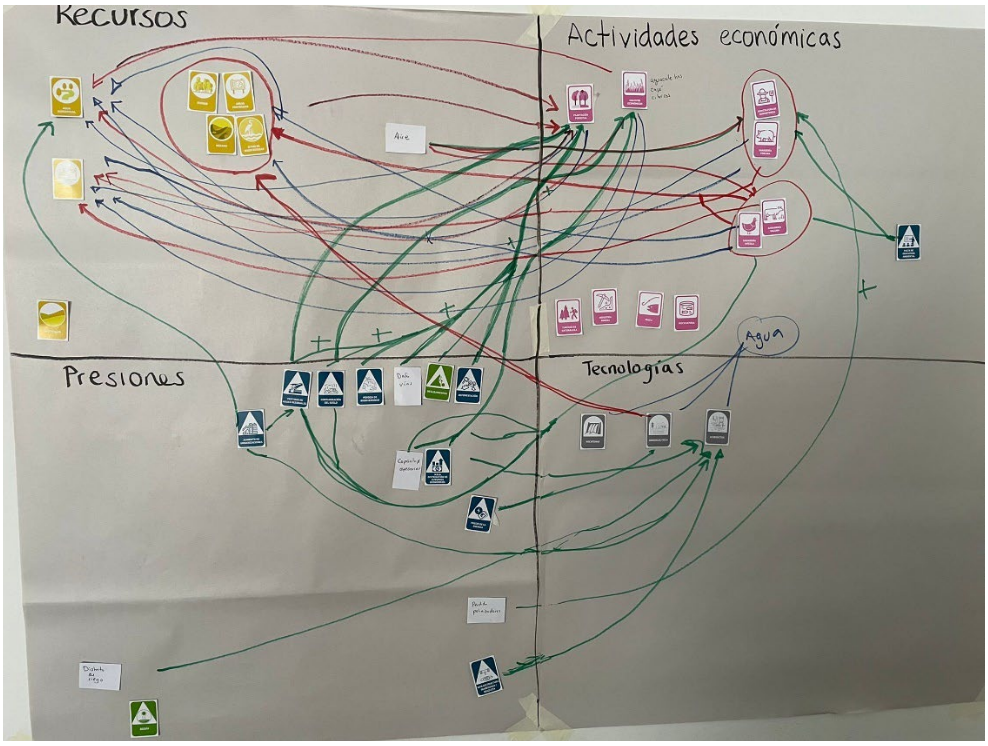

Figure 12 Participatory mapping of the interconnections among variables in the Nima Cauca – 'Upstream' group

