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SMARTLAGOON

DELIVERABLE 4.3

Sustainability of the Mar Menor region – A participatory system dynamics conceptual model

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101017861.

Innovative modelling approaches for predicting Socio-environMentAl evolution in highly anthRopized coasTal LAGOONs

Deliverable 4.3

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Abstract

Over the last decades water quality and ecosystem health of the Mar Menor in Spain, one of the biggest hypersaline lagoons in the Mediterranean has declined dramatically, causing important economic and social impacts. SMARTLAGOON´s primary goals are to build a systemic understanding of the socio-environmental interrelationships that affect the Mar Menor coastal lagoon and its ecosystem and to predict the socio-environmental evolution in this highly anthropized coastal lagoon while increasing local and citywide awareness of the socio-environmental impacts, as well as the social and economic costs to the local community.

To achieve the above-mentioned goal, a participatory modelling workshop series encompassing five workshops is used as a temporary forum for selected experts/stakeholders, focusing on the socio-environmental dynamics that affect Mar Menor coastal lagoon and its ecosystem, for sharing knowledge and experiences, discussing solutions and intervention points for the selected sectors, as well as preferred policy options. Deliverable 4.3 lays the foundations of the participatory modelling work carried out in WP4 and focuses on mapping system interactions as perceived by the stakeholders, to gain an in-depth understanding of key dynamics and explore different management and policy solutions for the sustainability of the Mar Menor coastal lagoon area.

The environmental deterioration of this unique ecosystem has its roots in unsustainable economic practices. Untreated sewage from growing urbanizations attracting mass tourism was entering the lagoon over many years, nutrient runoff multiplied when agriculture and livestock expansion became possible due to water transfer from the Tagus-Segura basin and fish stocks suffered not only from the environmental changes, but also from overfishing. Laws and regulations enacted to save the lagoon ecosystem, were only slowly implemented, and still lack sufficient control and enforcement. In addition, an increasing European demand for fresh fruits and vegetable deliveries all year round at lowest possible prices, acts as a barrier to enable the necessary changes to stop nutrient runoff from agriculture.

The contribution of the research depicted in this deliverable is twofold: (1) it provides a system dynamic picture – in the form of causal loop diagrams – that represents a conceptual articulation of the socio-economic dynamics mapped with the help of stakeholders in the Mar Menor area and by desk research, (2) it generates qualitative (socio-economic and policy) relevant insights into the Mar Menor crisis, reflecting its complexity as a multi-faceted problem with implications for all socio-economic sectors and governance levels. This work will serve as input for a system dynamics model, which will be developed as the next step.

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Abbreviations

BOTG	Behavior Over-time Graph
CLD	Causal loop diagram
GDPR	General Data Protection Regulation
GMB	Group model building
NGO	Non-governmental organisations
SD	System Dynamics
SFD	Stock and flow diagram
SMLG	Smartlagoon project
TAC	Total allowance catch
UCAM	Catholic University of Murcia

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1. Introduction

1.1. Background

The Mar Menor is one of the biggest hypersaline lagoons in the Mediterranean with a surface area of 135 km^2. It is located in South-Eastern Spain and considered as one of the most iconic natural areas in the Region of Murcia. The lagoon together with its surrounding wetlands form a unique ecosystem, with several protection statuses such as Natura 2000 network, RAMSAR Convention and Barcelona convention (Velasco et al., 2018). However, over the last decades the lagoon ecosystem has undergone drastic changes. It went from being oligotrophic in the 1970 to eutrophic (Pérez-Ruzafa et al., 2005).

The reasons for these changes in the lagoon ecosystem are to be found in changes in land-use and human activities in the catchment area of the lagoon. The opening of the Tagus-Segura water transfer in 1979 brought additional water to the semi-arid region, which enabled the change from the traditional cultivation of extensive dry crops to intensively irrigated crops. In addition, agricultural areas expanded (Lloret et al., 2015) and number of livestock has increased. Urban development along the coastline, but also in the rest of the catchment was triggered by a growth in agriculture and increase in tourist numbers. Both economic activities, tourism/urbanization, and agriculture, have contributed to increased nutrient levels in the Mar Menor and a deterioration of the water quality and ecosystem. While the problem of urban sewage runoff was largely solved by increasing the wastewater treatment capacity (an exception are stormwater overflows during heavy rainfall), nitrate runoff from agriculture is still considered a problem. Today the catchment area (1255 km^2) is largely covered by intensive irrigated agriculture, while the coastline is covered by villages, tourist accommodations and infrastructure like ports.

Tourism, especially on the west coast of the Mar Menor without direct access to the Mediterranean Sea, and the local population are the ones suffering the most from a deterioration of the ecosystem. Increasing frequency of algae blooms, periods of anoxia, massive fish kills, jellyfish blooms, muddy seafloors jeopardize the attractiveness of the Mar Menor as touristic destination, but also as place to live and endanger fishermens' livelihoods.

The aim of the SMARTLAGOON project is to build a systemic understanding of the socio-environmental evolution and current dynamics in the Mar Menor catchment and lagoon. By establishing environmental as well as social-media sensors, developing models that help to (a) understand the land-use and runoff dynamics in the catchment and (b) the biophysical processes in the lagoon, as well as (c) the socio-economic and cultural dynamics behind, the SMLG project will be able to predict short-term environmental dynamics, as well as test policies and provide advice concerning long-term changes, that are necessary to halter or even reverse the environmental degradation of the lagoon ecosystem.

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1.2. Purpose of deliverable

The purpose of this deliverable is to summarize the approach and first results of the participatory group model building process, which are used to understand the socio-economic-environmental dynamics in the Mar Menor catchment as well as the implications of possible management solutions. The results form the basis for a system dynamic model, which will be developed during the SMARTLAGOON project and will allow to assess different management solutions. This deliverable builds on two series of group model building workshops and on information collected in previous deliverables, especially D4.1 “Technical brief on the environmental, economic, social and legislative conditions and constraints of the Mar Menor region and thematic maps” and D4.2 “Description of BMPs, policies and associated scenarios for water pollution control and flood mitigation measures”.

2. Methods

Complex challenges require innovative approaches to understanding and addressing their underlying dynamics. System Dynamics (hereafter SD) methodology offers a holistic framework for comprehending the behavior of complex systems and for developing practical strategies to improve performance and achieve desired outcomes (Forrester, 1968; Sterman et al., 2000). Given the complexity of the research topic investigated we have opted for a participatory group modelling technique, which has been proven to be effective for both conceptualization of a problem and guiding in the development of complex model simulations (Andersen et al., 1997; Vennix et al., 1990).

The system dynamics model will be developed through a series of 5 workshops (Figure 1) with experts and local stakeholders, who have in-depth knowledge about the socio-economic, cultural and environmental dynamics in the Mar Menor catchment. The insights gained from the workshops are used alongside other sources of information to construct causal-loop-diagrams (CLDs) (see section 3.3). The CLDs are iteratively revised and validated by the stakeholders and form the basis for the system dynamics model. The system-dynamics model allows for mathematical modelling of the most important dynamics and to test different management options. The results of the modelling will be presented and discussed with the stakeholders before the model is coupled with the other models developed in SMARTLAGOON and made publicly available via an online interface.

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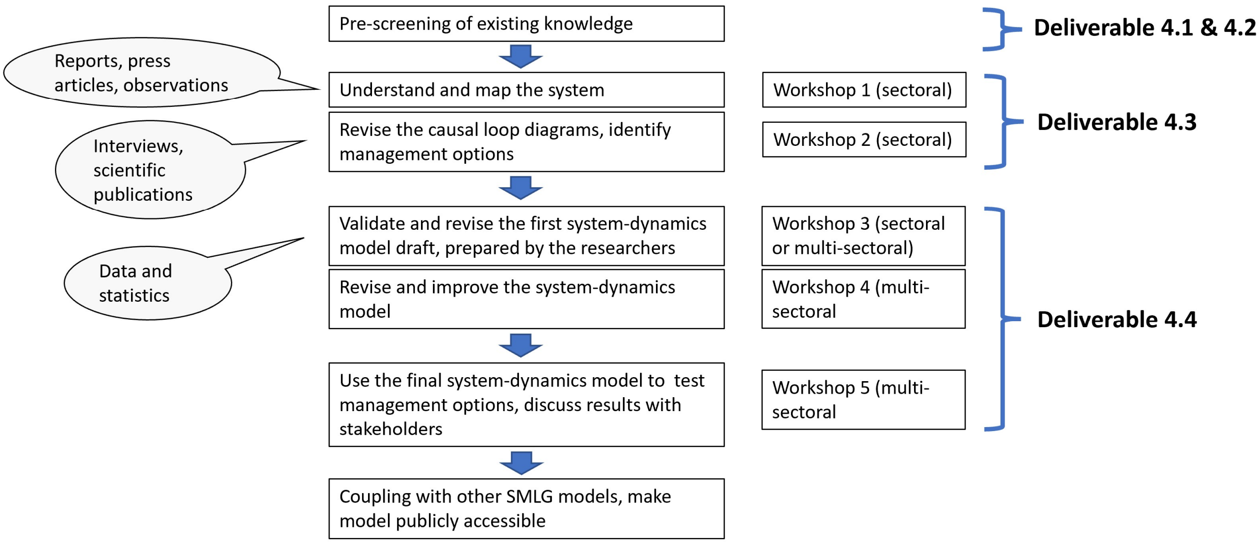

Figure 1 Methodological framework

2.1. System-dynamics modelling

This section provides an overview of the SD methodology, highlighting its applications in socio-environmental studies. It explores the fundamental characteristics of systems, including feedback loops and non-linearity, which shape their behaviour. Additionally, we describe the steps undertaken in SD model development, emphasizing the importance of Group Model Building (hereafter GMB) as a collaborative approach to engage stakeholders in problem-solving and decision-making. The case study on the Mar Menor Lagoon illustrates how SD and GMB can be applied to address complex challenges in practice. By employing the SD methodology and GMB, policymakers and stakeholders can gain a deeper understanding of complex systems and develop effective strategies to navigate the complexities of today's world. Key characteristics of the systems, steps undertaken in the SD model development as well as advantages, challenges and limitations associated with the SD models are briefly introduced next.

2.1.1. Key Characteristics of Systems

1. **Feedback Loops:** Feedback loops are essential to understand the complex systems, involving feeding information about the system's output back into the system as input, potentially influencing future output (Richardson, 2011) They can be classified as positive or negative, with distinct effects on system behaviour.
    - **Positive feedback loops** amplify or reinforce initial conditions, leading to exponential growth or decline. They can trigger runaway effects, such as melting polar ice caps due to global warming, where the melting process accelerates as less reflective surfaces remain (Lane, 2007; Richardson, 2011; Sharp, 1983).
    - **Negative feedback loops** promote self-regulation and stability. They help maintain the system within specific limits, such as regulating blood sugar levels in the body through insulin production (Lane, 2007; Richardson, 2011; Sharp, 1983)

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2. **Non-linearity:** Non-linearity is a fundamental characteristic of systems where cause and effect do not have a proportional or linear relationship. Nonlinear systems can exhibit significant and unpredictable output variations in response to minor input changes (Forrester, 1971). Feedback loops, threshold effects, and interactions among system components contribute to non-linearity.
    - Chaos refers to random and unpredictable behaviour in nonlinear systems driven by sensitive dependence on initial conditions. Small disparities in initial conditions can lead to vastly different outcomes.
    - Bifurcation occurs when a small input change produces a substantial output change, causing the system to transition between stable states.
    - Emergence describes complex patterns or behaviours from interactions among simple components within a nonlinear system. Understanding nonlinear systems is crucial for predicting and managing their behaviour and designing effective interventions (Bar-Yam et al., 1998).

2.1.2. SD Model Development Steps

1. **Problem Definition**: Identify the problem to be modelled and define the system's boundaries.
2. **Causal Loop Diagramming**: Develop a causal loop diagram (CLD) which is a diagram to visualize feedback loops and causal relationships between key variables in a system (sction 3.3).
3. **Stock and Flow Diagramming**: Convert the CLD into a stock and flow diagram (SFD) that illustrates how system stocks change over time due to various factors.
4. **Formulate Equations**: Write mathematical equations describing relationships between variables in the SFD.
5. **Model Simulation:** Use software like Vensim or Stella to simulate the model and observe system behaviour under different conditions.
6. **Model Validation**: Test the model against real-world data and other information sources
7. **Policy analysis:** Use the model to analyse the impact of different policies or interventions on the system and identify the most effective strategies for achieving desired outcomes.

2.1.3. Advantages, Challenges and Limitations Associated with SD simulation

The main advantages of SD simulation are discovering a system's emergent properties and characteristics, creating quantitative analysis for qualitative problems, identifying the essential system variables, predicting the long-term effects of decisions, and helping stakeholders learn about the nature of their problems.

However, SD simulation can be time-consuming and require significant data to develop and test the model. It also assumes that the modelled system is closed, which may only sometimes be true in complex systems involving external factors. Therefore, having an appropriate boundary for the system is very important. Furthermore, the accuracy of the SD model mainly depends on the quality

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of input data and assumptions made during the modelling process. Therefore, accurate assumptions, complete data, and various data validation can lead to reliable simulation results. Moreover, interpreting the simulation results can be challenging since the model can be complex and involve numerous variables and feedback loops. It may require a high level of technical expertise to fully understand the model's results and implications (Luna-Reyes & Andersen, 2003)

Finally, implementing policy changes based on SD simulation results may be resistant to stakeholders who must fully understand the model's underlying assumptions and limitations. Therefore, effective communication and stakeholder engagement is critical to successfully implementing policy changes based on SD simulation results (Stave et al., 2019; Zimmerman et al., 2016).

2.1.4. Group Model Building

Engaging stakeholders and incorporating their input and feedback is critical to ensure that the SD model is relevant and useful for decision-making in the context of the Mar Menor lagoon. Group model building (GMB) is a participatory approach to problem-solving and decision-making that involves bringing together a diverse group of stakeholders to develop a model of a complex system collaboratively. This approach is often used when there is a need for more consensus or agreement among stakeholders or when multiple interrelated factors must be considered in decision-making (Hovmand, 2014).

GMB technique employs system mapping to create causal loop diagrams (CLDs). CLDs visually represent the complex feedback loops and interactions between different system components, as the stakeholders understand it. It helps to identify the underlying causes of the problem and potential interventions that can be made to address it (Kopainsky & Luna-Reyes, 2008; Videira et al., 2010).

CLDs or system mapping are well suited to participatory research as they allow stakeholders to visually represent and communicate their understanding and knowledge of the system and its complexity. It can facilitate stakeholder communication and collaboration, leading to a more comprehensive and effective response to the problem investigated and various needs of the stakeholders.

In the case of the Mar Menor lagoon, GMB is used to engage stakeholders from diverse sectors, such as government agencies, NGOs, scientific experts, the agriculture sector, the fishing industry, and tourism over a series of workshops to collaboratively develop a simulation model that represents the coastal lagoon system's complex socio-ecological and economic dynamics. Through GMB sessions, stakeholders shared their perspectives and knowledge, identified key variables and relationships, and developed a shared understanding of the system's behaviour and dynamics that address the challenges facing the Mar Menor lagoon.

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2.1.5. The GMB Sessions

GMB adopts an evidence-based approach in crafting scripts that can effectively steer the process (Andersen, 1997; Hovmand, 2011). This standardized approach ensures that workshops can be conducted consistently across diverse sectors, allowing for session duration and timing flexibility. Each workshop spanned 4 hours, incorporating brief breaks, and was conducted and facilitated in Spanish.

