COASTAL
Collaborative Land-Sea Integration Platform

Deliverable D12 Model Scope and Feedback Structure

REVISION

WP 4, T 4.1
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CO	Confidential, restricted under conditions set out in Model Grant Agreement	
CI	Classified information as referred to in Commission Decision 2001/844/EC)	
Deliverable type		
R	Document, report	X
DEM	Demonstrator, pilot, prototype	
DEC	Web sites, patent fillings, videos, etc.	
OTHER	Software, technical diagram, etc.	

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Executive summary

The responsibility for developing, validating and applying System Dynamics (SD) models for land-sea interactions lies with Work package 4 (Systems Modelling). These models will be used to formulate and support strategic business and policy analyses aimed at improving coastal-rural synergies. The objective is to provide tools and demonstration examples for the Multi-Actor Labs (MALs). The interaction of reinforcing and balancing feedback structures with non-linear and delayed system responses results in complex dynamics with the possibility of counterintuitive responses to business and policy decisions. Holistic combination of systems-theoretical principles, scientific knowledge, and the experience and insights of business and governance representatives, referred to as 'local knowledge' will help identify the important system transitions, compare business and policy decisions, and evaluate the social-environmental resilience of the system. The outcomes can be used to formulate innovative, evidence-based management strategies for improving coastal and rural development. A separate SD model of the coastal-rural interactions will be developed for each case study, starting from the qualitative understanding of these interactions developed in WP1. Nevertheless, it is expected that many of the interactions are similar in nature which makes the exchange of tools, models, results and expertise between the MALs extremely important. As much as possible, use will be made of existing scientific models and readily available data, collected for each case study in WP2. These will be translated into graphical 'look-up' functions quantifying the interaction between specific systems variables. The activities of WP4 start with a delineation of the model scope for each case study, and translation of the mental models resulting from the sector workshops (Task 1.3) into causal loop diagrams representing the system feedback mechanisms in a qualitative way. Together, the boundaries of the model, policy interventions and business levers, and general and case-specific indicators define the qualitative architecture of the system for the case studies. This will help focus the data and model collection activities in WP2 (Task 2.1).

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Abbreviations and acronyms

B	Balancing
CLD	Causal Loop Diagram
DTF	Data Task Force
LSI	Land-Sea Interaction
MAL	Multi-Actor Lab
R	Reinforcing
SD	System Dynamics
SF	Stock-Flow

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1 Introduction

The purpose of this deliverable is to provide an overview of the problem scope and feedback mechanisms in the context of land-sea interaction for the six case studies (multi-actor labs). COASTAL adopts an interactive Systems Dynamics (SD) approach for supporting business decisions. This implies that local stakeholders are directly and indirectly involved in the formulation, testing and application of models to their own problem context. SD modelling (Sterman, 2000) is widely used since the 1950s for problem analysis in applications ranging from logistics, control management, engineering and financial management to public policy. By nature, SD modelling is strongly problem-driven and analysts using SD-based approaches are to avoid modelling the system 'as a whole', if this can be avoided. Clients or 'problem owners' and business analysts interact to create mental models or 'mind maps' clarifying the problem at hand, and defining the way the problem(s) are connected to specific policy or management indicators and potential solutions. The COASTAL sector workshops, organised in the second half of 2018 for the MALs, were aimed at developing raw mind maps for specific sectors (agricultural, environment, water management, fisheries, …). Processing and polishing of the mind maps results in more refined conceptual models, which can be used to formulate graphical models, Causal Loop Diagrams or CLDs showing the relevant feedback mechanisms explaining the problem. These CLDs can be quantified in 'stock-flow' models which allow examining the combined impact of reinforcing and balancing feedback mechanisms on the dynamics of the system. Typical questions that can be answered are: why do certain businesses fail and others not under similar circumstances? What happens when new enterprises grow too rapidly? Why do certain management strategies work on the short term, but not on the long term? Although the human brain can provide part of the answer this becomes more difficult when multiple factors play a role. This is certainly true for complex social-environmental systems such as coastal regions which are densely used and rapidly developing, with economic activities competing for resources such space, water, skilled labour, and use of transport infrastructure.

The true strength of SD modelling lies in the transparency of the graphical models, enabling interactive design and use of the models, the limited data requirements and high computing speed allowing interactive use and comparison of different options available to address the problem. The qualitative modelling activities, resulting in problem scoping, mind maps and causal loop diagrams, and quantitative modelling activities are equally important (Figure 1). Both require a combination of communication and analytical skills from the supporting project teams.