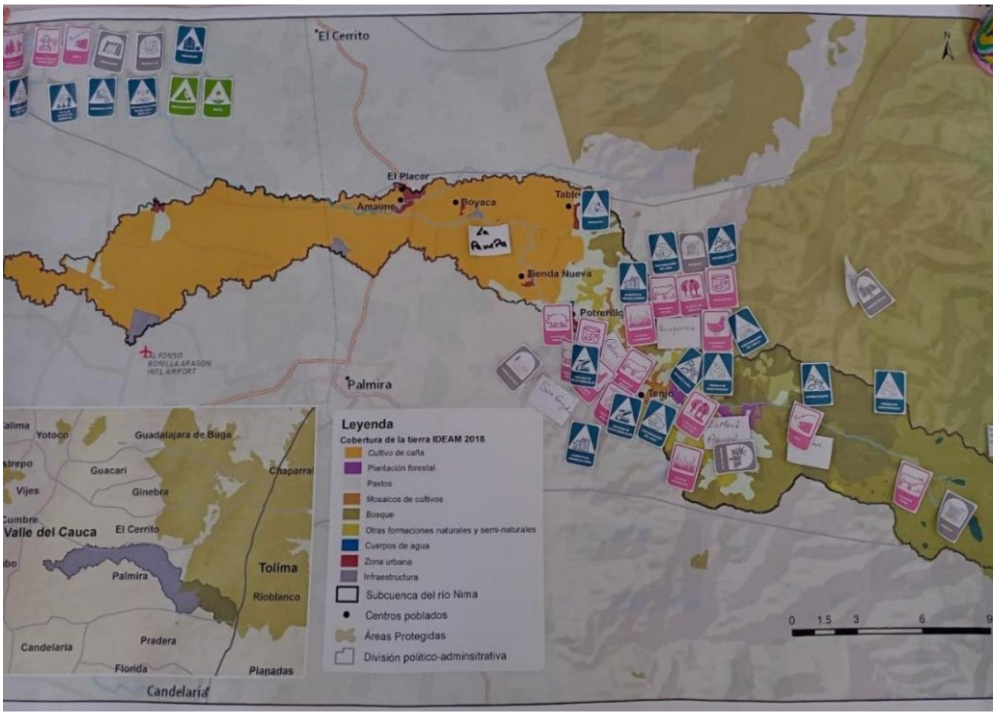

Figure 13 Participatory mapping exercise in the Nima Cauca – 'Upstream' group

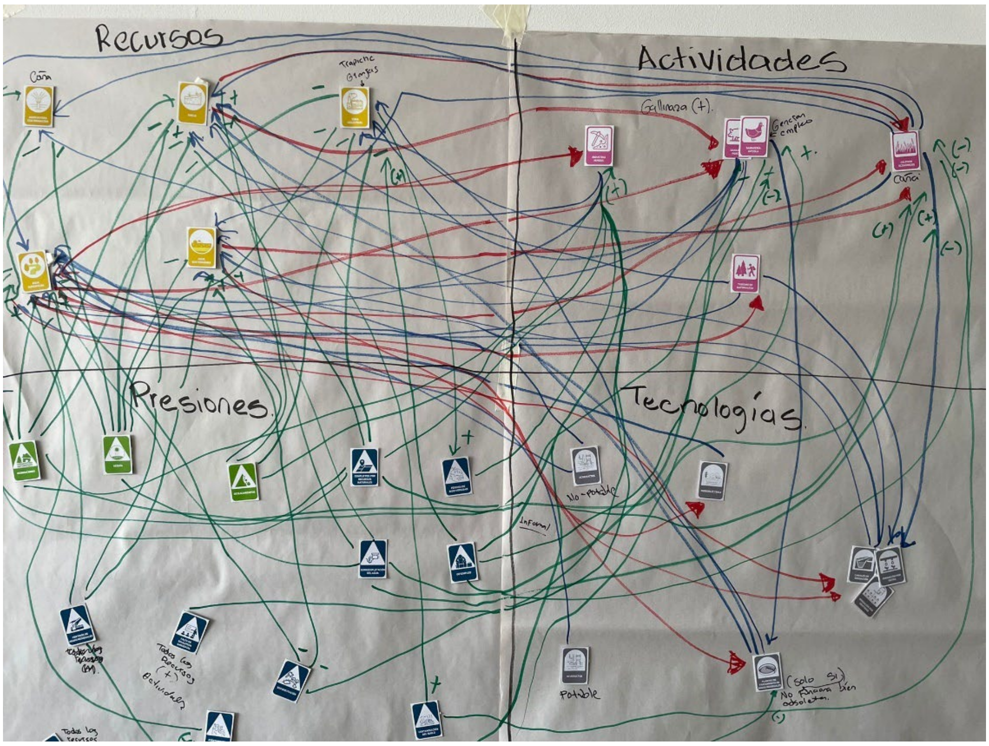

Figure 14 Participatory mapping of the interconnections among variables in the Nima Cauca – 'Downstream' group

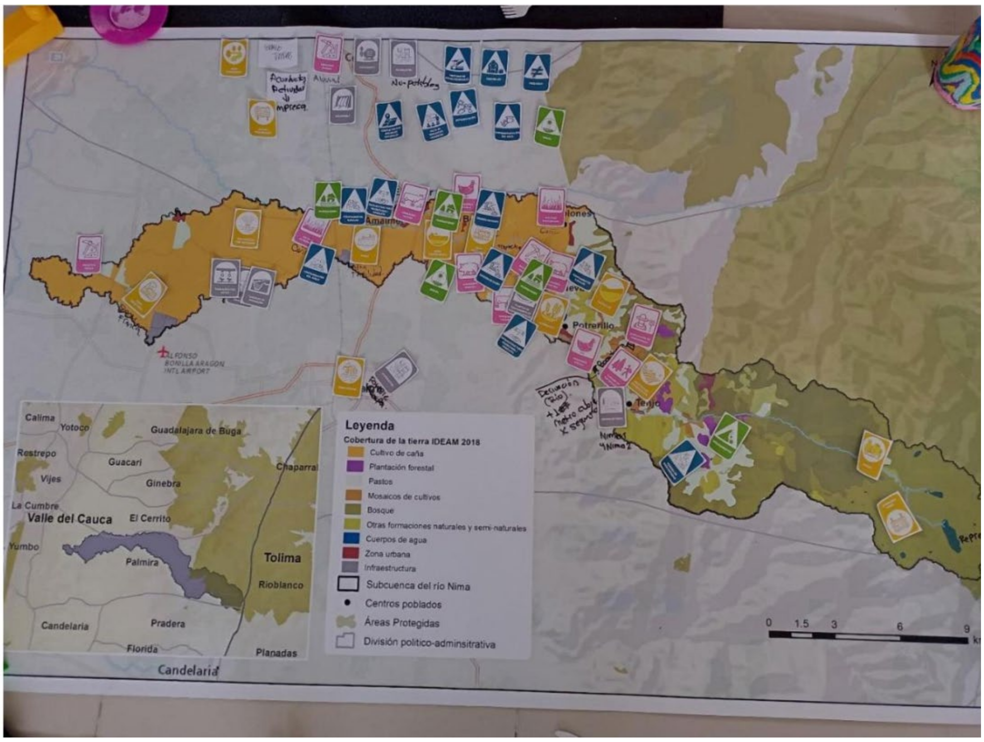

Figure 15 Participatory mapping exercise in the Nima Cauca – 'Downstream' group

At the end of the exercise, a member of each group presented and discussed the main results obtained, ultimately helping to better understand the main problems upstream and downstream of the sub-basin. Basically, the downstream area was characterized by the following elements:

- **Resources**: Irrigated agriculture (mainly sugarcane, approximately 42% of the basin), soil, groundwater and surface water. It was remarked also that it is an industrial zone.
- **Socio-economic activities:** "Illegal" mining (uncontrolled gravel and sand mining), livestock (swine and poultry), eco- tourism, sugarcane production (which generates a lot of employment but also by-products).
- **Technologies:** aqueducts (potable and non-potable), hydroelectric plants, irrigation canals, drip irrigation systems, gravity irrigation and wastewater treatment (currently not working well).
- **Pressures:** related to climate (floods, drought and landslides). Other pressures: Natural resource conflicts (generate pressures on industry and soils), biodiversity loss, unemployment, water overexploitation, soil contamination, deforestation, lack of environmental education, illegal settlements, erosion and sewage discharges.

The following main connections among key elements were drawn (Table 2).

Table 2. Overview of the connections among: a) socio-economic activities, resources and pressures; b) technologies, resources and pressures. Reference is made to the 'downstream' part of the Nima-Cauca.

a)

Economic activities	Affected resources	Pressures
Irrigated agriculture (sugarcane)	Surface water Groundwater	Conflicts on water use Overexploitation of water resources Pollution (burning)
	Riparian forests	Deforestation
Livestock farming	Soil	Wastewater discharge Soil contamination
'Uncontrolled' mining	Soil Riparian forests Surface water	Change of water course Increased risk of flooding Landslides

b)

Technologies	Affected resources	Pressures
Wastewater treatment plants	Surface water	Outdated infrastructures
Drinking water supply systems	Surface water	
Other water supply systems	Surface water	Inefficient infrastructure
Irrigation systems	Surface water Groundwater	Reduction of water availability in case of drought
HPP	Surface water	Reduction of river flow

Similarly, the upstream area was characterized by the following elements:

- **Resources:** Surface water, soil, Forest - Protected areas - Paramo - Biodiversity sites, soil, grasslands, air (not mentioned before).
- **Main socio-economic activities:** Forest plantations, economic crops (avocado, coffee and citrus - small scale), subsistence agriculture with some pig farming, livestock and poultry farming (often linked to the lack of environmental education), fish farming, mining and ecotourism.
- **Technologies:** water intakes, hydroelectric power plants, aqueducts.

- **Pressures:** climate-related (e.g. landslides are prioritized mainly due to forest plantations and drought). Other pressures: loss of biodiversity, deforestation, soil and water pollution, increased urbanization and dumping from farms.

The following connections among key elements were drawn (Table 3).

Table 3. Overview of the connections among: a) socio-economic activities, resources and pressures; b) technologies, resources and pressures. Reference is made to the 'upstream' part of the Nima-Cauca.

a)

Economic activities	Affected resources	Pressures
Forest plantation	Surface water Roads Soil Biodiversity	Overexploitation of the water resource. Roads damaged because of transport from plantation Issues with pollination, wild animals move elsewhere Erosion Deforestation Water contamination
Livestock farming at crops (family level)	Surface water Air	Wastewater discharge Lack of efficiency of irrigation service Lack of pollination Odors Lack of training in good practices
Economic crops (coffee, avocado, citrus)	Soil Surface water	Use of chemicals and fertilizers Lack of financial subsidies Lack of training in good practices
Poultry farms	Surface water Air	Wastewater discharge Odors
Cattle farming	Soil Forest	Soil erosion Deforestation

b)

Technologies	Affected resources	Pressures
HPP	Surface water Biodiversity	Sediments in case of heavy rains Reduced river flow Fish species High energy costs
Other water supply systems	Surface water	Inefficient infrastructure Lack of irrigation districts

Some remarks were also performed during the discussion. First, although water resources are abundant in the area, the lack of effective policies and the limits of existing infrastructure (both for drinking and for irrigation purposes) currently hamper the access to water for consumption and multiple purposes. A lack of government investment and commitment in the protection of quality and access to water, as well as in territorial planning, has been also highlighted.