There were two main phases to developing the CLD: identifying the variables that best describe the problem concerning the current state of the Mar Menor region and the second to identify the relationship and polarity between the variables. The first stage includes exercises where the participants are asked to draw the behaviour over-time graphs (BOTGs) describing the identified variables' dynamic behaviour and consider both positive and negative externalities for them. With this exercise, we engaged them in an open discussion, using the conceptualization methods from systems thinking, such as how other variables impact their initial variables and their polarities. The second phase included an exercise where participants were challenged to think about hidden variables in case of doubts or difficulties in identifying polarities between the variables. This process identified the main issues, opportunities, obstacles for sustainable development, and inter-sectoral synergies in socio-environmental and economic development interaction.

The process of conducting GMB and its adaption to generic steps of SD modelling is typically organized in several stages, including the problem identification, where the group works together to identify the specific problem or issue (see section 2.3) that will be addressed in the case study. Next is model development, which entails creating a conceptual model in two main stages. This process requires collaboration with stakeholders to develop a causal loop diagram (CLD) that represents the complex interactions and feedback loops among the system components. In the first workshops, the group collaboratively develops an initial conceptual model of the Mar Menor system. This step involves identifying key variables and their relationships, which are used to create a draft CLD (Table 1). The model development process continues in the subsequent workshops, depending on the progress made during the initial sessions. Validation exercises may be conducted to refine and improve the conceptual model at each process stage (Table 3).

Once the conceptual model is developed, the modelling group proceeds to data collection. They gather data from various sources, including stakeholder input, local knowledge, existing databases, and literature. This data is used to populate the model and test its validity against the identified problem(s) reference mode. Model testing and refinement follow the data collection stage. The modelling group collaborates with stakeholders in a cross-sectoral workshop to compare the model outputs with the stakeholders' understanding of the system. This process helps identify any discrepancies or gaps in the model and allows for necessary refinements. The model may undergo refinement or adjustments based on the testing results obtained during the final workshops. The modelling group then utilizes the developed model for scenario analysis. They explore different scenarios and potential outcomes for sustainable development in the coastal lagoon. They provide

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stakeholders with valuable insights to make more informed decisions and understand the consequences of different courses of action.

In the final workshop, an interactive interface is typically provided to stakeholders for easy analysis and exploration of the modelling results. This interface can take various forms, such as a web-based dashboard or a graphical user interface utilizing the interface feature of Stella software.

2.2. Stakeholder mapping and engagement

In connection with developing the public participation plan of the SMARTLAGOON project (Deliverable 7.1), different stakeholder organizations and groups covering different sectors were mapped. The WP4 team engaged with relevant organizations and stakeholder groups, which were contacted by e-mail and phone and invited to take part in the workshop series pertaining to the group modelling exercise. Information about the SMARTLAGOON project, the system dynamics modelling process and about their rights concerning General Data Protection Regulation was provided to all potential participants to allow them to take an informed decision about their participation. The informed consent-form and written information material was sent to them per email before the workshop and was also made available as printouts/handouts during the workshops.

2.3. Participatory group model building

The system dynamics model will be developed through a series of 5 workshops (Figure 1, section 2) with experts and local stakeholders, who have in-depth knowledge about the socio-economic-environmental dynamics in the Mar Menor catchment. The first two to three workshops were envisioned as sectoral workshops, to properly identify the dynamics in each sector. Later in the process (from workshop 3 or 4 on), multi-sectoral workshops will be carried out to better account the dynamics between the interlinked sectors and to gain a comprehensive understanding of the "holistic picture" that describes best the system under scrutiny.

To be able to define the SD model hypotheses, for the sectoral workshops, the research team has formulated the following objectives:

- To understand which dynamics have led to the environmental degradation of the Mar Menor lagoon ecosystem, but also how the degradation influences the economic activities and living conditions of the people in the region.
- What has to be done to sustain economic activities, good living conditions **and** allow the recovery of the lagoon ecosystem in the future?

Workshop participants were asked to elaborate on these issues from their sectors perspective using the workshop handouts prepared by the modelling team and shared prior the sessions. It was important to take this perspective to avoid that sectors were engaging in mutual blame on the current situation of environmental degradation of the Mar Menor lagoon. Stakeholder observations

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of socio-economic and cultural changes, as well as of the environmental deterioration process of the Mar Menor lagoon ecosystem over time, deliver valuable information on how the environmental and socio-economic-cultural dynamics are linked to each other.

2.3.1. First workshops

Structure of first workshops (workshop 1)

Each workshop was commenced with an introduction to the SMARTLAGOON project and the structure of the stakeholder workshop (Table 1). This was followed by an introduction to systems thinking, variables of interest and their behaviour over time. In the first individual exercise participants were asked to select one to several variables, which in their opinion depict important dynamics in the Mar Menor catchment. They were requested to reflect on and draw the development of these "variables of interest" over time on printed sheets of paper. The colour green represented their "hope" scenario, red their "fear" scenario, and black their expected most probable development of the parameter. The participants also noted down the time horizon for each parameter from the past to the future. We then asked the participants to briefly describe their variables to initiate group discussions.

Table 1 First workshop - group model building (GMB) session outline

Segment	Content	Tools/materials	Activity level
Introduction	Introduce team; explain process; outline of topics and system approach		Whole group/presentation
Behaviour-over-time graphs (BOTG)	Introduction and explanation		Presentation
	Making individual BOTG of variables driving the problem	Individual BOTG templates	Individual
	Prioritizing variables, discarding duplicates	modelling team collecting BOTG sheets	
Connecting variables	Explanation of connecting variables		Presentation
	Polarity identification		Presentation
	Illustrating connections	Mapping board	Group work
Map Creation	Convert connections to CLDs	Mapping board	Group/modelling team
Map consolidation	Tidying up the map and then validation with participants		Group/modelling team
Action ideas	Generating potential actions to shift the system	Action idea templates	Individual
Action idea placing	locating action ideas on CLD	Mapping board	Group work

In the next step, we introduced systems mapping, causality and polarity, hidden variables and feedback loops. In the following group exercise, we asked the participants to build CLDs. For this, the researchers noted down the variables of interest identified by the participants on post-it notes, which were pinned to a white board. In the exercise, the participants were asked to connect the variables on the white board with arrows. Positive polarity, that is two variables moving in the same direction, were represented by red arrows. Negative polarity, that is two variables moving in

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different directions, were represented by blue arrows. Following this approach, the participants connected the variables to build feedback loops, and we emphasized to consider and add hidden variables in cases where the relationship between variables was unclear.

In the final step, we asked the participants to think about potential actions that could be taken to ensure the recovery of the Mar Menor ecosystem, while ensuring good living conditions in the region and maintaining economic activities. We wrote down the stated action ideas on post-its and instructed the participants to pin them to the relevant parameter that would be influenced by the action. We asked the participants to focus on variables of interest and action ideas relevant to their specific sector. For details on these exercises we refer to the Appendix of this document.

Participation in workshop 1

The first set of workshops in the series of workshops (workshop 1) were sectoral workshops (see also Figure 1). The aim of workshop 1 was to understand what has led to the environmental degradation of the Mar Menor lagoon, and how the degradation influences economic activities and living conditions of the local population. We carried out separate workshops with the following stakeholder groups:

- Environmental Non-Governmental Organisations (NGOs)
- Researchers
- Agricultural sector
- Fisheries
- Tourism sector
- Public administration – regional government
- Public administration – national government

Workshop 1 was carried out between 27. February and 3. March 2023 and covered the sectors as shown in Table 2. The workshops with the environmental NGOs, the researchers, the agricultural sector and fisheries were carried out at the Catholic University of Murcia (UCAM) and lasted between 3.5 and 4.5 hours. The workshop with the tourism sector was held at a hotel in La Manga, Campo de Cartagena, and lasted 3 hours. The workshop with representatives of the regional government was carried out at the Murcia Council of Water, Agriculture, Livestock, Fishing and the Environment in Murcia with a duration of 2 hours. The workshop with representatives of the national government was held at the Ministry of the Environment in Murcia and lasted 2 hours. All workshops were held in Spanish and facilitated by a native Spanish speaker (from the partner VIELCA) with the support of four researchers from NIVA and a note taker (from VIELCA), who recorded notes of all group discussions. Written and informed consent was obtained from all participants prior to the workshops. After the workshops the participants received a short summary of the workshop outcomes.

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Table 2 Participation in workshop 1

Sector	Participants description	Participants details (f=female, m=male)
Environmental NGOs	Workshop was cancelled, participant was interviewed instead.	1 female
Research	Participants represented research institutes and universities, with a variety of disciplinary backgrounds including marine biology and ecology, hydrogeology, hydrology and geography.	4 female, 3 male
Agriculture / Agrobusiness	Participants represented ecological small-scale farming, livestock farming as well as farm equipment supply (technical and mercantile background).	5 male, 1 female
Fisheries and surface flooding	Participants represented fisheries, fisheries development associations, marine biology research, as well as persons affected by surface flooding.	3 male, 3 female
Tourism	Participants represented nautical and water sports, tourism associations, hotel owners and hotel owners' associations, as well as tourism research.	3 male, 2 female
Regional government	Participants represented wastewater treatment services, the municipality of Murcia, the institute of agricultural and environmental research	4 male, 0 female
National government	Participants represented marine sciences, biology, forestry and architecture and the national government	5 male, 3 female

2.3.2. Second workshops

Structure of second workshop (workshop 2)

In the second round of workshops, we started each workshop again with a short presentation of the SMARTLAGOON project and some details on the system dynamics modelling process to refresh their memories and to provide new workshop participants a short insight into the project (Table 3). Concepts important for understanding the modelling process such as polarities and feedback loops were introduced to the participants with the possibility to ask questions about them. In the next step we started with the exercises. The first exercise consisted in looking at one of several CLDs, which were developed based on the participants inputs in the first series of workshops and amended with other sources of information (i.e., literature, reports). To facilitate the refinement process of the CLDs, each loop contained in the CLDs was described by a short storyline. Participants were asked to individually read through the storylines and afterwards to discuss in the group if the dynamics displayed in the CLD were correct or should be changed. For the second exercise, the research team had prepared some questions which were related to the CLD or the dynamics in the sector and these questions were discussed with the group. One week before the workshop the participants have received a handout with the CLDs, the storylines of each loop as well as the questions, so they could beforehand reflect on them.

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Table 3 Second workshop - group model building (GMB) session outline

Segment	Content	Tools/materials	Activity level
Introduction	Introduce team; explain process; outline of topics and system approach		Whole group/presentation
Recap	Summary of results of first workshop; recapitulacion of important concepts related to CLDs		Presentation
Individual revision of CLDs	Individual revision of CLDs and storylines	Handouts with printouts of CLDs and storylines	Individual work
Group revision of CLDs	Revision of CLDs in the group with zoom-in on detailed level	CLD on screen	Group/modelling team
Questions to CLD (individual answers)	Individual preparation time for questions related to CLDs	Handout	Individual work
Questions to CLD (group discussions)	Group discussion of questions related to CLD	Handout and CLD on screen	Group/modelling team

Participation in workshop 2

To better reflect the cross-sectoral expertise and interests of the participants (attending in the first round), in the second round of workshops (workshop 2) we did minor adjustments to the composition of the sectoral groups. This was done to be able to dive deeper into the dynamics of each sector, but also because we noticed in the workshop 1 series, that some participants had multiple roles i.e. being farmer and member of an NGO or working as researcher on a specific sectoral topic like fisheries, agriculture or tourism. We grouped the participants in a way that would best accommodate this and engage them in the discussions. In addition, we decided to postpone the workshops with the regional and national government due to the upcoming local and national elections at the end of May and July 2023.

Workshop 2 was carried out between 10. and 16. May 2023 and covered the sectors as shown in Table 4**Error! Reference source not found.**. The workshops were carried out at the premises of the Oceanographic Institute of Spain (Instituto Español de Oceanografía), the Catholic University of Murcia (UCAM) and in a hotel in Los Alcazares, to minimize the travel distance for the participants. Each workshop lasted around 3 hours. Except from the workshop with the environmental NGOs and research, which was held in a mix of Spanish and English language, all workshops were held in Spanish language and facilitated by a native Spanish speaker (from the partner VIELCA). Notes were taken in Spanish by a note taker (from VIELCA) and translated afterwards. Written and informed consent was obtained from all new participants before the workshop started. After the workshops participants were provided with a short summary of the results of the second workshop.

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Table 4 Participation in workshop 2

Sector	Participants description	Participants details (f=female, m=male)
Environmental NGOs and research	Participants were from research and environmental NGOs, some had double roles as researchers working in NGOs.	5 female
Agriculture / Agrobusiness	Participants had a background in intensive farming, ecological farming, livestock farming as well as farm equipment supply (technical and mercantile background).	6 male, 2 female
Fisheries	Participants represented fishermen and researchers in marine biology and coastal water temperatures.	3 male, 2 female
Tourism	Participants represented nautical and water sports, tourism associations, hotel owners and hotel owners associations, as well as tourism research.	3 male, 2 female

2.3.3. General Data Protection Regulation (GDPR)

Running and organizing stakeholder workshops concerns issues related to the processing of personal data. In line with the responsible research and innovation approach that underpins SMARTLAGOON, adhering to the GDPR requirements is a natural part of the workshop design, preparation, and processing of data. The work is in line with the ethical standards of SMARTLAGOON (outlined in the Data Management Plan, Deliverable 6.9) as well as the regulations and advice set by the Norwegian Agency for Shared Services in Education and Research, which is the responsible agency as this work package is led by NIVA (Norway). In the group-model building process we are not collecting more information than needed. Participation is voluntary and based on informed consent. It has no bearing on the possibilities to participate if participants e.g. did not want to take part in pictures. The project team is transparent about its reasons for collecting the data and how it will be processed and shared. As long as the data is processed and not yet anonymized participants have the possibility to request insight into their personal data.

3. Results

3.1. Stakeholder and current policy mapping

As referred in the previous chapters, stakeholder mapping together with a screening of existing knowledge on Mar Menor socio-economic and environmental challenges were carried out earlier in the project and are depicted in deliverables D4.1, D4.2, and D7.1. Identification of relevant stakeholders was done by reviewing the public participatory processes of different earlier projects run in the Campo de Cartagena watershed, classifying the identified organizations in 10 groups by their activity, contacting them by telephone and e-mail, and aiming to engage them for the SMARTLAGOON project. SMARTLAGOON stakeholder contacts include actors from agriculture, environment, fishing, municipalities, professional institutions, Regional and National governments, science and universities, tourism and water utilities. Deliverable D7.1 is a living planning document, which helps the project partners to coordinate (to some extend) the participatory actions to be carried out in the whole SMARTLAGOON project.

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In deliverable D4.2 existing policies related to the sectors, which affected the environmental status of the Mar Menor lagoon, were reviewed. The aim was to identify *Best Management Practices* (BMPs) that were already implemented or are currently under implementation in the Mar Menor and Campo de Cartagena region.

From this review, the following main points should be highlighted:

- European Directives together with National, Regional and Local policies and regulations cover diverse topics and adress several sectors that affect the ecological status of the Mar Menor lagoon.
- A total amount of 316 BMPs was identified in the review of 20 different policy documents.
- The main topics adressed in the BMPs were: *Nutrient inputs* with 62 BMPs, *Environmental restoration* with 34 BMPs and *Water management* with 28 BMPs.
- 197 of the 316 identified BMPs were contained in three legal documents, which were issued by the Regional Government and deal with multiple topics.
- Other 65 BMPs came from three legal documents, which were issued by the National Government. They are mainly related with hydrological planning and flood risk management.

As a final reflection, BMP's review coincides with the stakeholder's general perception that the system is overregulated. Concretely, 110 different BMPs address the agricultural sector, 39 BMPs address Tourism and 17 Livestock farming.