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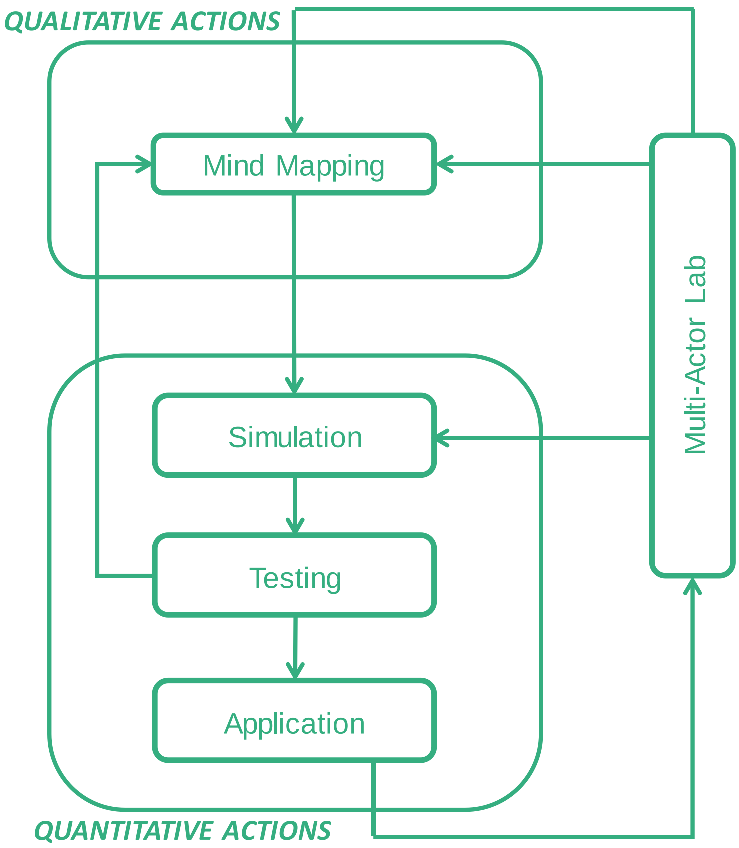

Figure 1 Workflow in COASTAL for designing, testing and applying SD-based tools together with the Multi-Actor Labs.

A tutorial example was used during the kick-off meeting to demonstrate the role of system feedback. The example concerned the interaction between tourism, pressure on space and the attractiveness of a coastal region for new tourists (Figure 2). Limiting the total number of tourists can be necessary to avoid economic collapse of tourism, depending on the capacity of the region (Figure 3).

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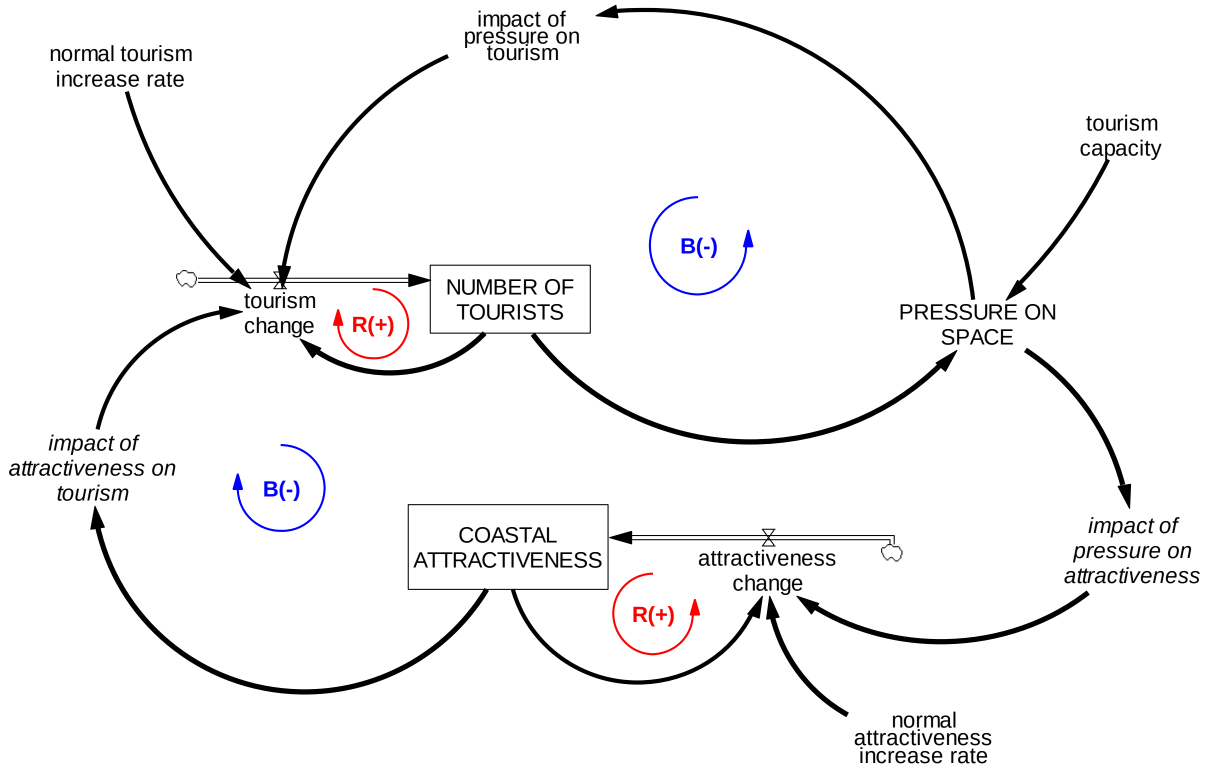

Figure 2 Tutorial example of a stock-flow model for tourism development used during the project kickoff meeting (June 2018) with reinforcing (R) and balancing (B) feedback loops indicated.