A lack of institutional control is also limiting on the hand the willingness of companies to reduce the levels of contamination of the water sources, and on the other hand conditioning the efficiency of planning particularly in the upper zone of the sub-basin. Both companies and communities need to be made aware of the need to preserve natural resources, especially water. In the case of livestock companies, commitment is needed to comply with environmental regulations and treat waste. Forest plantations must also commit to responsible water use, giving priority to drinking purposes. Communities need education in waste management and awareness of the importance of preserving natural resources. Additional training activities related e.g. to agricultural practices are also needed to teach people to cultivate while protecting natural resources (water, soil, air, beneficial fauna).

Although there are protection areas for the forests in the upper areas of the sub-basin, more commitment is needed in their protection since there is the threat of cattle ranching expansion, as well as deforestation for urban settlements. In this sense, the establishment of protected areas, forest restoration activities should be promoted, as well as exploring the implementation of alternative/innovative crops and agricultural practices that can have a reduced impact on deforestation, soil erosion and water resources. Also, continue promoting PES schemes to the livestock sector, but extend it to owners of farms with forest conservation areas.

More in general, a more balanced development models for productive activities in the area should be identified. Sugar cane production, paper production, agriculture and livestock must be made more sustainable in the long term, as they are crucial for the socio-economic well-being of local communities, but have a high impact in a fragile environment.

Based on the evidence of the workshop, the CLD has been further revised including the elements highlighted in purple in the following Figure 16. It is worth to remind, as already highlighted in the previous sections, that the CLD does not aim to represent an exhaustive or final description of the pilot area. It rather provides a dynamic and 'living' description of system state, and can be updated as new knowledge or data becomes available during the project.

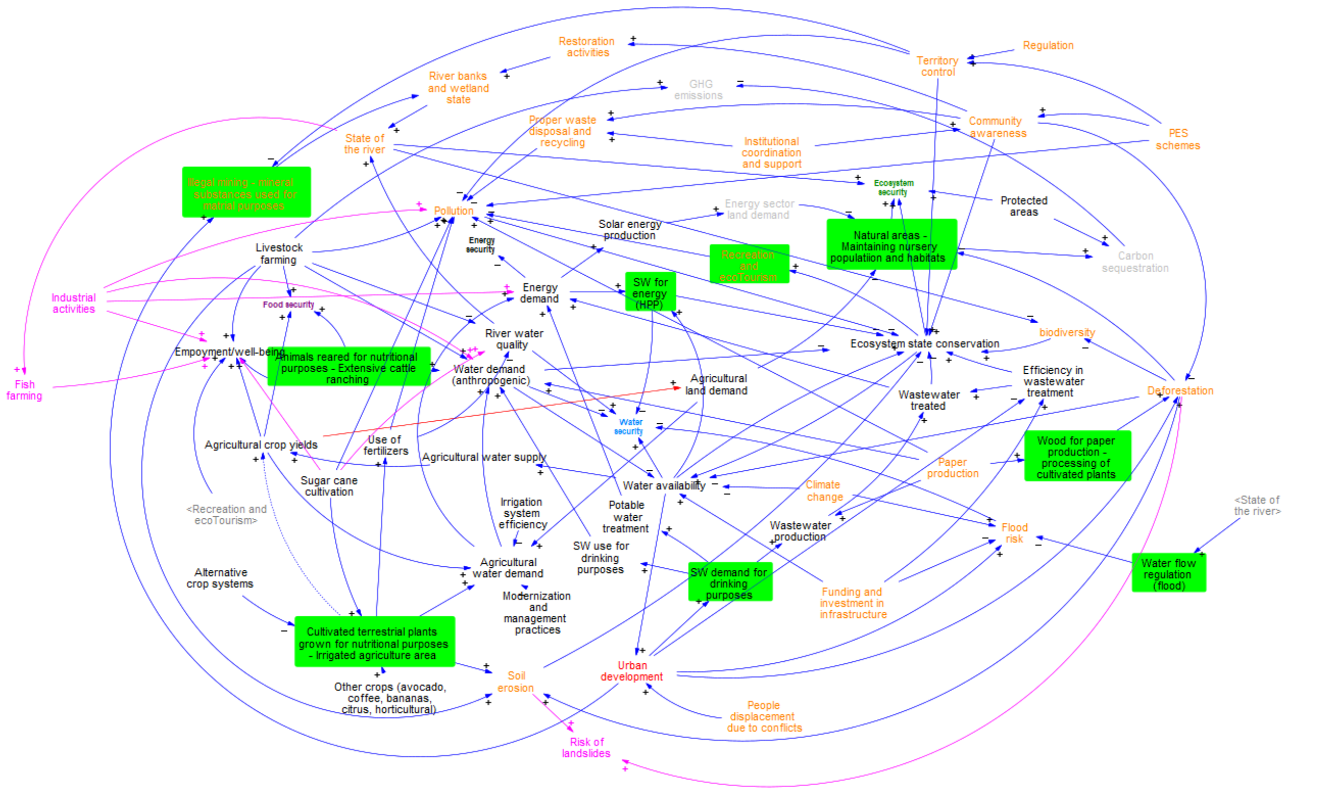

Figure 16 Revised CLD developed for the Nima-Cauca pilot, including further information from the 1st WS