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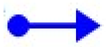
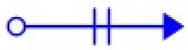
How to read causal-loop diagrams (CLDs)

CLDs are diagrams that aid visualizing how different variables in a system are causally interrelated. The diagram consists of variables and arrows between them indicating the direction of the causality. CLDs are accompanied by short narratives, storylines, which describe the dynamics displayed in the CLD. Closed loops are very important features in CLD, as they determine a systems behavior over time, once the CLDs are converted in stock and flow diagrams in SD modelling. The signs and symbols used in the CLDs, and storylines described in the following chapters, are explained in Table 5 and are meant to help the reader understanding the CLDs. All CLDs, which are presented in this deliverable are linked as shown in the cross-sectoral CLD. Top-level CLDs describe causality structures, which were mentioned in several workshops and have links to several sectoral CLDs. The sectoral CLDs were developed together with stakeholders in the sectoral workshops.

Table 5 Signs and symbols used in CLDs

Sign or symbol	Explanation
	Red arrows indicate a causality with positive polarity i.e., the variables, which are connected by the arrow show the same trend (increasing or decreasing).
	Blue arrows indicate a causality with negative polarity i.e., the variables, which are connected by the arrow show opposite trends (i.e. one increasing and the other decreasing or vice versa).
	Time delay mark; this mark on a red or blue arrow indicates that the effect happens delayed and over long time periods.
	Feedback loop sign; an R in the title of the loop indicates that it is a reinforcing loop, an B indicates that it a balancing loop.
Cursive variable names	Cursive variable names in a diagram indicate that this is a copy of a variable, which already exists in the CLD. Sometimes it is necessary to copy variables to avoid that the CLD gets too crowded.
nutrients in MM (separate CLD)	Letters in brown color indicate that the CLD links to another CLD.
illegal activities	Letter shaded in grey in the storylines indicate that this is a variable name, which can be found in the respective CLD.

3.2. Cross-sectoral CLD – overall system with subsystems interlinkages and causalities

The interlinkage and causality among subsystems play a crucial role in understanding complex systems. Breaking down a system into smaller subsystems allows for easier comprehension and management of its intricacies. Each subsystem can be analyzed independently, enabling a more focused examination of specific dynamics and relationships within that particular subsystem.

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In the case of the Mar Menor lagoon and its catchment area, the subsystems (Figure 2) storyline sheds light on the socio-economic and environmental aspects of the system. It highlights the interconnectedness of various systems and their relationship with the prevailing environmental conditions. Specifically, the model emphasizes the impact of nutrient discharge into the Mar Menor (MM) resulting from inefficient catchment management and socio-economic activities in the surrounding area.

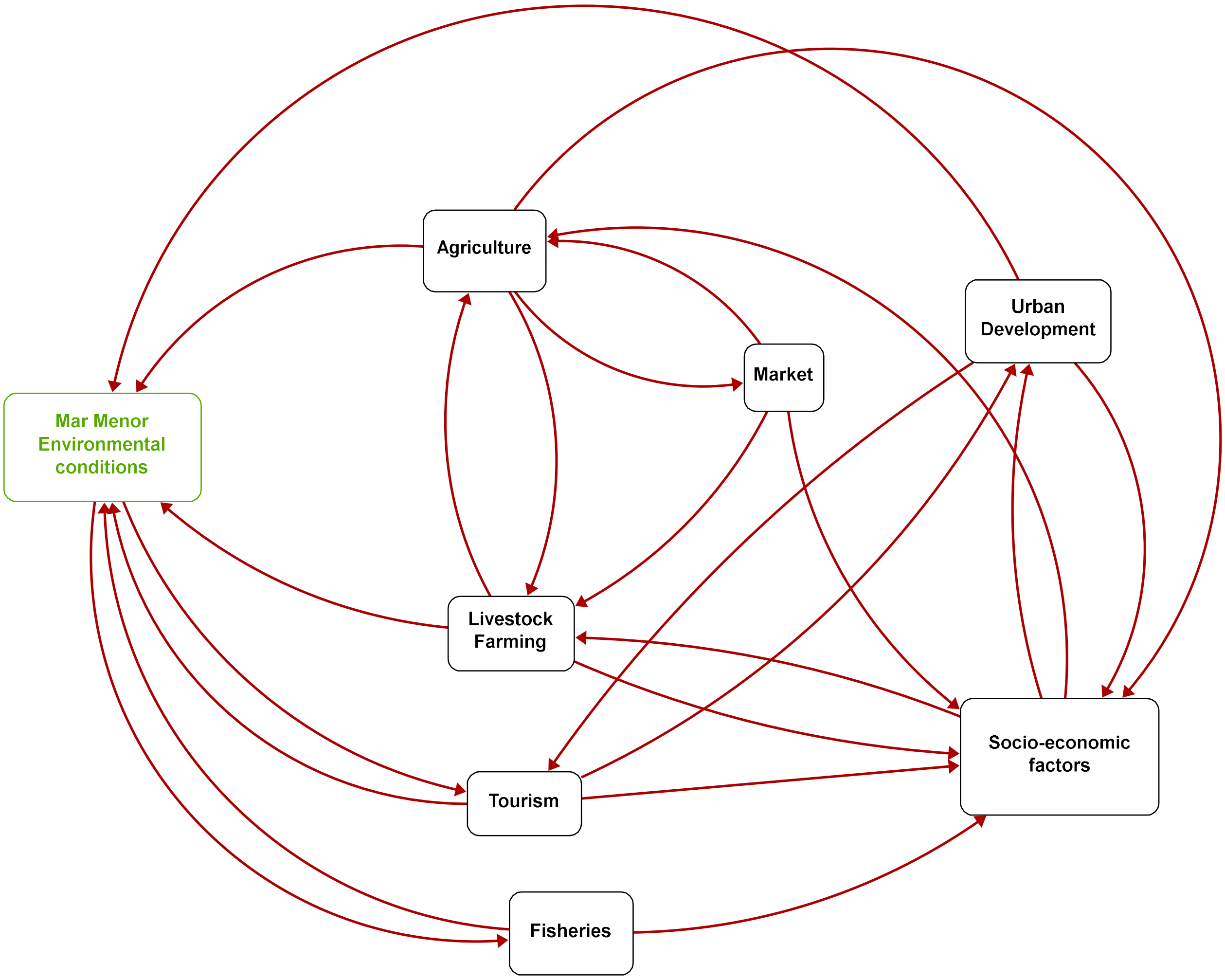

Figure 2 Cross-sectoral CLD – overall overview with subsystems

The main socio-economic activities in this region include agriculture, livestock farming, tourism, and fisheries. These activities exert ecological pressure on the lagoon and contribute to its environmental degradation. However, their contribution to this process varies. Agriculture and livestock farming are claimed as the primary direct sources of nutrient inflow into the lagoon nowadays (Moragues Pitarch, 2022). Wastewater discharge from urban and tourist development has also added to the stock of nutrients in the Mar Menor over several years, but this problem was largely solved when sufficient wastewater treatment capacity was built. However, during extreme rainfall episodes, there is still wastewater from urban areas loaded with nutrients entering untreated into the lagoon.

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The agricultural market subsystem elucidates the agricultural sector's changing practices to reduce its production footprint without altering the food supply chain and market structure. This subsystem tries to consider sales of agricultural products in food markets, requirements for shape of agricultural products and contractual agreements in the agriculture sector, analyze the conflicts and synergies of the food production supply chain, and policies to reduce ecological pressure on the Mar Menor.

The socio-economic subsystem captures the dependence of the local economy on each sector and the population dynamics driven by job opportunities within these industries. This subsystem also plays a vital role in the intensity of urban development in the area.

The fisheries sub-model is closely tied to the tradition and culture of the fishing communities around the lagoon. However, it has diminished over time due to the over-exploitation of fish stocks in the Mar Menor. The situation has gotten worse in recent years due to multiple fish kill incidents, biodiversity, excessive nutrient discharge, and frequent algae occurrences (Guaita-García et al., 2022).

3.3. Top-level CLD

3.3.1. Top-level "Nutrients in Mar Menor"

The top-level system (Figure 3) illustrates the causal relationship between nutrient inflow from agriculture and urban areas to the lagoon and in simplified form the changes in the lagoon ecosystem. Through many years of influx of nutrients (and other contaminants), the nutrient level in the Mar Menor increased more and more. This caused higher chlorophyll concentrations, and algae blooms happened more frequently. This results in reduced benthic vegetation (vegetation at the bottom of the lagoon), which reduced the lagoon ecosystems' capacity to bioremediate nutrients and contaminants. Over time, this leads to an even greater accumulation of nutrients in the lagoon.

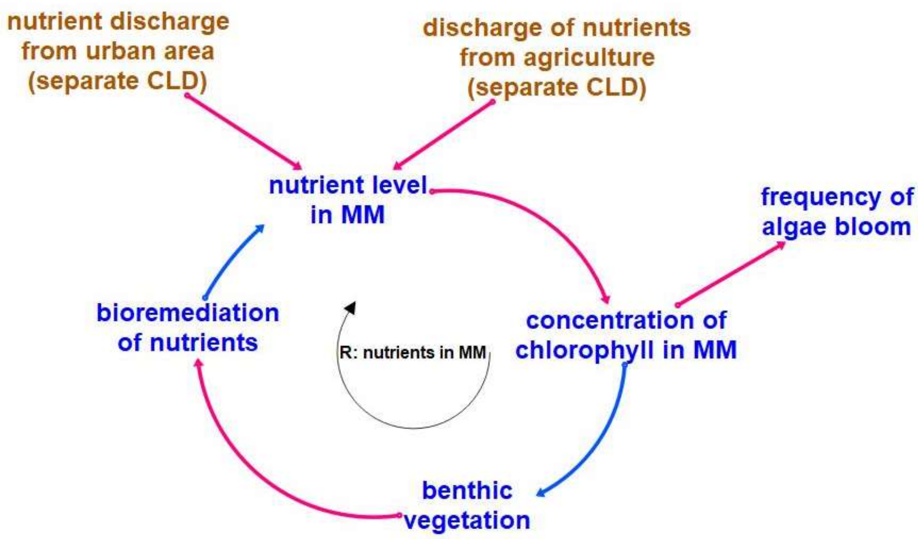

Figure 3 Top-level "Nutrients in Mar Menor" CLD

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This primary reinforcing feedback loop serves as an environmental control loop which allows assessing how socio-economic subsystem changes will affect the lagoon ecosystem. Successful management plans will be those that result in reducing nutrients discharge into the lagoon and shifting the direction of this reinforcing loop towards the negative direction, thereby benefiting the lagoon ecosystem and supporting socio-economic activities simultaneously to adapt to this process. While the nutrient loop captures the main dynamics in the lagoon ecosystem in this study, it is important to note that it is a simplified representation of the catchment processes and complex dynamics in the lagoon ecosystem. The focus of the system dynamics model is to model the socio-economic-cultural dynamics that have led to the environmental degradation of the lagoon ecosystem. Other models that are applied by the SMARTLAGOON consortium cover water dynamics in the catchment (López-Ballesteros et al., 2022)and the water and nutrient dynamics in the lagoon (Senent-Aparicio et al., 2021).Both SWAT and QWET models developed in WP2 will provide input to the system dynamics modeling at a later stage. All the sectoral workshops mentioned this overarching dynamic, which offers a top-level summary of the objectives for the socio-economic subsystems we were collectively building. These workshops benefited from the expertise of professionals representing diverse sectors.

3.3.2. Top-level “Law enforcement”

The top-level “Law enforcement” CLD (Figure 4) represents the need for more control of existing policies including consequences for those who do not comply with the laws. Existing policies with the aim to improve the environmental conditions in the Mar Menor lagoon are needed according to the observation of the participants in all sectoral workshops. This CLD illustrates at the top-level the lack of systematic enforcement of laws in all socio-economic sectors and emphasizes the need for authorities to exert better control and reinforce environmental laws. The diagram consists of two feedback loops.

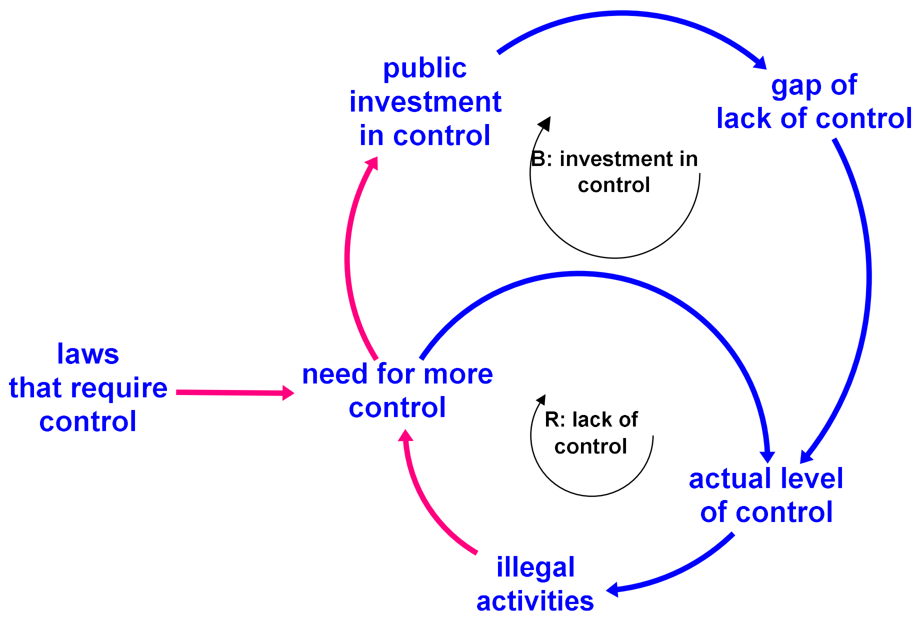

Figure 4 Top-level “Law enforcement” CLD

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Reinforcing loop: Lack of control
The first loop demonstrates a reinforcing mechanism wherein illegal activities and a lack of government control over law enforcement contribute to a reinforcing system. Illegal activities will increase the need for more control. The higher the need for more control, the lower the actual level of control, thereby creating an environment that encourages further illegal activities as individuals engaging in illegal activities face minimal consequences, thus perpetuating the loop.

Balancing loop: Investment in control
The second loop represents a general driver for improvement by promoting a favorable state of increased systematic settlement of the laws. This entails investing in enhanced control measures (public investment in control) to ensure that all actors comply with the law and that the gap of lack of control is closed.

The variables and indicators related to systematic control and inspection, aimed at ensuring that all economic activities align with environmental laws, will differ, and be tailored according to each specific sector.

3.4. Sectoral CLDs

3.4.1. Water dynamics

Water is essential for every business and is particularly prominent in semi-arid climates, where the irrigation agriculture model depends on water transfer. While the Tagus-Segura water transfer has provided a significant boost to agricultural production in the past, it has also led to an imbalance in the area's hydrology. The loops contained in the water dynamics CLD (Figure 5) are described in detail below, sorted after the main dynamics.

Available water sources and preferences
The ”Available water sources and preferences” CLD (Figure 6) illustrates the various available water sources for agriculture and the preferences and expectations of the sector for the next years. To accurately reflect the farmers' favorite water source, we have included information on the price and quality of each water source. Water quality (lower salinity) is crucial for achieving high yields and harvesting rates. The water sources available for farmers mainly differ chemically in salinity and nitrate content and throughout the farming year in their availability (i.e., more reclaimed wastewater is available in summer, when the high number of tourists increases the wastewater amounts). The different water sources also come with different costs, i.e., transfer, pumping, desalinating, etc.; both variables act as balancing factors in determining farmers’ preference for different water sources. Their preferences might change based on water availability and the agricultural water revenue, it is essential to note that the price and quality are relative values and can vary based on the agricultural water revenue, which depends on the total water demand and yearly gross economic benefits. This variable is endogenously influenced by the yield and the farmers' contractual agreements (sales and market CLD) for each season or year.