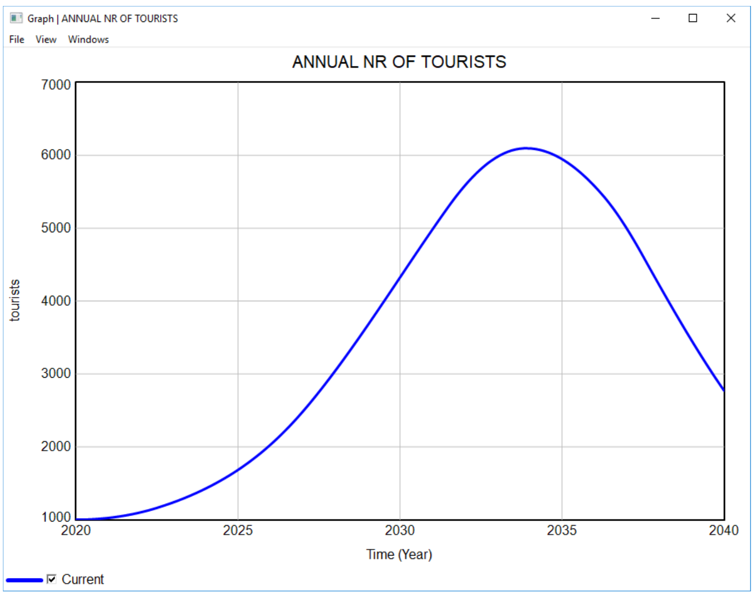

Figure 3 Typical 'overshoot-and-collapse' behavior of the tourism model, caused by overexploitation of a finite resource, in this case space.

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The tourism diagram is an example of a generic feedback structure with a renewable resource (in this case attractiveness of the coast for tourism) causing overshoot and collapse behaviour. The feedback structure of Figure 2 has several reinforcing (indicated in red as "R(+)") and balancing (indicated in blue as "B(-)") feedback loops. A reinforcing feedback refers to positive feedback, for example exponential population growth (more people → more births → more people). Balancing feedback loops do the opposite. The occurrence of both can lead to the type of dynamics shown in Figure 3.

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2 Methodology

A proper description of the problem to be addressed is of critical importance for the design and successful application of SD models (Sterman, 2000; Hovmand, 2014). A number of questions need to be answered in what is usually referred to as the 'problem scope'. Insufficient attention for the problem scope will lead to models which lack focus, are not solving the problems or answering the questions of the intended users, and inefficient modelling projects. A common mistake is for modellers attempting to model the system as a whole rather than the problems generated by its dynamics (Sterman, 2000). In addition, the model should not be a complete representation of the system in all its detail, but a simplification of reality. For COASTAL the general focus lies on land-sea interactions at a local-regional scale, but the problems of the Multi-Actor Labs (MALs) require a more detailed specification of the modelling process. Fortunately, the project is strongly problem-driven with a key role for the local partners and stakeholders in the definition of the issues to be analysed.

Defining the problem scope, i.e. the purpose of the model and what is to be included or not, is of key importance and depends on answering a number of questions:

a) **Problem definition**: which problem(s) are to be addressed with the model and why? If multiple problems occur, can these be prioritized or should separate models be developed? The model design depends on this problem definition.
b) Related to the previous question: who is the **problem owner** perceiving the existing or future situation as a problem, or who is affected by the problem and who or what is causing the problem? For example, an administration such as a water utility company may identify drought as a problem to be addressed (problem owner), while farming is the primary sector affected with multiple causes (climate change, competing users, mismanagement, ..)underlying the problem. The model design should reflect a problem which is relevant for the problem owner and include it's causes.
c) As implied by the word System Dynamics is a technique to analyse problems of the **structural dynamics** of the underlying system. SD modellers are less interested in equilibrium states and the systems studied (and the corresponding models) can well be out of equilibrium. A good example is the "overshoot-and-collapse" behaviour of the sixth system archetype shown in Table 1 (Section 2). For the complete duration of the simulation the system is out of equilibrium. This makes SD modelling different from other numerical and analytical exercises focusing on the correct representation of the (equilibrium) state of the system at a certain point in time (for example, a water or accounting balance). SD modelling is less appropriate or useful if the problem identified is not inherently dynamic. In such cases a different approach is needed. Nevertheless, hybrid model frameworks combining tools and expertise can be very useful. For example, a water balance can (and should be) used to calibrate an SD model addressing water resource management.
d) Depending on the complexity, dynamics, need for quantified modelling and other factors modellers should always ask themselves if a quantified stock-flow model is the appropriate tool for understanding and analysing a problem. Stock-flow modelling can be used in COASTAL to make solutions **evidence-based**. There may be no need for modelling to develop solutions, or alternative