5.3 Isonzo-Soča pilot area

The PSDM process in the Isonzo-Soča case study was slightly different from the previous one. Due to the limited availability of the local stakeholders, it was not possible to carry out the first round of individual semi-structured interviews for the identification of the sectoral nexus challenges according to the stakeholders' perceptions. Therefore, a participatory workshop was organized as the first step for the development of the CLD.

To facilitate the interactions with the stakeholders, different cards were prepared to represent potential elements of the system. The baseline description of the case study was used for defining the most important cards to be used during the workshop. However, to guarantee a certain level of Flexibility, participants were allowed to create new cards, if the felt that key elements of the system description were missing.

Given the complexity of the Nexus management, the participants were divided in three different groups, each discussing a specific interface, i.e. water/energy, water/food and water/environment. This is mainly because the water resources play a key role in the nexus management in this case study.

The three groups followed the same social mapping process:

1. Mapping the key pressure: after a brief introduction to the concept of inter-sectoral security, participants were asked to select the most urgent pressures affecting the security from a set of pre-defined cards. Then, they were required to locate those pressures on the map. Meanwhile, the moderator put the selected pressure-related cards in a separate blank sheet for building the causal diagram.
2. Mapping the main activities: Once the key pressures were selected, participants were required to select the main activities related to those pressures, i.e. the activities that can be either impacted by the

pressures (e.g. agriculture impacted by the drought), or be the cause of the pressure (e.g. agriculture causes water pollution). As in the first step, participants were required to locate the selected activities on the map. The connections among the pressures and the activities were reported in the CLD.

3. Mapping the key resources and infrastructures. The guiding questions were: “What are the main ecological resources and infrastructures that need to be used to sustain the selected activities? What are the resources affected by the selected pressures?”. As done in the previous steps, the cause-effects connections described by the stakeholders were reported in the causal diagram.
4. Validating the causal diagram. The final part of discussion concerned the validation of the causal diagram develop during the discussion. Participants were required to add/delete elements and connections in the diagram. At the end of this phase, three causal diagrams were obtained.

The following Figure 17 shows the results of the discussion in one of the groups.

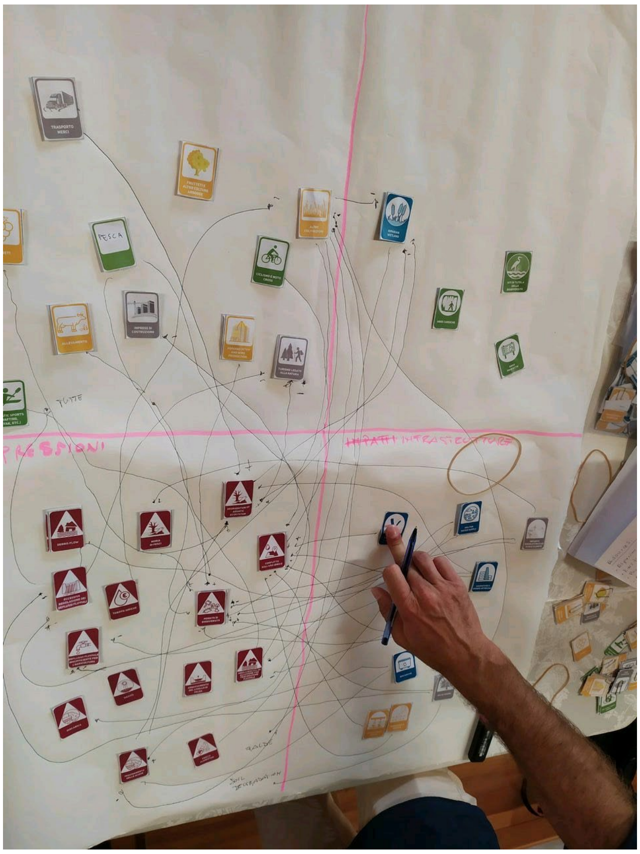

Figure 17 Participatory mapping of the interconnections among variables in the Isonzo-Soča

The following sub-sections describe the discussion in the different sectoral tables.