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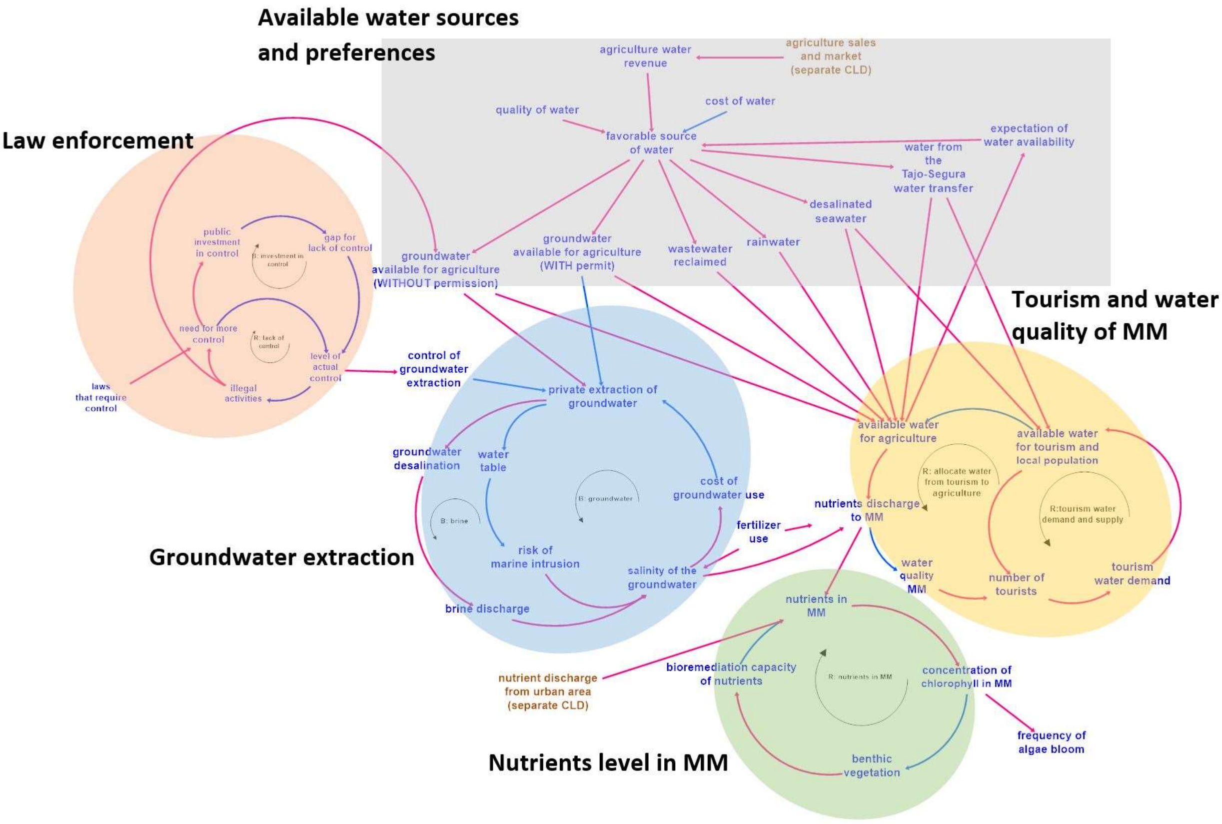

Figure 5 Water Dynamics CLD – complete overview

The farmers' expectation of available water pertains to their perception of water availability based on previous years. This variable may not necessarily reflect the real water availability each year, but it represents the farmers' perception of water availability and influences their prioritization among different water resources. Additionally, this variable captures the time delay in behavioral changes following alterations in the actual availability of water, such as the cessation of water transfer due to political decisions or climate change.

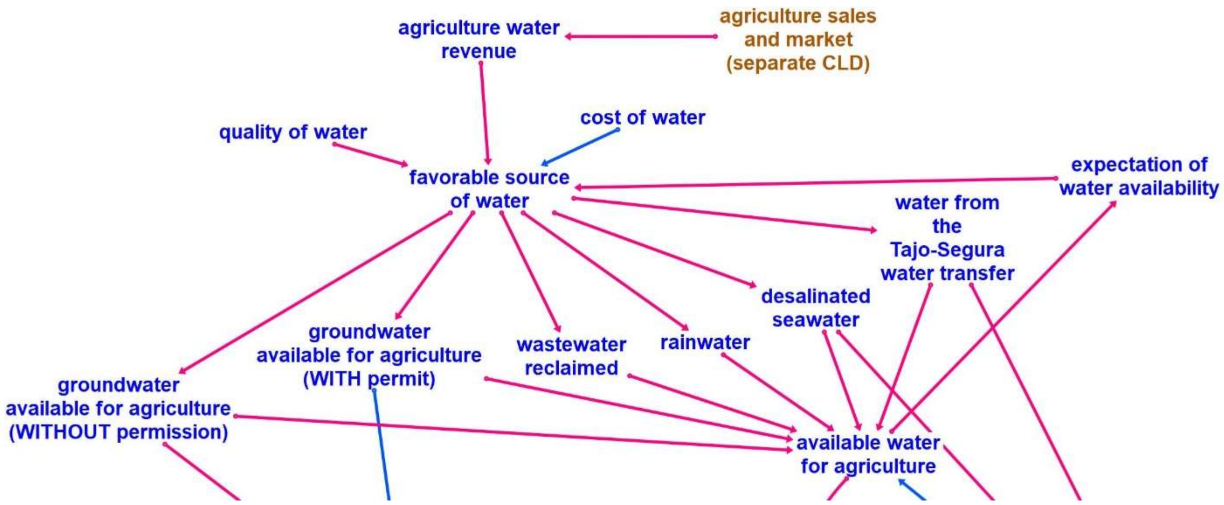

Figure 6 CLD "Water sources and preferences", details from Water dynamics CLD, grey square in Figure 5.

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Law enforcement

Within the region, the illicit utilization of groundwater has become a significant issue among the existing water resources. During the workshops and based on prior research, the knowledge holders raised ethical concerns regarding water usage in Campo de Cartagena (Fernández-García et al., 2021). The lack of systematic and regular control, inspection, and sanctioning of illegal groundwater abstraction has allowed this issue to persist as depicted in the "Law inforcement" CLD (Figure 7).

The **reinforcing loop "lack of control**" depicts how lacking control and sanctioning amplifies the space for illegal activities, particularly illegal groundwater extraction. On the other hand, the **balancing loop "investment in control"** represents a corrective mechanism that involves investment in improving law implementation, conducting frequent monitoring, and sanctioning illegal activities. This will enhance the effectiveness of policies, ultimately leading to a higher level of control over groundwater extraction and the prevention of illegal well operations.

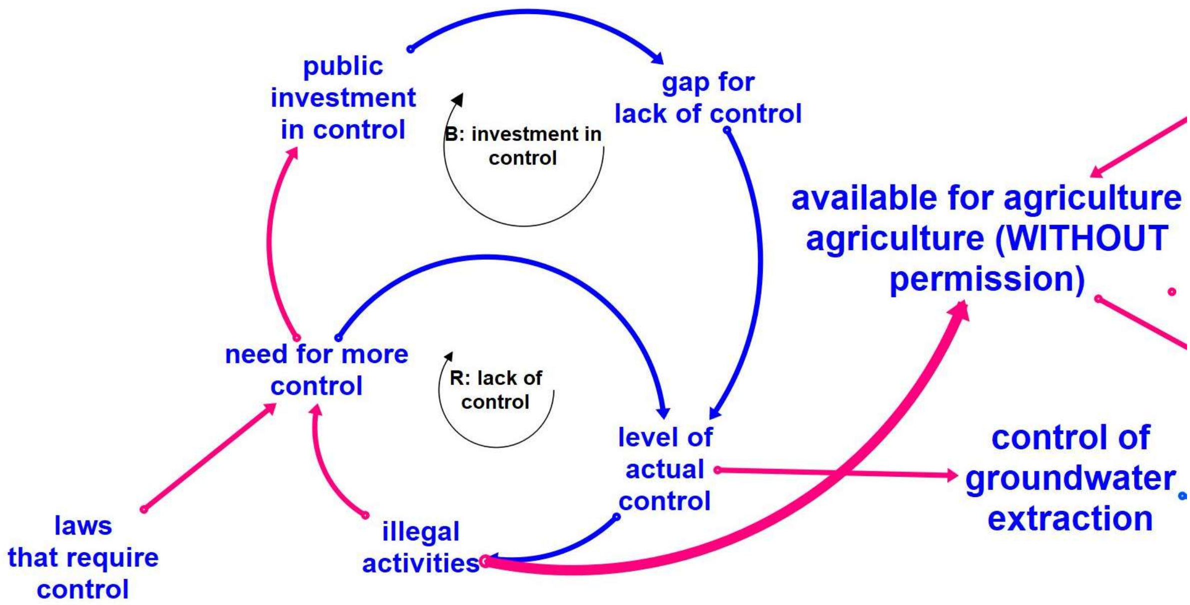

*Figure 7 CLD "Law enforcement", details from Water dynamics CLD, **orange oval** in Figure 5*

Groundwater extraction

The excessive exploitation of groundwater causes a decline in the aquifer's water level, leading to an increased risk of marine intrusion and higher salinity in the groundwater. The elevated salinity, in turn, escalates the cost of desalination. In the long run, this higher cost might reduce groundwater extraction rates. This is displayed in the "Groundwater extraction" CLD (Figure 8).

The **balancing loop "groundwater**" demonstrates how costs act as a regulating mechanism in controlling groundwater usage. However, self-regulation is activated when the aquifer level becomes critically low. Self-regulation is a mechanism that relies on the high cost associated with certain actions to serve as a deterrent and balance against further exploitation of groundwater resources. To maintain the aquifer level and ensure its sustainability, investing in a robust law enforcement system is imperative. This reinforcement mechanism plays a crucial role in governing

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and preserving optimal groundwater extraction rates, strengthening the balancing loop that regulates the overall management of groundwater resources.

On the other hand, the brine discharge generated during the desalination process contributes to an elevation in groundwater salinity. Additionally, the use of fertilizers in the agriculture sector is another factor that adds to the salinity of groundwater. The increased salinity of groundwater strengthens the **balancing loop "groundwater"** and serves as a source of nutrient discharge into the Mar Menor lagoon. This interplay is depicted in the **balancing loop "brine"**.

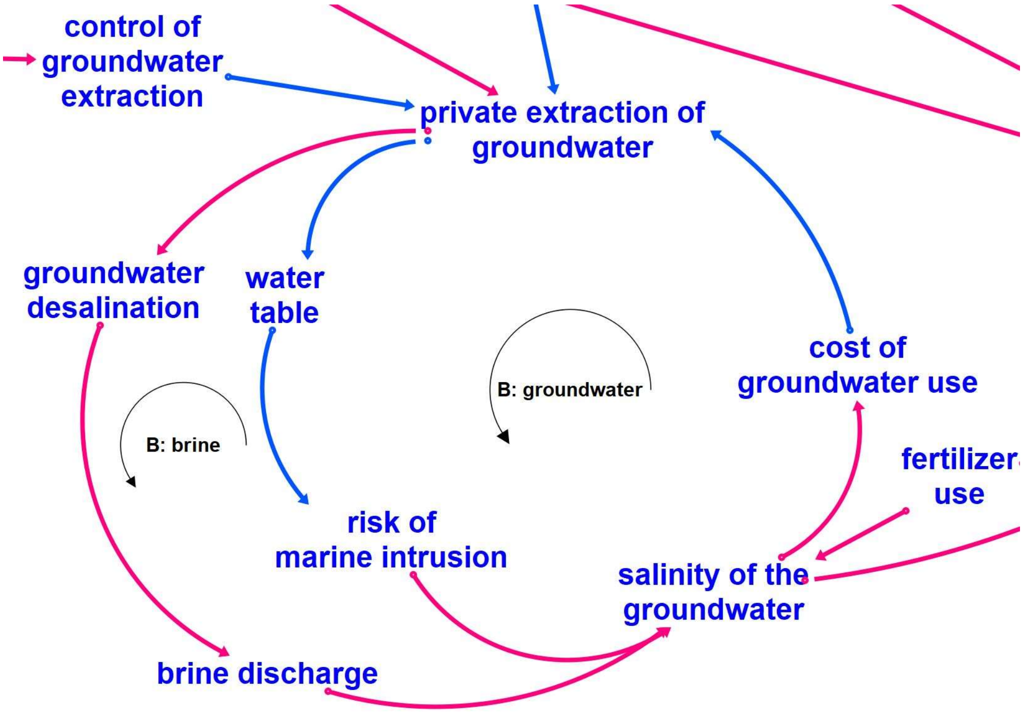

*Figure 8 CLD "Groundwater extraction", details from Water dynamics CLD, **blue oval** in Figure 5*

Tourism and water quality of Mar Menor

How tourism depends on water quality is shown in the "Tourism and water quality of the Mar Menor" CLD (Figure 9). Irrigation water (available water for agriculture) and the use of fertilizer add nutrients to the lagoon and result in a decline in water quality. The tourism industry relies heavily on the lagoon's water quality. Lower water quality leads to a decrease in the number of tourists visiting Mar Menor. This reduction in tourist numbers (**reinforcing loop "tourism water demand and supply"**) subsequently lowers the water demand of the tourism industry, resulting in less available water for tourism. Even though tourism, in comparison to agriculture, mainly uses water from the Tajo-Segura water transfer and from desalinated seawater, the reduction in tourist numbers opens discussions regarding allocating the surplus of water previously designated for tourism to the agriculture sector. This mechanism creates a vicious cycle wherein increased agricultural activity leads to even more nutrient discharge into the lagoon, ultimately resulting in a further decline in tourist numbers (**reinforcing loop "allocate water from tourism to agriculture"**).

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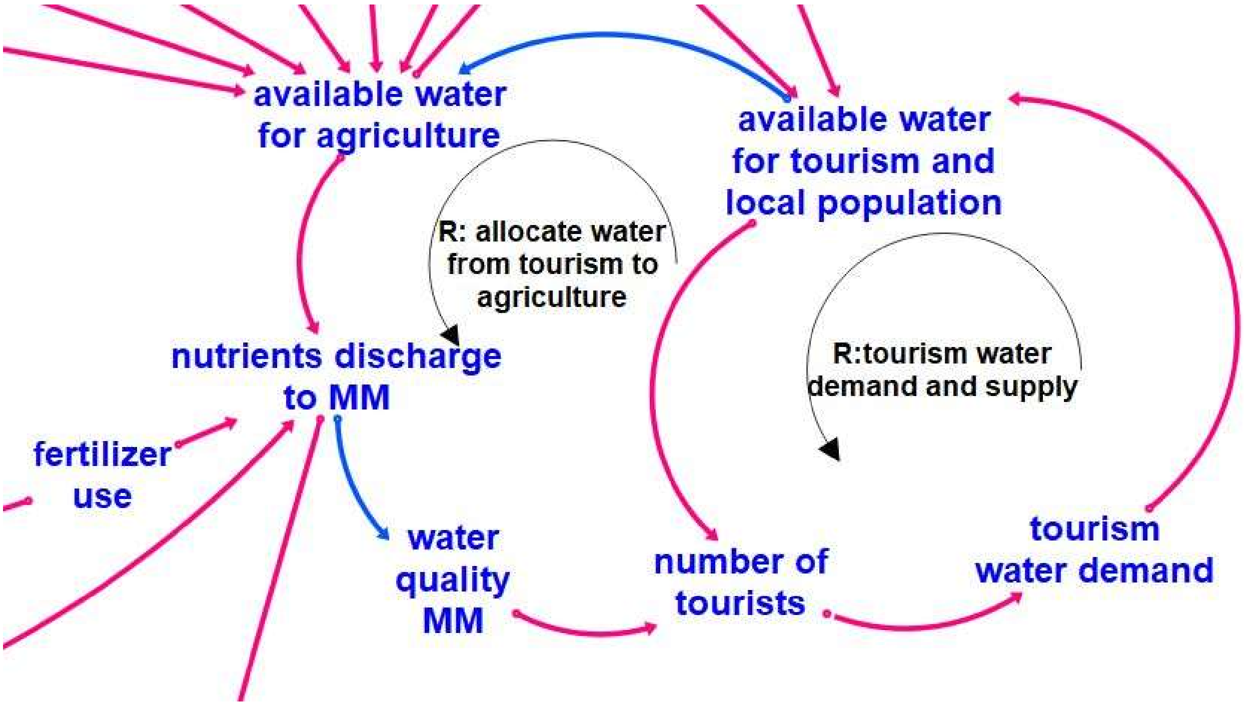

Figure 9 CLD "Tourism and water quality of Mar Menor", details from the Water dynamics CLD, yellow oval in Figure 5

Nutrients in Mar Menor

The "Nutrients in Mar Menor" CLD (Figure 10) exemplifies how nutrients discharges effect the lagoon ecosystem. The depicted feedback loops show the region's main water dynamics and how they influence the top-level **reinforcing loop "nutrients in MM.**" The nutrient in the lagoon exceeds its bioremediation capacity. This sets off a vicious cycle where increased nutrient level and diminished bioremediation capacity result in higher nutrient levels within the lagoon. The elevated nutrient levels lead to a higher concentration of chlorophyll. The frequent presence of algae blooms leads to a decline in benthic vegetation, further compromising the lagoon's bioremediation capacity. A well-executed management strategy would focus on minimizing nutrient discharge into the lagoon, restoring the lagoon's environment, and reversing the current trend of environmental degradation. A growing accumulation of nutrients in the lagoon results in its deterioration. However, appropriate management practices can reduce nutrient levels and improve the lagoon environment. This approach also benefits the lagoon's ecosystem and could support socio-economic aspects in adopting the new set of practices for this positive transformation.