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approaches (stakeholder interviews, numerical modelling, literature research, field work, …) may be more appropriate.

e) **Model purpose** is equally important and highly relevant for the design of an SD model. The purpose of the model can range from problem solving, introducing SD techniques, demonstration and educational training for awareness raising. It's important to emphasize that SD models are technical instruments, generally not appropriate for interaction with persons not familiar with, or, interested in models as such. This is even true for well-polished SD models. Therefore, the COASTAL consortium adopted an approach were modelled scenarios and solutions are used for interacting with stakeholders, rather than the model structures themselves. Nevertheless, the stakeholders have been directly involved in the conceptual modelling (WP1). Furthermore, a number of tutorial presentations were developed to take audiences through the process of SD modelling step-by-step, in case the added value of SD-based policy analysis is to be demonstrated with a concrete example. Depending on the application of the model (research, policy or business analysis, training, …) one should decide on the focus, level of detail, layout and presentation of the model.

f) The level of detail or **granularity** of a model refers to the way it is composed of individual parts or variables. The complexity of SD models should be in the feedback structure and interactions between variables rather than the total number of variables. The reason is that this feedback structure determines the dynamics of the model and hence the way the model responds to policy and business decisions. Excessive model granularity is to be avoided, certainly in the earlier phase of the modelling process. Instead the focus should be on understanding problems from the correct feedback structure. The challenge for COASTAL is that stakeholders often tend to add as many factors as they consider important. Although the potential role of system feedback is explained to the workshop participants it is not their first concern. This necessitates a careful translation of the mental models of the stakeholders into a model structure which captures the meaning of the discussions in stock and flow variables.

g) **Boundary adequacy** of SD models refers to the degree the spatial, temporal, administrative boundaries of a model, and problem scope, have correctly been identified as related to the problem definition. For example, an SD model addressing the impact of climate change related drought on agriculture can have climate scenarios as driving mechanism but there is no need to include or **internalize** the underlying mechanisms of climate change in the model unless there exists feedback from the model system.

A common approach in System-Dynamics modelling is to start from a time horizon, extending back into the past to allow for historical calibration of the model and into the future to draw the time-dependent boundary of the model as related to the purpose. For example, sea level rise will be less relevant for models with a time horizon of a decade. From there so-called 'reference modes' (Sterman, 2000) are to be defined : time graphs and data showing the dynamics of the problem over time. This is then followed by the formulation of 'dynamic hypotheses', narratives explaining the problems observed. Once the dynamic hypotheses have been agreed upon these can be translated into graphical, qualitative feedback structures providing a conceptual model of the problem. Next, the conceptual model is quantified into a stock-flow model, tested

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and used to generate, analyse and compare different strategies to address the problem. The SD modelling cycle is iterative, building on the expertise of the modellers and feedback from the potential users and stakeholders, and allowing for growing insights in the problem. Rather than following such a step-wise approach COASTAL follows a more pragmatic approach, combining certain principles of SD modelling with multi-actor analysis. These principles include the consideration for system feedback for understanding problems, the use of qualitative, mental models as a basis for quantitative modelling, and a model architecture based on 'stock' and 'flow' variables (Sterman, 2001). This is very important for understanding both the purpose, methodological principles, and limitations of the systems modelling in COASTAL. Furthermore, it is to be emphasized that modelling should not be narrowed down to the activity of quantitative (stock-flow) modelling but concerns the complete workflow, including exchanges with stakeholders and narrative or qualitative project activities.

At the general level the modelling activities in COASTAL are based on an iterative workflow (Figure 1) and follow a more practical approach directly exploiting the co-creation by domain experts, modellers, stakeholders and end-users (Figure 4).