Water – Energy

In the water/energy group, mainly populated by energy experts, the discussion focused on the interaction between water and energy management. The Slovenian regulation of river outflows, established by the Osimo agreements was immediately identified by stakeholders as the main pressure on the water-energy sectors (and even on the environment and agriculture ones). In fact, this is either i) excessive, generating drought, or, on the contrary, ii) non-existent, leading to river flooding. All these pressures, in turn, cause further pressures on aquatic ecosystems, which is suffering from the lack of both minimum vital runoff and river flow continuity. Therefore, according to stakeholders, the main pressures related to the water-energy sectors are not caused by infrastructures or activities in the Italian territory, but in the Slovenian one (e.g., Salcano hydroelectric power station, water sports, etc.). Downstream of the Slovenian Salcano dam, it is instead mainly the pressures that affect the infrastructures (and activities). For example, drought was identified as the reason for the reduced use of hydroelectric plants in favour of thermoelectric power plants; river flooding as the reason for the raising of artificial banks and embankments, to the detriment of the use of Nature-Based Solutions for flood risk management; and the over-regulation of river runoff as a cause of decreased agricultural production. Groundwater bodies, urban areas, biodiversity protection sites and perifluvial wetlands were instead identified as the main resources affected by pressures and infrastructures. In particular, in the view of stakeholders, excessive river runoff variation and droughts lead to an overused of water from groundwater bodies especially for agricultural practices; at the same time, flooding causes damage on urban areas and the consequent raising/building of embankments destroys perifluvial wetlands.

Water - Environment

The discussion at this table was held in English due to the presence of a Slovenian participant. The group was mainly populated by experts in environmental issues and some of the water policy experts from the regional Authority. Following the participatory mapping framework, the discussion started from the most important pressures. It is worth noticing that most of the “pressure” cards were located by the stakeholders on the downstream part of the river basin. This is mainly because most of the existing pressures due to human activities are located downstream, whereas the upstream part of the basin is largely dominated by natural areas. As for the other tables, the key element in the map, and in the related causal diagram, is the discontinuous flow of water in the Isonzo river. Several impacts on the water-related ecosystems were mentioned by the stakeholders. Interestingly, participants highlighted that several impacts on the water-related ecosystems – i.e. both the Isonzo river ecosystem and the riparian wetlands - are due to the construction of grey infrastructures and measures for controlling the flood risk. For example, the cutting of the riparian trees is provoking the success of endogenous species. The developing of artificial embankments is reducing the flow of sediment in the river, with a consequent impact on the quality of the wetlands’ ecosystem. Consequently, the capacity of the Isonzo system to produce Ecosystem Services related to the protection of the biodiversity, and the production of cultural and recreative ecosystem service – e.g. eco-tourism.

Water - Agriculture

The participatory mapping activity related to the water/agriculture interaction led to numerous interesting conclusions regarding the extent of the water problem in the Soča basin, also thanks to the presence of different types of agricultural experts. The heterogeneity of the group ensured a discussion of the problems from multiple points of view, with constant dialogue between the stakeholders, resulting in a comprehensive analysis of the phenomenon. Within the working group, particular emphasis was given to pressures, located only in the section of the river on Italian territory and in the Sagrado and Monfalcone area, such as fish mortality, bank erosion, river siphoning, hydropeaking, etc. These are considered by stakeholders as direct consequences of the main pressure, i.e., water scarcity. In fact, it directly affects activities in the area including agricultural production, livestock activities, vineyards, and small-scale tourism. Some infrastructures partially compensate for the pressures by reducing the impacts, such as a lamination work that favours biodiversity in the stretch of the Dottori Canal in Monfalcone. The resources most affected by these pressures are vineyards, wheat and maize crops, and biodiversity. In conclusion, the non-constant flows from upstream areas of the river are the main cause of the pressures acting on downstream infrastructures and resources, and it is commonly believed that this is due to the hydroelectric production activity at the Salcano dam on Slovenian territory.

At the end of the participatory exercises, the CLDs developed in each of the discussion tables were digitalized and aggregated. The following Figure 18 shows the aggregated CLD for this case study.