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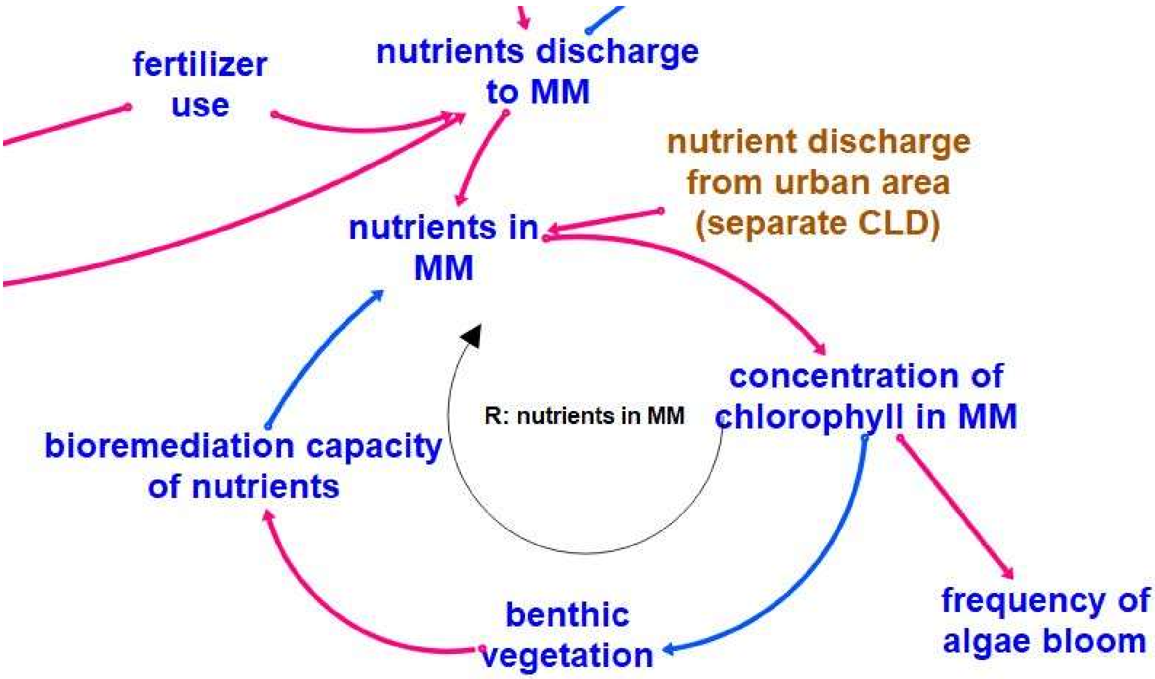

Figure 10 CLD "Nutrients in Mar Menor", details from Water dynamics CLD, green oval in Figure 5

3.4.2. Agriculture

The CLD for agriculture is very complex (Figure 11). It shows (green oval) how agricultural yield is produced based on different farm inputs (fertilizer, irrigation water, fieldwork, administrative work, technology, other input costs). However, the actual yield also depends on other conditions like soil quality and degradation or the beforehand agreed yield sales amounts with intermediaries (orange oval). The CLD also shows in a simplified version the sales of and market for agricultural products (yellow oval) with prices and product amounts as main profit determining variables and farmers, intermediaries, and supermarket chains as actors. Displayed are also how the main input factors (irrigation water, fertilizer use and intensive field work) link to national and EU policy goals of having a greener and less intensive agriculture (blue oval).

The names of the variables in Figure 11 might be difficult to read. For better readability we refer to the following figures, which provide zoomed-in sections of the CLD. The loops contained in the agricultural CLD are described in detail below, sorted after the main dynamics.

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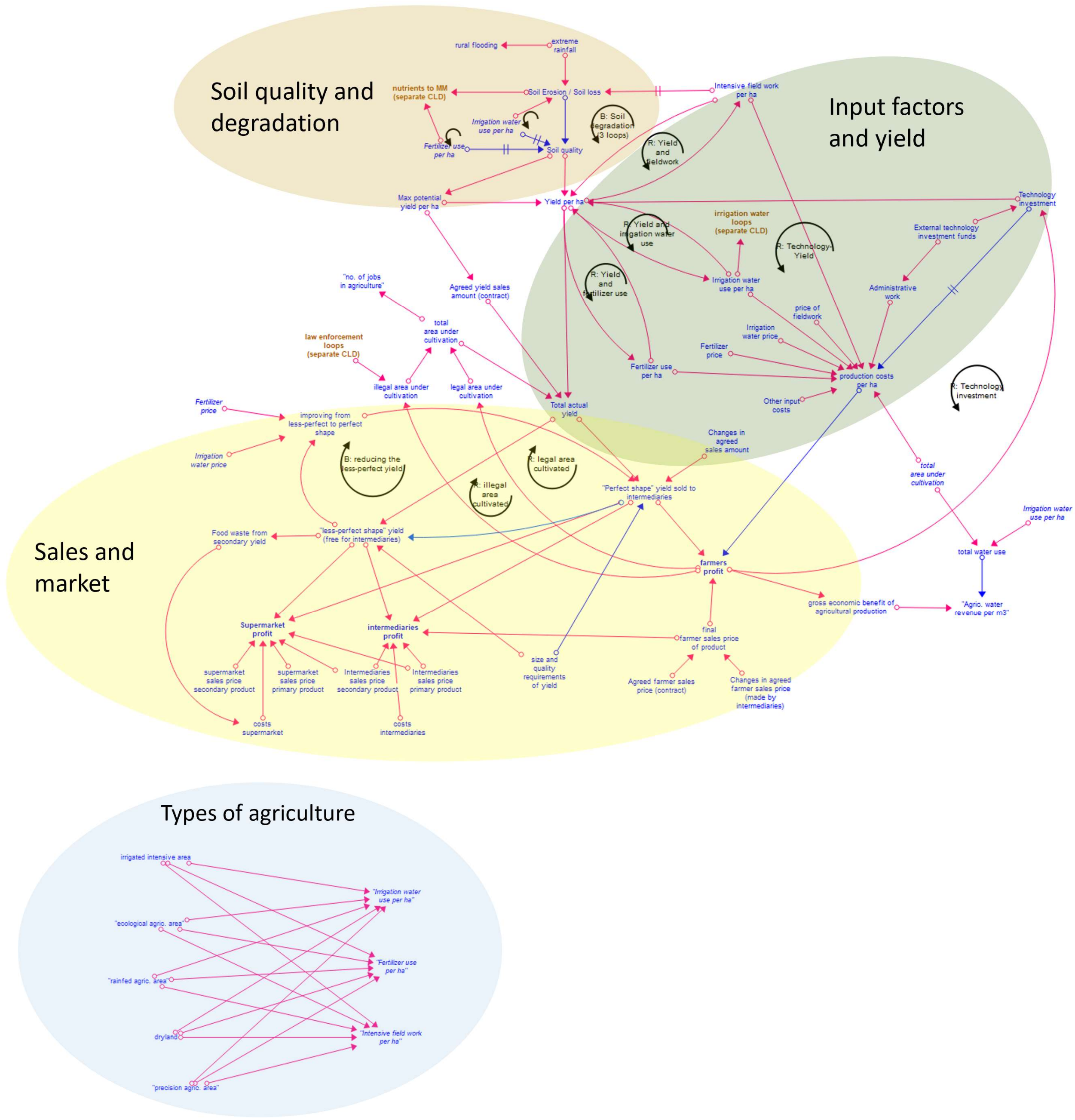

Figure 11 Agriculture CLD – complete overview

Input factors and yield

There are three very short loops related to Yield per ha (Figure 12).

Reinforcing loop: Yield and field work

The first loop describes that the more intensive field work (such as ploughing, harvesting, agrochemical application) is done, the higher is the yield per ha. To further increase the yield per hectare, even more intensive field work is needed. Of course, there is an upper limit to this.

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Reinforcing loop: Yield and irrigation water use

The second loop describes that the more irrigation water is used per ha, the higher is the yield per ha. To further increase the yield per hectare, even more irrigation water use is needed. Of course, there is an upper limit to this.

Reinforcing loop: Yield and fertilizer use

The second loop describes that the more fertilizer is used per ha, the higher is the yield per ha. To further increase the yield per hectare, even more fertilizer use is needed. Of course, there is an upper limit to this.

In addition, there are two loops, which display the role of technology investment on yield. These are:

Reinforcing loop: Technology investment

Another possibility to spend the farmers profit is investment in technology. Technology investment will over time reduce the production costs per ha. The lower the production costs per ha, the higher the farmers' profit.

Reinforcing loop: Technology – Yield

Technology investment can also lead to an increase in the yield per ha, leading to an increase in the total actual yield, to an increase in the "perfect" yield sold to intermediaries and finally to an increase in farmers' profit.

Soil quality and degradation

Related to these three loops, which increase the yield per ha on the short run, are three loops which show soil degradation as a reduction of soil quality in the long-run (Figure 12).

Balancing loop: Soil degradation (three loops)

This loop describes the downside of intensive agriculture. Over a longer time period intensive field work leads to soil erosion, especially in combination with heavy rainfall. The more soil erosion/soil loss happens, the worse gets the soil quality i.e. the capacity of the soil to sustain plant productivity. With decreasing soil quality also, the yield per hectare decreases and more intensive field work is needed to compensate for the reduced yield.

The other two loops are only indicated by small loop signs. They show similar dynamics: Too much irrigation water use per ha will lead to increased soil erosion or reduce soil quality, thus reducing the long-term yield per ha. Similarly, will too much fertilizer use per ha lead to reduced soil quality.

All three variables soil erosion, fertilizer use and irrigation water use, have a positive polarity (the more, the more) to the nutrients to MM and build a link to the top-level reinforcing loop "Nutrients in MM".

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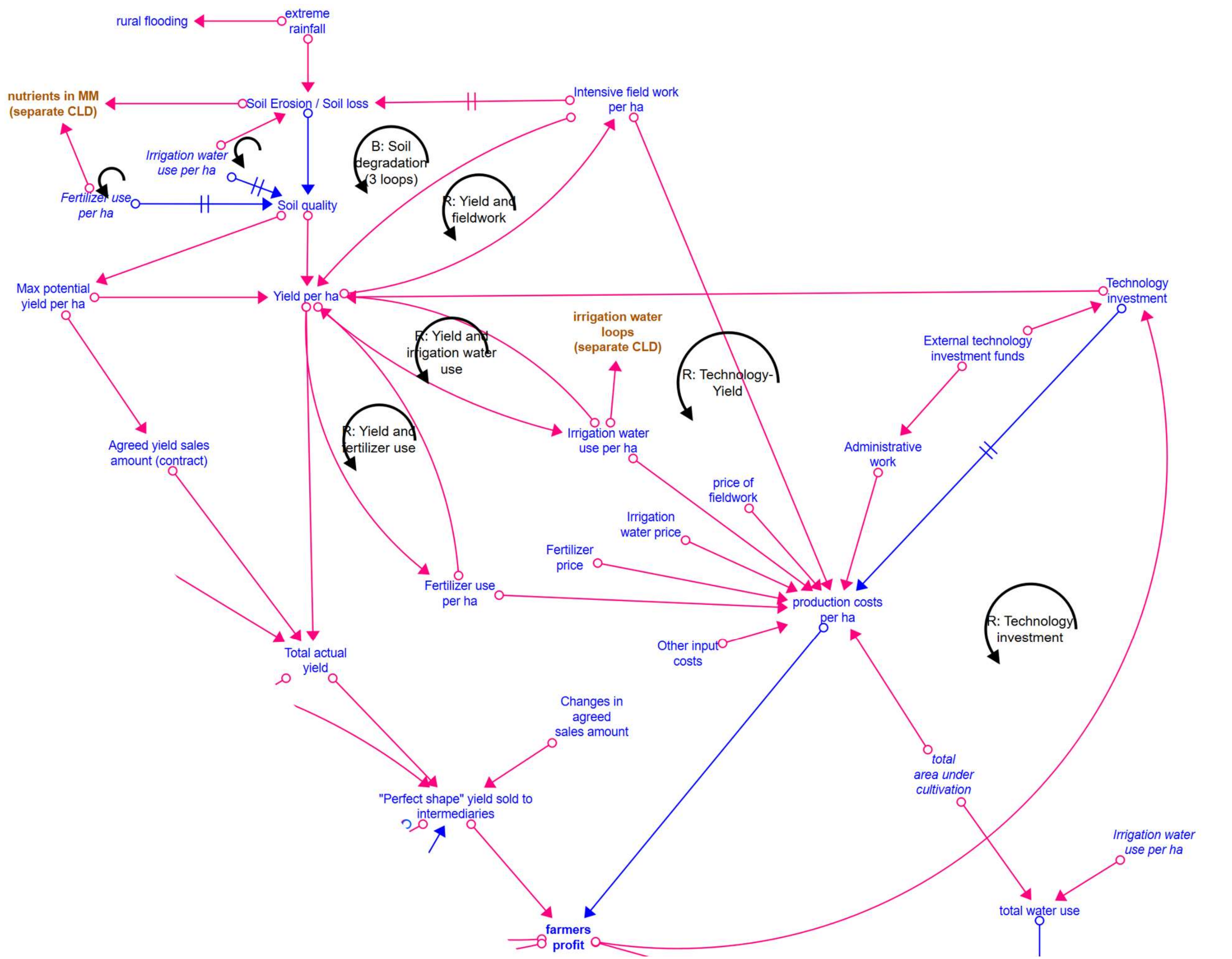

Figure 12 CLD "Soil quality and degradation" (brownish oval in Figure 11) and CLD "Input factors and yield" (green oval in Figure 11)

Types of agriculture

Fertilizer use, irrigation water use and intensity of field work, depend on what type of agriculture (intensive irrigated, rainfed, dryland, precision, ecological agriculture) is done (Figure 13). EU's common agricultural policy (CAP) aims for a greener CAP in the future to halt and reverse biodiversity loss, make agriculture contribute to climate change mitigation and enable efficient management of natural resources[1]. These dynamics are covered in the blue oval in Figure 11**Error! Reference source not found.** and detailed in Figure 13. The EU CAP also aims to improve farmers' position in the value chain and support viable farm income, dynamics, which are also covered in our CLD (see Figure 14).