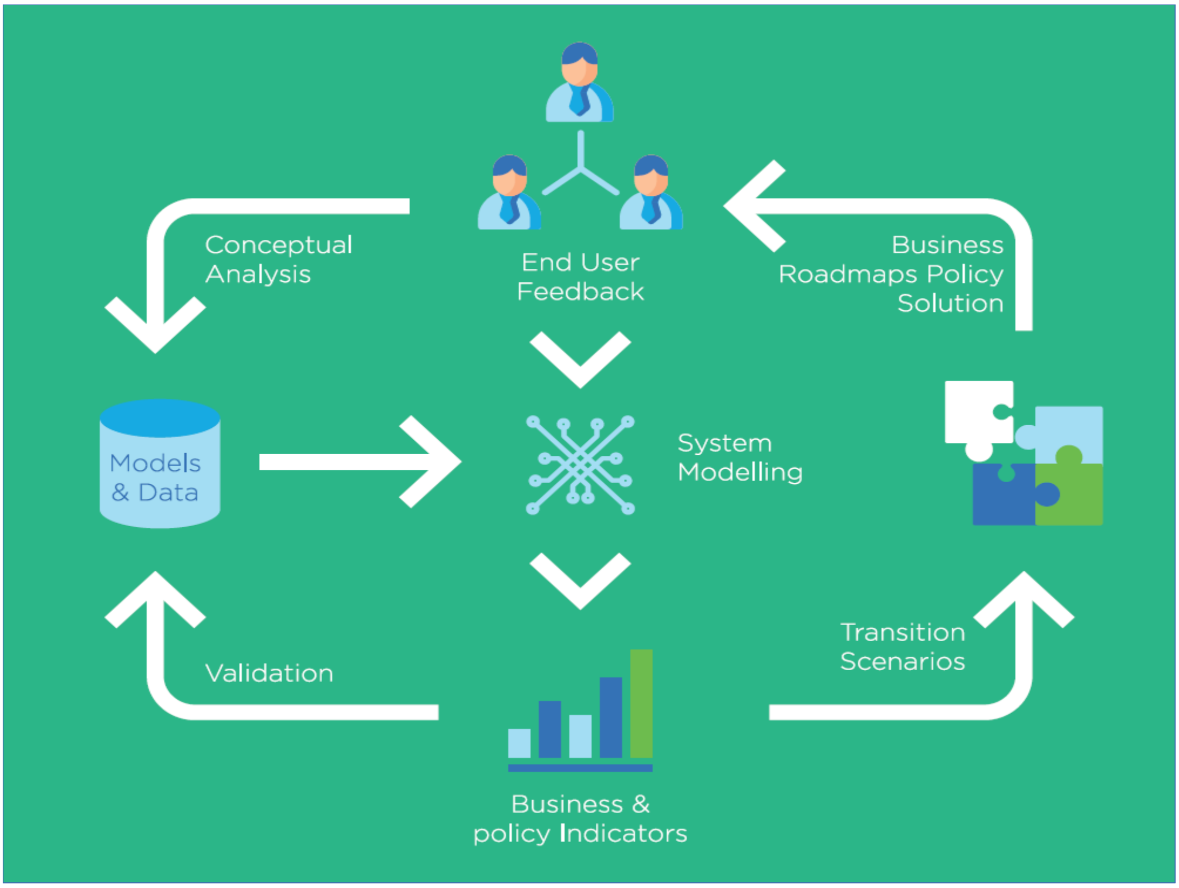

Figure 4 General workflow in COASTAL (design GEONARDO) and positioning of the modelling and supporting data collection activities in the project (left-hand side).

The conceptual analyses were initiated by the six sector workshops organised for each MAL during the first six months of the projects. Typically, 5-15 participants from a key coastal are rural sector were invited bring forward their concerns and priorities as regard to land-sea interactions. Each workshop consisted of a session

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of 1-3 hours (Tiller et al., 2019), and resulting in graphical models or 'mind maps' identifying the land-sea interactions identified during the discussion. Awaiting the outcomes of the sector workshops a parallel exercise was carried out by asking the project teams for the MALs to complete a generic template with land-sea interactions (Figure 5). The template is partially based on the land-sea interaction table presented during the Maritime Spatial Planning Conference addressing Land-Sea Interactions, organised in Malta on June 15-16, 2017 (Stancheva, 2017). The table was adapted to include key economic activities and environmental issues known to be potentially relevant for the COASTAL case studies. Completion of the table by all MALs was considered important to obtain an overview of the similarities and differences in system feedback. The tables were automatically screened with a path tracing algorithm to identify a short list of feedback mechanisms and compared with the outcomes of the sector workshops. A summary of the problem scope and feedback mechanisms is given in Section 3.