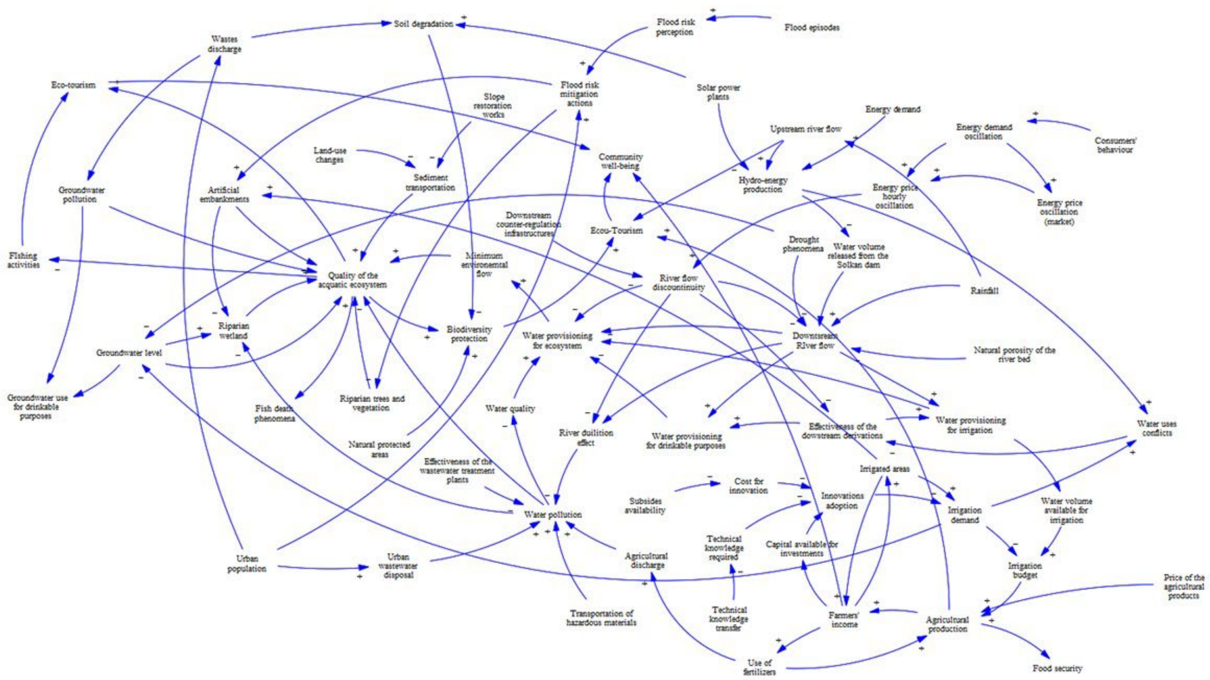

Figure 18 CLD developed for the Isonzo-Soča pilot, based on the information from the 1st stakeholders WS

6 Lessons learned from REXUS pilots

The present section provides some details on the main lessons learned (so far) from the REXUS pilot areas, as far as the PSDM development and implementation process is concerned. The evidence from pilot areas, mainly in terms of barriers encountered and opportunities emerged, is highly relevant for updating and revising the framework throughout the REXUS projects.

- Clear identification of the objective(s) of the process. Typically the PSDM process could be used for solving a problem or asking a question about a system, for designing new interventions, for identifying vulnerabilities or weak points, for building engagement and shared understanding and ownership of an issue amongst stakeholders, for allowing 'marginalised' perspectives to be communicated to powerful actors. The objectives of the process, although defined at the beginning of the activities, should typically be updated throughout the process.
- Besides identifying the objectives of the whole process, the definition of the specific aim of the SD models that are being built is fundamental. This is an 'iterative' process as well, as the priorities and needs might be significantly different for diverse stakeholders and may become clearer as the participatory process evolves. Ideally, the focus of modelling activities should become clear not later than at the end of Step 3.

The activities in the Isonzo-Soča pilot area are paradigmatic in this regard. The modelling activities started taking -rather generically – into account the issue of flood risk over the area, and the potential impacts on the agricultural sector, on the urban areas and on the river state. However, both targeted interviews and the evidence from the 1st WS highlighted that the *hydropeaking* phenomenon needed to be considered more specifically, rather than extreme floods, since it had a much greater and frequent impact over the area and was thus perceived as a key issue to consider for some stakeholders.
This also helped highlighting the challenges in defining a single 'common' objective, as the interests and priorities from different stakeholders might also significantly differ.

- The spatial dimension of the analysis is an issue that should be carefully considered for different reasons.
    - First, dealing with a spatial analysis is not immediate for SDM, and particularly for stock and flow models. As detailed in the Section 2, the spatial dimension can be taken into account in multiple ways, and this is crucial specifically when dealing with the need to adapt input data for the SDM (particularly from the 4th Step on). 'Aggregating' spatial data is an effective option, but this clearly can limit the quality and the detail of results.

An effective option to deal with spatial data emerged in some REXUS pilots consists in the development of 'lumped' models with some degree of aggregation of spatial information based on the identification of 'homogeneous' areas over the pilot area. Just to make an example, this emerged as an effective option in the Pinios pilot, where approximately 10 homogenous sub-units (in terms of hydrological features, land use, soil characteristics etc.) were identified. Same holds true for the Nima-Cauca pilot, where a broad distinction in three main areas (upstream – middle - downstream) with different activities, conditions and challenges to deal with, has been proposed.

-
    - Second, the scale of the analysis directly affects the quality of information that can be shared with decision-makers. According to a wide literature, SDM works better on a strategic/planning level (and thus typically on a larger scale). Working on a smaller scale might require a more specific development of sub-models, as well as the involvement of different stakeholders (with likely more steps and iterations in the framework).