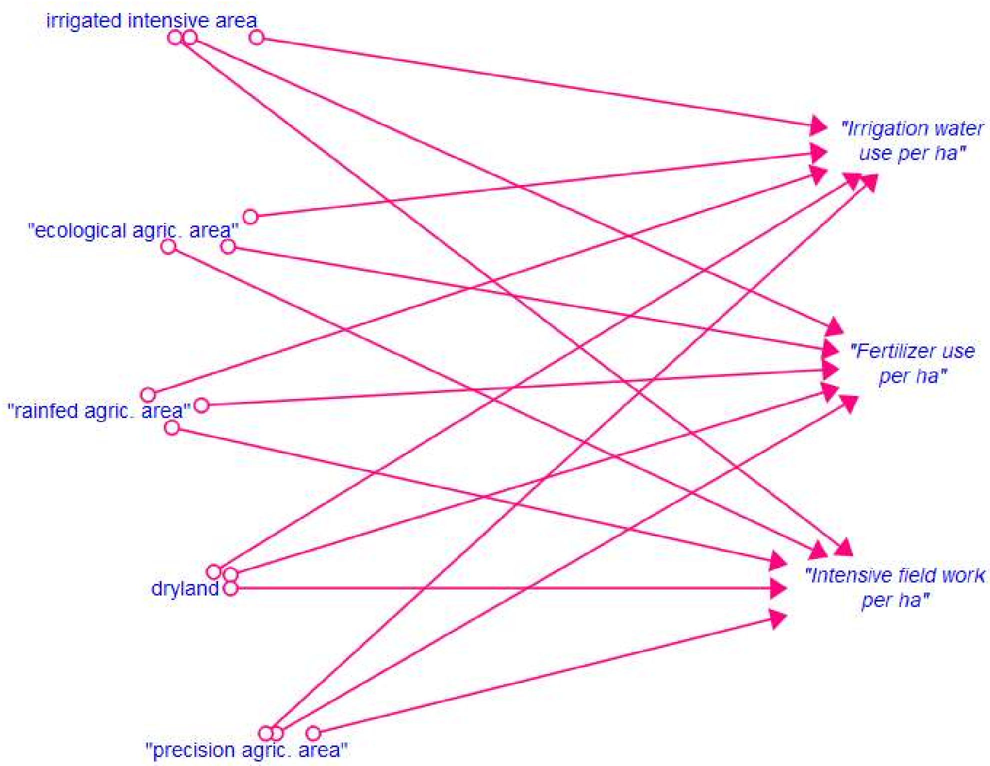

Figure 13 CLD "Types of agriculture", details from Agriculture CLD, blue oval in Figure 11

Sales and market

In the bottom of Figure 14 the dynamics of sales of agricultural products in food markets are displayed. The farmers sell their production to intermediaries, which then sell them further to supermarkets. In reality there might be several intermediaries, but we have to decided to simplify this to one layer. There are contractual agreements between farmers and intermediaries, which determine the farmer sales prices, but intermediaries can change them. There are also requirements on the size and quality (shape) of agricultural prducts. Products, which do not fulfill these requirements (less-perfect shaped yield), are not payed by the intermediaries, but as they are mixed with the "perfect shaped" yield they are together with it transported to the storehouses. According

[1] https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cap-2023-27/key-policy-objectives-cap-2023-27_en

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to our stakeholders this less-perfect shaped yield is – at least partly – also sold, but without generating a revenue for the farmers, only for the intermediaries and producers.

Reinforcing loop: legal area cultivated

The total area under cultivation determines (together with other factors like yield per ha and the agreed yield sales amount) the total actual yield in a year. The higher the total actual yield the higher is also the amount of “perfect” yield sold to intermediaries, but also the “less-perfect” yield, which is taken by the intermediaries, but not paid. The higher the “perfect” yield sold to intermediaries the higher is the farmer’s profit. The more profit farmers make, the more money they have to invest in an expansion of their cultivation. Here the loop splits in 2 loops – the first where higher farmers profit leads to an increase in the legal area under cultivation and the second (**Reinforcing loop: illegal area cultivated**) where higher farmer profits lead to more illegal area under cultivation. The latter probably happened more in the past and is reduced by actual governmental control. Both legal and illegal area under cultivation make up for the total area under cultivation.

Balancing loop: reducing the “less-perfect” yield

When farmers achieve a “less-perfect shaped” yield, their profit decreases as they do not receive payment for this part of their yield from the intermediaries. As a result, farmers attempt to minimize the amount of these less-perfect products by increasing the use of fertilizers and irrigation water (improving from less-perfect to perfect shape). The higher the fertilizer and irrigation water usage, the greater the quantity of "perfect shaped" yield sold to intermediaries and consequently the higher the farmer’s profit.

Throughout this process, farmers constantly assess whether the additional cost of fertilizer and water use is a worthwhile investment based on the expected revenue generated from the extra sales. They carefully calculate the potential return on investment to determine if the increased fertilizer and irrigation water expense are justified.

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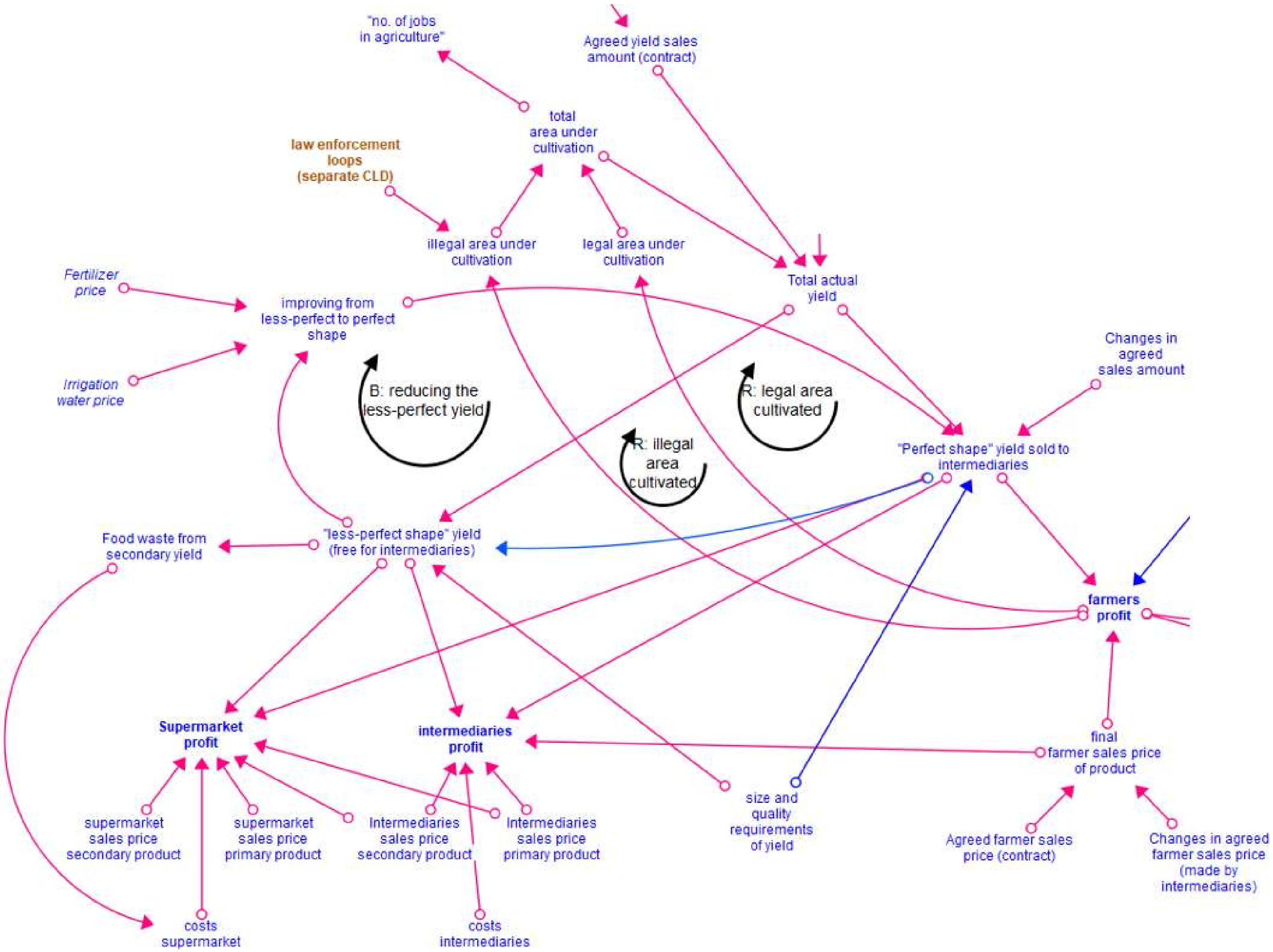

Figure 14 CLD "Sales and market", details from Agricultural CLD, yellow oval in Figure 11

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3.4.3. Livestock

The CLD for livestock (Figure 15) describes the dynamics of how livestock production poses the risk of slurry leakage to the environment, with nutrients from the slurry being introduced into the Mar Menor. Livestock farming makes an important contribution to the local economy but can also result in high amounts of nutrients being released into the Mar Menor, in the case that slurry is not properly managed or illegally dumped. The legal requirements for slurry treatment are becoming stricter, posing a significant economic risk to the livestock farmers. Currently the standard treatment of slurry is to store and dry it on open slurry storage basins, alternative solutions are central collection and treatment of slurry in a large treatment plant (with the downside high transport requirement, which is expensive and goes along with climate gas emissions) or decentralized smaller biogas plants. Livestock slurry has also the potential to be transformed into compost, which can replace part of the mineral fertilizer used in agriculture. However, compost based on slurry of different animals does vary in its composition and nutrient content, which makes application by farmers more challenging.

The livestock CLD consists of six loops, which are described in detail below. We start in the middle.

Reinforcing loop: Livestock density and livestock profit

The higher the number of livestock, the higher the livestock profit and the higher livestock profit, the more money farmers have to invest in new livestock.

Balancing loop: Risk of slurry leakage and fines

With a higher number of livestock, the amount of slurry increases. This again increases the risk of slurry leakage to the environment especially in case of extreme rainfall and it is linked to the top-level loop “Nutrients in Mar Menor”. With the risk of slurry leakage, the risk of fines for leakages also increases. The payment of fines will decrease the livestock profit. The risk of fines is determined by the actual level of government control i.e., there are no fines without previous control. This variable links to the top-level loop “law enforcement”.

In the workshops, participants mentioned that the current fines are not high enough to motivate farmers for proper slurry management or to deter them from leading slurry into the environment. Some livestock farmers accept the risk of getting fined and compensate for the fine by just increasing the density of livestock and increasing the livestock profit.

Reinforcing loop: Slurry technology investment

Instead of increasing livestock numbers, the livestock profit can also be used for investment in slurry treatment technology. This will then reduce the risk of slurry leakage, the risk of fines and finally increase the livestock profit.

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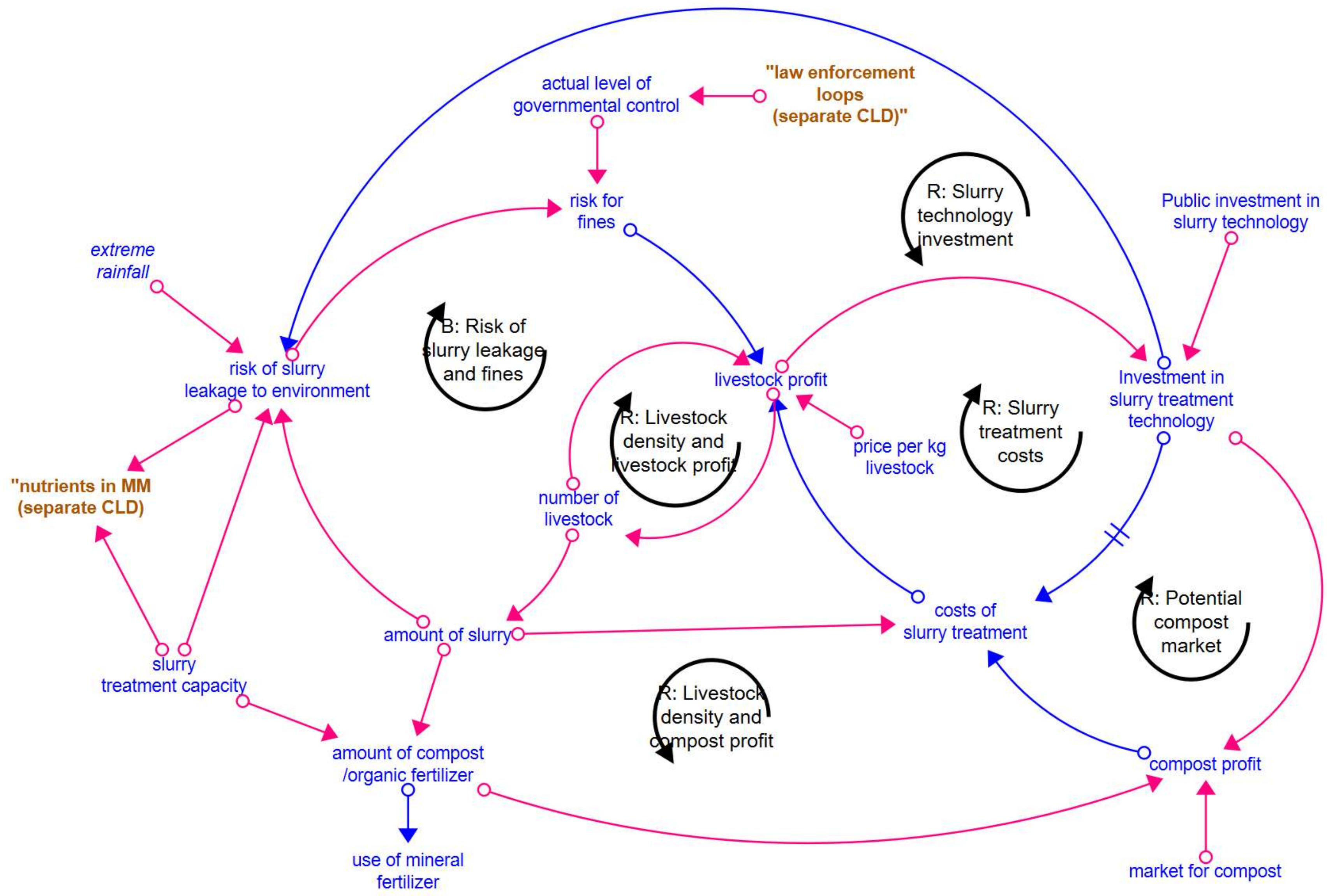

Figure 15 Livestock CLD

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Reinforcing loop: Slurry treatment costs

An investment in slurry treatment technology will over time also reduce the costs of slurry treatment and thus increase the livestock profit. However, this depends on the type of slurry treatment technology chosen. In the beginning the investment costs for decentralized biogas plants will be high, but then reduce over time, whereas for centralized solutions, the transport costs will probably remain the same.

Reinforcing loop: Potential compost market

If the slurry treatment technology allows to produce compost, an investment in slurry treatment technology could lead to a profit from compost sales (compost profit), which would reduce the overall costs of slurry treatment and thus increase the livestock profit.