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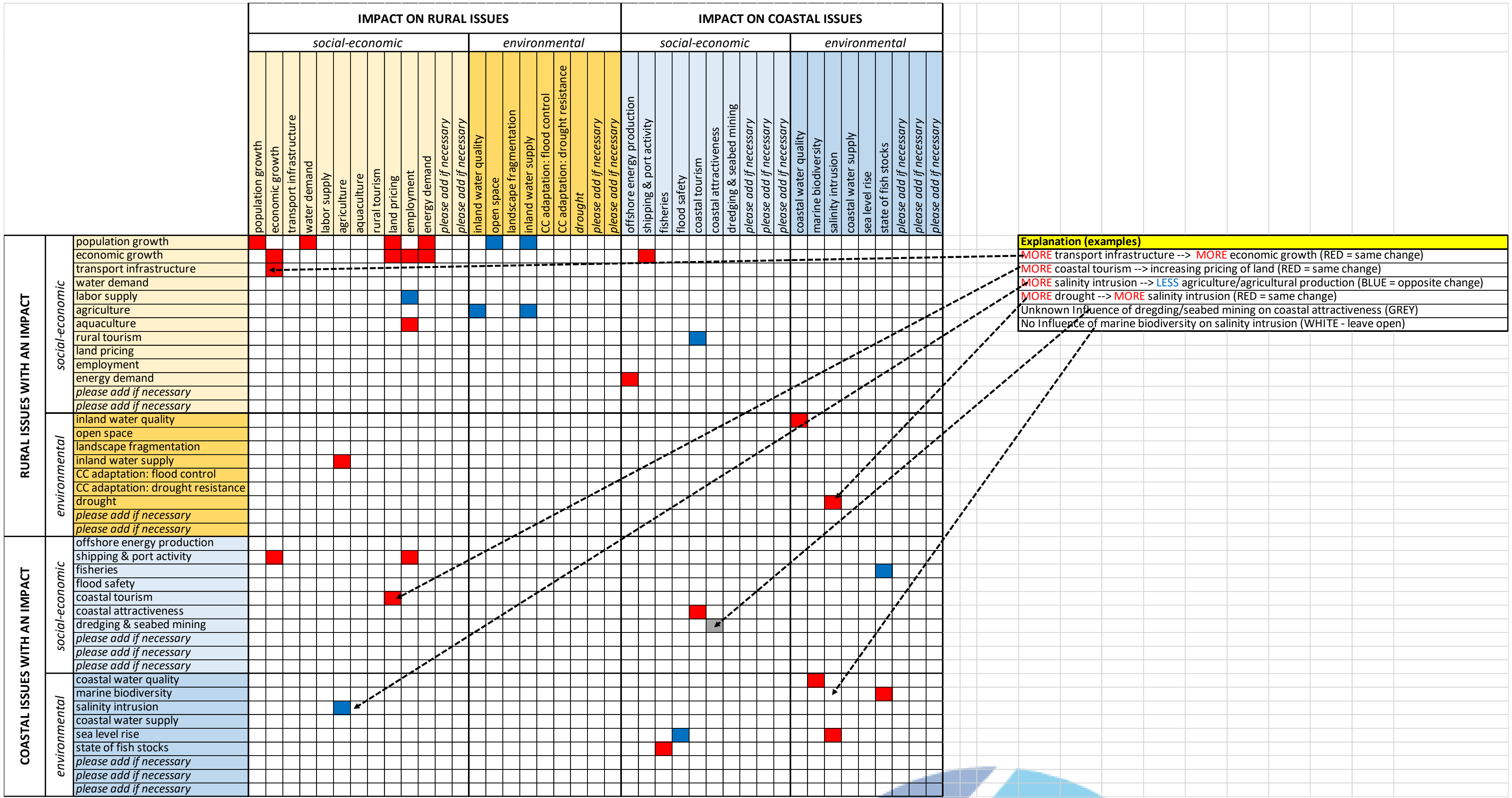

Figure 5 Template for social-economic and environmental land-sea interactions, clarifying the interpretation of the cell colors.

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Table 1 shows several causal loop diagrams and examples of stock-flow models generating different behaviour modes for the system. The three fundamental modes of behaviour are: exponential growth (reinforcing feedback), goal-seeking behaviour (balancing feedback), and oscillatory behaviour (feedback with delay) for dynamics systems with feedback (Sterman, 2001). Interaction of the three fundamental behaviour modes can cause more complex dynamics such as S-shaped growth and overshoot-and-collapse.

The seventh feedback structure generates completely different **chaotic** behaviour. The example is based on the famous Lorenz attractor model (Jørgensen and Bendoricchio, 2001). It uses three **non-linear** equations including products of the stock variables x, y, and z. Contrary to the other behaviour modes the dynamics of the system the pattern is **irregular**, but deterministic (i.e. the time-dependent trajectory is determined by the initial conditions). The actual occurrence of the chaotic behaviour depends on the parameter settings and is highly sensitive to the initial conditions ('butterfly effect'). Potential applications of chaotic dynamics are found in meteorology and climate science, ecology, and macroeconomics, and non-linear models can be useful to generate more realistic dynamics of the system. For example, chaotic time series of the rainfall pattern or world oil price could be included to examine to examine the response of the land-sea system.

An exhaustive identification of all feedback loops is computationally demanding for complex systems with a large number of causal connections (see Section 3 for examples). The challenge is to identify the **dominant feedback loops** of the system which govern the dynamics. Loop dominance is a subject of an ongoing debate in the System Dynamics community (Sterman, 2000; Sato, 2017).