The issue of scale is being tackled specifically in the Spain pilot, where both the national scale and the river basin scale is analyzed. This will require the development of different (yet somehow interconnected) SD models.

- Integration of data, models and information. This issue needs to be approached considering two different perspectives:
    - A key issue with PSDM is the integration between different forms and sources of knowledge. In this direction, it is fundamental to clearly identify what the modeler is going to build the map from. Maps can be built in a 'purely' participatory mode, and therefore mainly through discussions during workshops, or can be preliminarily built by the analysts. In the REXUS project, we decided to use mainly the latter approach, for two main reasons: i) the baseline description was built by local team, already including to some extent local knowledge. It was mainly based on a well structured (and shared) format, which allowed building comparable models in different

pilot areas; ii) dealing directly with the Nexus dialogue in a participatory way may not be straightforward, thus developing a very basic version of the model mainly based on well-established biophysical dynamics may be useful for a more 'gradual' approach to the theme.

  - The integration with sectoral model needs to be tackled carefully, particularly when moving to the 'quantitative' modelling part. In the current phase of the project, we are approaching the issue and dealing with some preliminary considerations, such as the input (and output) data format, the spatial and temporal scale of data, the use of scenario analysis combining evidence from different sectoral models. In this direction, the preliminary identification of relevant variables and the selection of a set (or catalogue) of indicators (e.g. DOs, NIs, NRQs) with corresponding units is highly useful.

- The analysis and use of CLDs is not always easy, particularly when complex interconnections (e.g. feedback loops) need to be described. What is more, even when loops are noticed, understood, and discussed, it can be difficult to turn this dynamical view of a system into something usable or 'actionable'.
The complexity of the map to show should be dependent on the visual literacy of the participants. Depending on the stakeholders' profile (technical background, familiarity with the methods, etc.), the use of large maps or multiple interacting feedback loops, can be confusing although still relevant to give an idea on the potential complexity of Nexus systems. The point should be to think carefully about how to frame and introduce the map in ways which allow to keep as much complexity as possible (e.g. steps, colour codes and position nodes by themes).
Although the main contribution of PSDM is related to the description of the complexity of systems, one of the main lessons learned is to try to keep the model simple and manageable enough, avoiding the excess of interconnections. Focusing on key interconnections and major dynamics is the most suitable solution in this direction.

> In this regard, during the 1st WS in the Pinios pilot area, one of the participatory exercises has been specifically performed for the validation of the CLD model. Although during a preliminary presentation of the results obtained so far, the CLD was shown in its complexity, the exercise was performed starting from a 'blank' paper with only the variables included. All connections were drawn from the scratch from the stakeholders, asking them to focus on the most important ones and providing a description of the relevance they attributed to those. The results of this exercise then allowed identifying potential inconsistencies with the 'baseline' CLD, adding or removing arrows.
> In the Isonzo-Soča pilot, the activities performed in some groups during the 1st WS were driving to a very complex and interconnected CLD, which would have easily turned into an unmanageable model. The analysts have been working on a 'rationalization' of the model, and on the prioritization of the most crucial components.
> Alternative approaches may involve e.g. the validation of the whole map (can be suitable in case it is not too much complicated) or the analysis and revision of specific parts of the map (e.g. sectoral sub-models).

7 Conclusions and way forward

The present Deliverable 4.2 mainly aims to provide a description of the framework proposed in the REXUS project for PSDM implementation, with full details on the key methodological aspects. The proposed approach is based on two main 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 multiple steps and is meant to be ‘modular’ (i.e. not all the steps need to be implemented) and flexible, to guarantee enough space for adaptation according to the specificities of pilot areas. A key aspect of the proposed framework is the strong integration of ‘desk’ activities and participatory exercises.

The most relevant modelling issues emerged so far have been introduced in the present Deliverable, including the integration of PSDM with other models (not yet explored in full details). The state of activities in the REXUS pilots is also discussed, with details and lessons learned from some pilots. The expected level of PSDM implementation in pilot is also identified.

PSDM-related activities have been activated in all pilot areas and are being constantly updated as the LAAs evolve. For example, a few preliminary activities and follow-up events have been already scheduled in the Spain pilot area (both at National level and in the Jucar, with the 1st WS and a focus group held in 14th of October 2022) and in the Lower Danube (focus group and interviews at the beginning of November 2022). For such reasons, as already mentioned, the present Deliverable provides a preliminary version of the PSDM framework as it has been designed, but is constantly being updated and revised according to the experiences in pilot areas. It should be thus considered as a dynamic and living document, with a huge space for revisions and improvements (an updated version of the PSDM framework will be delivered at M36).One of the key aspects to be tackled in the next few months is the integration with other models and sectoral information, as well as the interactions with the Observatory, which are all crucial for an efficient transition to the ‘quantitative’ modelling phase.

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