Reinforcing loop: Livestock density and compost profit

The previously described loop gets reinforced when the livestock profit is invested in higher numbers of livestock, which generates large amounts of slurry and thus larger amounts of compost/organic fertilizer, which again increases the compost profit. A precondition for the compost dynamics would be that a market for local compost exists and that the necessary transport infrastructure is available. This would then allow to replace mineral fertilizer by local compost. Another issue mentioned in the workshops was that quality controls of compost must also be in place to assure that farmers receive high quality compost.

3.4.4. Tourism and urban development

Tourism is of high economic importance for the Mar Menor region. Tourism development went hand in hand with urban development. While in the past due to insufficient wastewater management, urban wastewater also contributed to increasing nutrient levels in the Mar Menor, this problem was largely solved by increasing wastewater treatment capacity. However, during extreme rainfall events, still uncleaned wastewater mixed with rainwater can enter the lagoon. The tourism sector is one of the sectors on which the environmental deterioration of the lagoon has the largest impact. When the reputation of the Mar Menor as an attractive touristic destination drops, tourist numbers decline, and housing prices are reduced. Especially for the west-side of the lagoon, to attract tourist good water quality and environmental conditions of the Mar Menor are of the uttermost importance. The tourism and urban development CLD (Figure 16) consist of 5 loops and the top-level loop “Nutrients in Mar Menor”.

Reinforcing loop: Nutrients in Mar Menor

Through many years of nutrient influx, the nutrient level in the Mar Menor continuously increased. This caused higher concentration of chlorophyll, and also more frequent algae blooms. This resulted in reduced benthic vegetation (vegetation at the bottom of the lagoon), which reduced the lagoon ecosystems’ capacity to bioremediate nutrients and contaminants. Over time, this leads to an even greater accumulation of nutrients in the lagoon.

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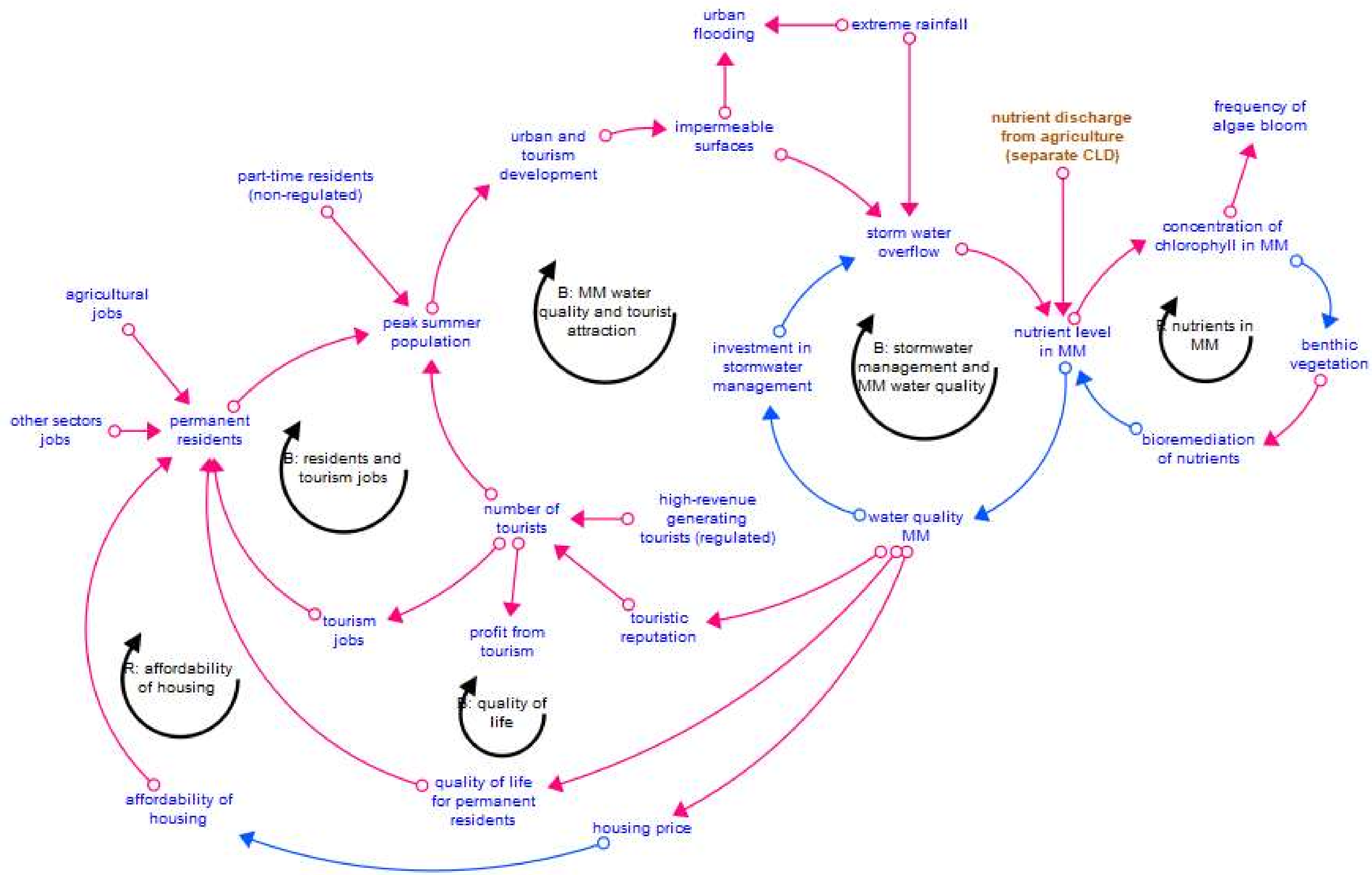

Figure 16 Tourism and urban development CLD

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Balancing loop: Stormwater management and MM water quality
More frequent stormwater overflows will lead to a higher nutrient level to the Mar Menor and a reduction in water quality. The reduced water quality leads to increased investment in stormwater management, which in the long run will result in less stormwater overflows.

Balancing loop: Residents and tourism jobs
The higher the number of tourists the more tourism jobs are created and the more permanent residents will move to the MM region, which then again will increase the peak summer population. The rest of the cycle is described in the “Balancing loop: MM water quality and tourist attraction”.

Balancing loop: Quality of life
Bad water quality in the MM leads to reduced quality of life for permanent residents. On the long run this may result in permanent residents leaving the Mar Menor, thus reducing the peak summer population. The rest of the cycle is described in the “Balancing loop: MM water quality and tourist attraction”.

Balancing loop: Affordability of housing
Reduced water quality in the MM results in a reduction of housing prices, which makes housing more affordable (affordability of housing) and thus will attract more permanent residents and increase the peak summer population. The rest of the cycle is described in the “Balancing loop: MM water quality and tourist attraction”.

3.4.5. Fisheries

Fisheries are closely connected to the traditions and culture of the Mar Menor. However, its economic importance has diminished over time due to the excessive exploitation of fish stocks in the MM. This decline has been exacerbated by multiple incidents of fish kills caused by the excessive discharge of nutrients in the lagoon. In recent years, the fish stock recovery has been slowed down by biodiversity loss and frequent algae blooms. Dynamics in fisheries are depicted in the “Fisheries” CLD (Figure 17).

During the workshops with the fisheries representatives, the significant driving force behind the depletion of fish stocks was consistently mentioned: overfishing. The need for systematic management plans and control of catches was emphasized. The participants expressed frustration about the chaotic state of illegal fishing and the lack of measures to monitor the catch per boat regularly. This led to a short-term mindset focused on immediate income rather than long-term sustainability.

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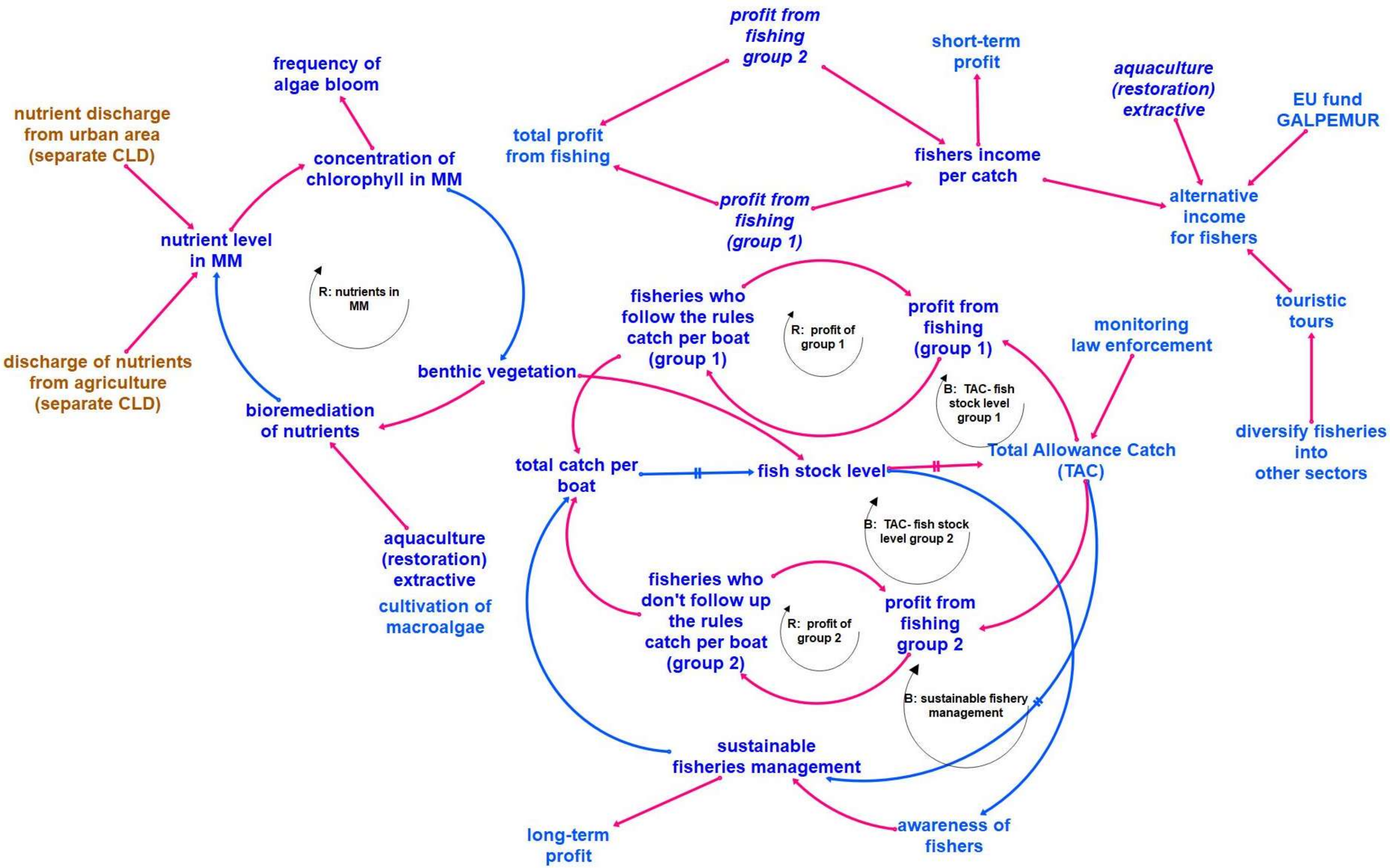

Figure 17 Fisheries CLD

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These dynamics described in the fisheries workshop are known in economics and environmental sciences as the “tragedy of the commons.” It refers to a situation where multiple individuals (i.e., fishermen) deplete or degrade a shared resource (i.e., fish stocks) to generate a short-term benefit for themselves, despite everyone's long-term interest in preserving the resource. It highlights the tension between individual self-interest and the well-being of a group or society. The concept was popularized by an essay titled "Tragedy of the Commons" written by Garrett Hardin and is a famous archetype in system dynamics modelling (Hardin, 1968). Hardin used the example of common grazing land, or "the commons," which was available for use by all members of a community. Individuals have little incentive to conserve or protect common resources like fish stocks for the long term. Instead, they focus on maximizing their own short-term gains, which can ultimately lead to a collective loss of the resource. Therefore, systematic management and controls of catches are needed to avoid the depletion of common resources.

The “tragedy of commons” for the fish resource in Mar Menor is displayed in the lower part of the CLD. It consists of four primary feedback loops, with two reinforcing loops (**R: profit of group 1** and **R: profit of group 2**), demonstrating the catch per boat for two fisheries. Group 1 adheres to the rules and adopts a long-term sustainable vision, while Group 2 disregards the rules and prioritizes short-term benefits. These loops also depict the corresponding profit gained from fishing activities. Additionally, two balancing loops (**B: TAC-fish tock level group 1** and **B: TAC-fish tock level group 2**) represent the impact of the fishing practices employed by Group 1 and Group 2 on the common fish stock. These loops are activated only when the fish stock in the Mar Menor reaches its environmental threshold, as indicated by the delay sign. The depletion of the shared fish stock is a source of frustration for Group 1, as it is caused by Group 2 exploiting the lack of systematic control in the system regarding the total allowance catch (TAC).

Balancing loop: Sustainable fishery management

This balancing loop depicts a sustainable approach to fisheries management that prioritizes long-term profitability. The proposed strategy involves implementing monitoring and enforcement measures on the total allowance catch (TAC) to mitigate the risk of overfishing by Group 2. Increased monitoring efforts lead to a reduction in the TAC, which in turn promotes more sustainable management practices. By adopting these sustainable practices, the fishing industry in Mar Menor is more likely to achieve long-term profitability.

Furthermore, implementing sustainable management practices results in a decrease in the total catch per boat. Over time, this contributes to the regeneration of the fish stock and leads to a higher overall fish stock level. As the fish stock level increases, the need for strict control and monitoring measures over the total allowance catch diminishes. It is important to acknowledge that the regeneration of the fish stock is a gradual and time-intensive process that can only be achieved slowly. In other words, there is no immediate solution. Within the workshop, participants engaged in discussions about potential parallel actions that could support the economic well-being of the fishers. One such action is the diversification of income sources, wherein fishing boats could be

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utilized for tourism purposes, offering tours in the lagoon. Additionally, participants explored the idea of engaging in aquaculture activities aimed at the environmental restoration of the lagoon. These parallel actions have the potential to provide alternative economic opportunities for the fishing sector.

Reinforcing loop: Nutrients in Mar Menor (MM)

The other important factor which plays a role in reducing the fish stock level is the top-level system illustrating the causal relationship between nutrient inflow from agriculture and urban areas to the lagoon. It highlights the impact of nutrient inputs on the lagoon and how it affects the overall ecosystem..Through many years of influx of nutrients (and other contaminants), the Mar Menor's nutrient level increased. This caused higher chlorophyll concentrations, and algae blooms occurred more frequently. This results in reduced benthic vegetation (vegetation at the bottom of the lagoon), which has a negative impact on the biodiversity and fish stock level and reduces the lagoon ecosystems' capacity to bioremediate nutrients and contaminants. Over time, this leads to an even greater accumulation of nutrients in the lagoon.

5. Discussion of results

In line with the SMARTLAGOON's main goal – i.e. *to build a systemic understanding of the socio-environmental interrelationships that affect Mar Menor coastal lagoon and its ecosystem, and to predict the socio-environmental evolution in this highly anthropized coastal lagoon, while increasing local and citywide awareness on the socio- environmental impacts, as well as the social and economic costs to the local community* – a temporary forum of selected stakeholders has been set within WP4. Specifically, this temporary forum took the form of a group model building -GMB- workshop series.

Given that the current ecological status of the Mar Menor is a multi-faceted problem with implications for all socio-economic sectors and governance levels (from local, to regional and national), the SMARTLAGOON GMB has engaged with stakeholders from government agencies, NGOs, scientific experts, the agriculture sector, the fishing industry, and tourism over a series of workshops to collaboratively develop a simulation model that represents the coastal lagoon system's complex socio-ecological and economic dynamics. Through the GMB sessions held, stakeholders shared their perspectives and knowledge, identified key variables and relationships, and developed a shared understanding of the system's behaviour and dynamics that address the challenges facing the Mar Menor lagoon.