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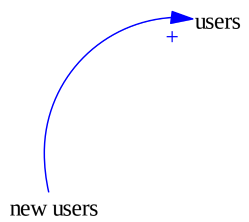
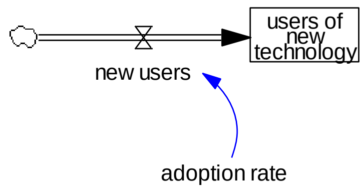
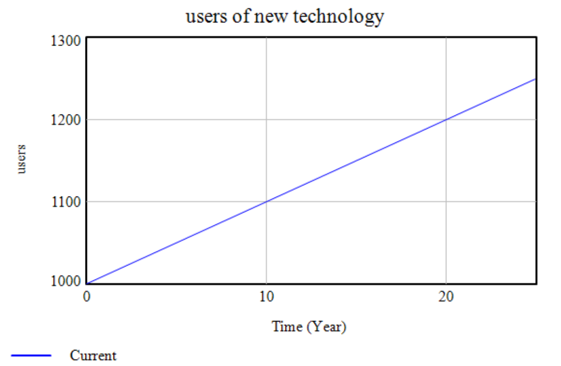
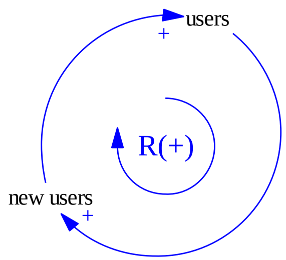
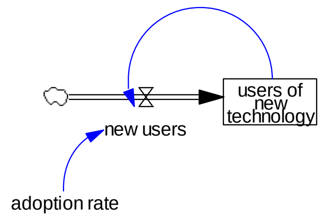
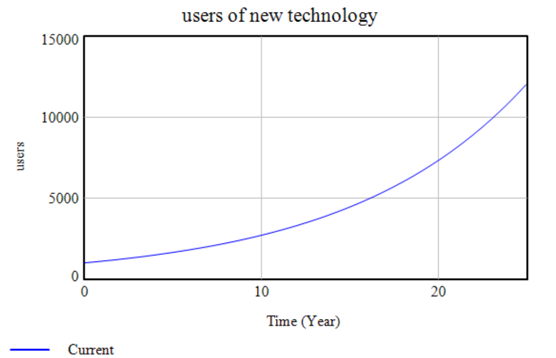
Causal Loop Diagram (WP1 & WP4)	Stock-Flow Diagram (WP2 & WP4)	Transition Dynamics (WP3 & WP5)
		 Linear growth (no feedback)
		 Exponential growth (reinforcing feedback)

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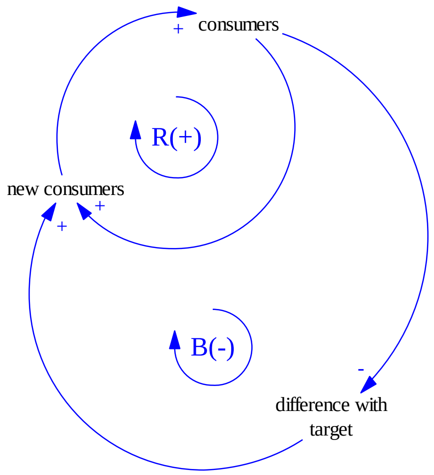
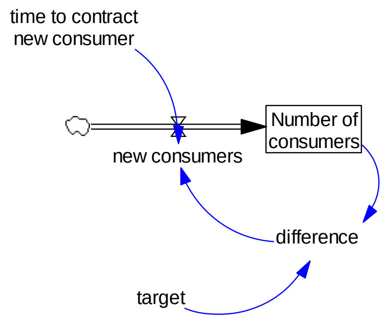
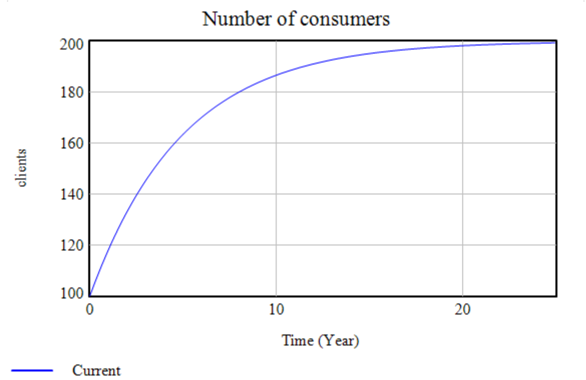
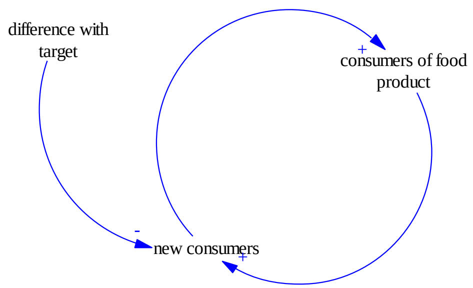
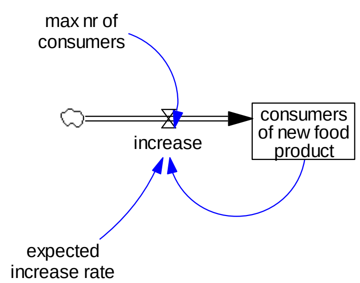