As a result, 7 causal loop diagrams have been developed, of which 2 top-level ones focusing on "Nutrients in Mar Menor" (Figure 3) and "Law enforcement" (Figure 4), and 5 sectoral CLDs depicting water dynamics (Figure 5), agriculture (Figure 11), livestock (Figure 15), tourism and quality of water (Figure 16) and fisheries (Figure 17).

The top-level "Law enforcement" CLD emphasizes the lack of systematic enforcement of existing laws, regulations and tools, as well as the need for authorities to exert better control and reinforce environmental laws and regulations. Current practices reported by stakeholders in all socio-

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economic sectors investigated proved these laws, regulations and tools are not working properly and this significantly contributed to the current anthropization of the Mar Menor lagoon area. This result is fully aligned with other research studies (see, among others (Garcia-Ayllon, 2018; Zuluaga-Guerra et al., 2023) as well as the European Parliament Committee on Petitions Mission Report (EP, 2022).

The top-level "Nutrient in Mar Menor" CLD serves as an environmental control loop which allows assessing how socio-economic subsystem changes will affect the lagoon ecosystem. This CLD points out that successful management plans and interventions schemes will be those that result in reducing nutrients discharge into the lagoon while supporting socio-economic activities that contribute to the restoration of the lagoon ecosystem. While the "Nutrient in Mar Menor" loop captures the main dynamics in the lagoon ecosystem in this study, it is important to note that it is a simplified representation of the catchment processes and complex dynamics in the lagoon ecosystem, keeping in mind that the main focus of the SD model is to capture the socio-economic-cultural dynamics that have led to the environmental degradation of the lagoon ecosystem. To this end, some of the variables pertaining to this loop (corresponding sub-system) will be treated as exogenous ones, with variables initialization and behaviour over time building on the results of the SWAT and QWET models developed in WP2.

Our 5 sectoral CLDs reflect the main socio-economic activities in the Mar Menor area including agriculture, livestock farming, tourism and urban development, fisheries, and how these activities exert environmental pressure on the lagoon, but also how the economic activities are impacted by the ecological status of the lagoon ecosystem. Water plays a fundamental role for all the businesses in the area, and any changes in the actual availability of the water (e.g. cessation of water transfer due to political decisions, extreme weather conditions – drought, climate change effects, etc.) can cause significant socio-economic impacts given the imbalance in the area's hydrology. Perceptions of water availability together with associated costs for different water sources determine farmers' preference for a water source against another. These perceptions are subject to change due to alterations in the actual availability of water.
Furthermore, as reported by the stakeholders during the workshops, within the region, the illegal use of groundwater has become a significant issue of water resources, and persists given the lack of systematic inspections and sanctioning of those not complying with the regulations. This is in accordance also with the results of a recent study (Zuluaga-Guerra et al., 2023) which shows that the insufficient use of command-and-control policies (e.g. sanctions) leads to a situation, in which the policy does not have the intended effect i.e., the reduction of illegally irrigated area.

The CLD depicting the agriculture sector, developed together with the stakeholders, turned out to be very complex, and illustrates the multiple ties agricultural sector has with other socio-economic activities in the area. EU's Common Agricultural Policy (CAP) aims for a greener CAP in the future to halve and reverse biodiversity loss, ensure that agriculture contributes to climate change mitigation and enables efficient management of natural resources. These dynamics are covered in Figure 11

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and further detailed in Figure 12. The EU CAP also aims to improve farmers' position in the value chain and support viable farm income, dynamics, which are also covered in our CLD (see Figure 14). When it comes to the livestock farming, stakeholders stressed it makes an important contribution to local economy but can also generate high amounts of nutrients being released into the lagoon if slurry is not adequately managed. The legal requirements for slurry treatment are becoming stricter, posing a significant economic risk to the livestock farmers. Livestock slurry has the potential to be transformed into compost, replacing part of the mineral fertilizer used in agriculture. However, compost based on slurry of different animals does vary in its composition and nutrient content, which makes its application more challenging. Thus, given the identified elements of the livestock farming CLD (Figure 15) we aim at investigating the consequences of livestock farming on nutrient discharge into the lagoon, and at assessing how price associated with various environmentally friendly options for slurry management influence farmers use as part of adoption of more sustainable agricultural practices.

There are other researchers, which have also used a system-dynamics approach for the case of the Mar Menor, but with slightly different focus. In the EU-project COASTAL - Collaborative Land-Sea Integration Platform[2] the aim was to develop business roadmaps and policy solutions for enhancing coastal-rural synergies in different European regions, one of them the Mar Menor region including the Campo de Cartegena. The SD-model developed for the Mar Menor region in COASTAL contains 7 sub-models (Karageorgis et al., 2021): Agricultural water balance, Agricultural nutrients balance, Sectorial development and economic profit, Mar Menor degradation, Coastal-rural recreation potential, Social awareness and governance, Sustainable land management practices. It covers similar dynamics than the CLDs described in this deliverable. Main differences are:

- COASTAL considers renewable energy facilities in form of photovoltaic panels as an additional income and job generation option, but they do not consider the impact of horizontally installed photovoltaic panels on runoff dynamics.
- The water and nutrient balance are modelled with a large degree of details – although not taking into account spatial dynamics as they can be modelled by other models applied in WP 2 of the SMARTLAGOON project. However, nutrient inputs to the Mar Menor from livestock activities are not considered.

Zuluaga-Guerra et al. (2023) developed a SD model, which covers the socio-ecological dynamics of the Segura River basin, of which the Mar Menor is a part of. Beside environmental dynamics, which lead aquifer overexploitation, nitrates in groundwater, loss of drylands and agro-natural areas and salinization of the Segura River, it includes two interesting loop dynamics, which influence each other: A balancing loop that shows how the legalization of illegally irrigated areas increases the option for the regulating agency to sanction irrigated areas, but due to the rare use of this sanctioning option, its effect on the reduction of illegal irrigated areas is very limited. What mainly drives the expansion of illegally irrigated areas is a reinforcing loop linked to that balancing loop, which describes how the increase in irrigated area (legal, newly legalized, and illegal area), raises

[2] https://h2020-coastal.eu/

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farmers expectations that it is possible to receive even more water from the Tagus-Segura transfer and be able to irrigate more land. This is a very interesting dynamic, because it shows that water from the Tagus Segura transfer is not considered as a limited resource by the farmers in the area. In the SMARTLAGOON workshops we saw similar indications, even though they were not limited to water from the Tagus-Segura transfer but encompassed all viable water sources and mainly groundwater.
What the SD model of Zuluaga-Guerra et al. (2023) also shows is that the insufficient use of command-and-control policies (in this case sanctions) leads to a situation, in which the policy does not have the intended effect i.e., the reduction of illegally irrigated area. SMARTLAGOON covers similar dynamics in our top-level “law enforcement” CLD (Figure 4).

In comparison to existing SD models of Zuluaga-Guerra et al. (2023) and as developed in the COASTAL model, our research team identified also agricultural sales and market dynamics as important drivers of irrigation agriculture development and policy resistance within the system. As far as sufficient data is available these underlying dynamics will be included in our SD model. Furthermore, we will examine the impact of farmers' perceptions regarding available water for irrigation farming and how their expectations affect the delay in policy implementation dynamics. Moreover, we explore the consequences of livestock farming on nutrient discharge into Mar Menor and evaluate the implications of various environmentally friendly options for managing slurry. Tourism and fisheries are of high economic and cultural importance and are the sectors, which are most affected by the deterioration of the lagoon. These dynamics will also be incorporated in our SD model.

6. Conclusions and way forward

The CLDs presented in this deliverable are based on the discussions with stakeholders in two rounds of sectoral workshop and are amended with other information sources like reports or scientific papers. The research team plans at least one more round of CLD revision with the stakeholders. This will be done by asking them for written feedback, interviews and through discussions in the third set of workshops (scheduled for autumn 2023). In parallel to the revision process the research team will start converting the CLDs in stock and flow diagram (SFDs), i.e., populate the CLD with data and equations. We foresee that this will lead to some changes on the CLDs, primarily due to availabiltiy or lack of data. In addition, we will discuss with the SMARTLAGOON consortium on how to couple the SD model with the SWAT and QWET models developed in WP2.

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8. Appendix

Slides introducing exercises during workshop 1

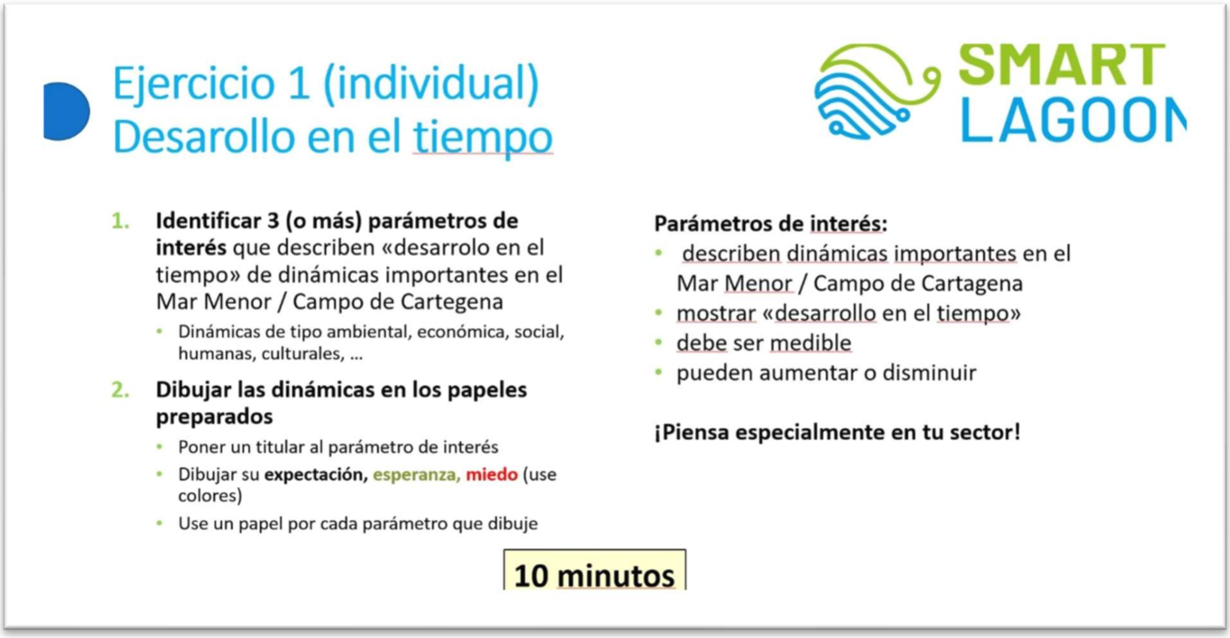

Figure 18 Excercise 1: Drafting individual BOTG of variables driving the problem

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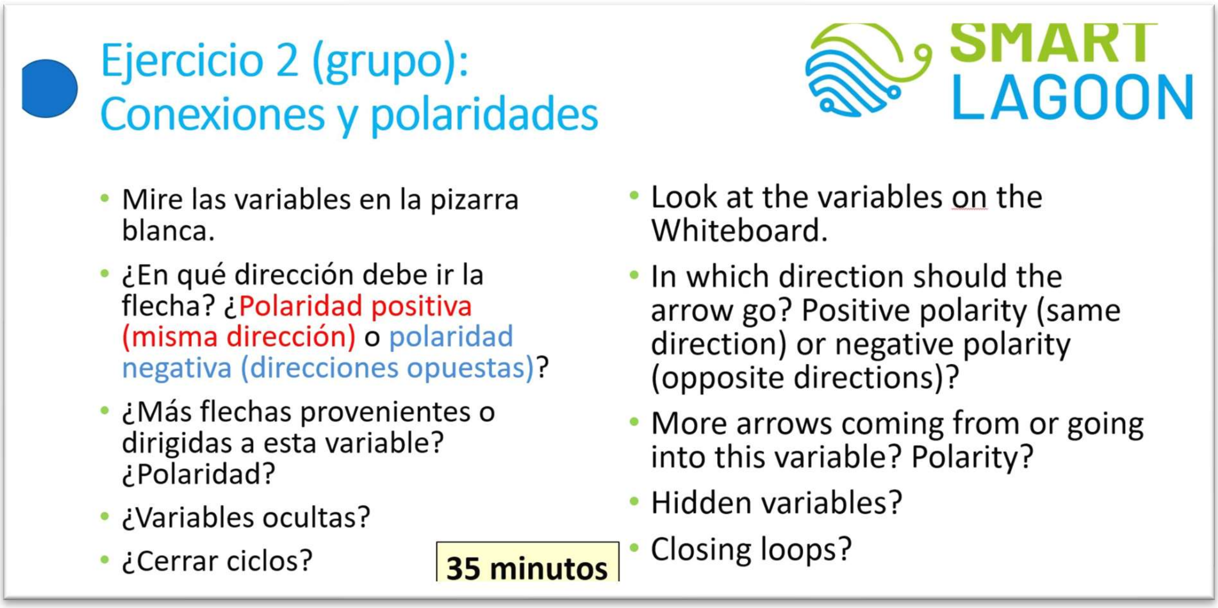

Figure 19 Exercise 2: Connecting the variables and polarity identification

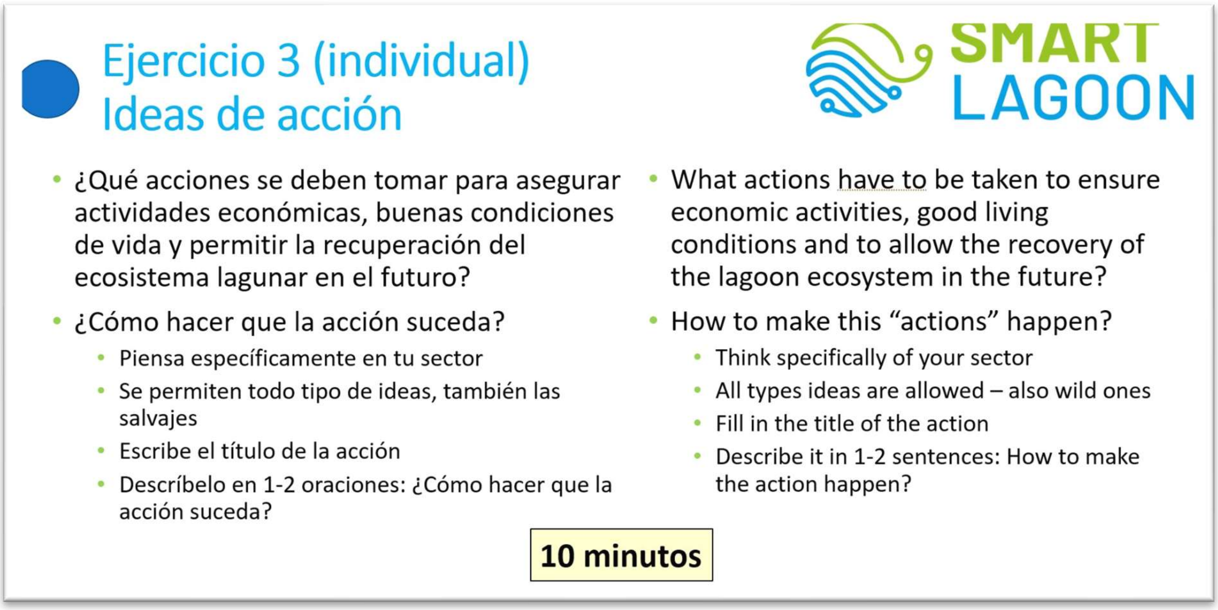

Figure 20 Exercise 3: Generating potential actions to shift the system

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End of Deliverable 4.3

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