Goal seeking behavior (balancing feedback)





S-shaped growth

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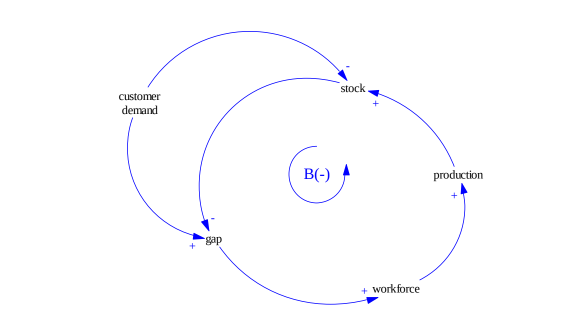
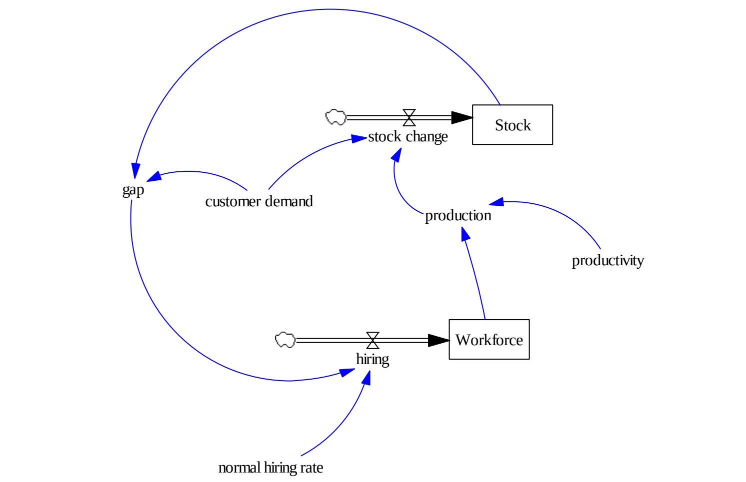
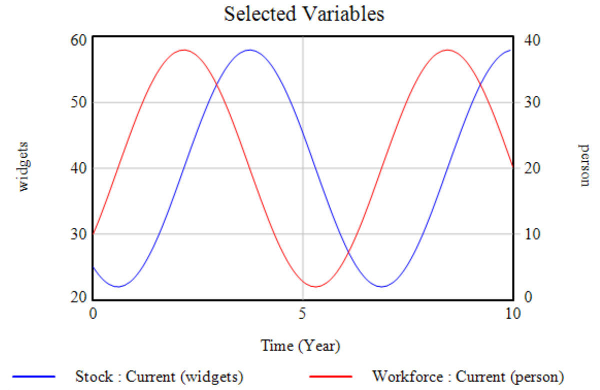
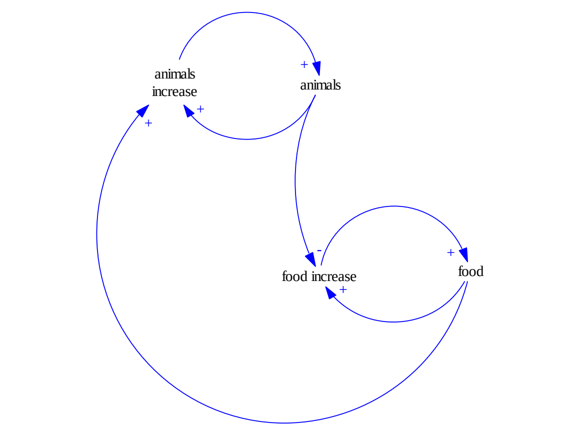


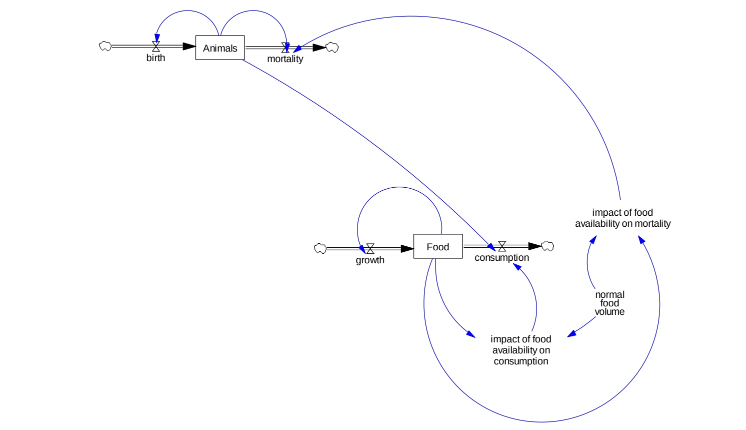


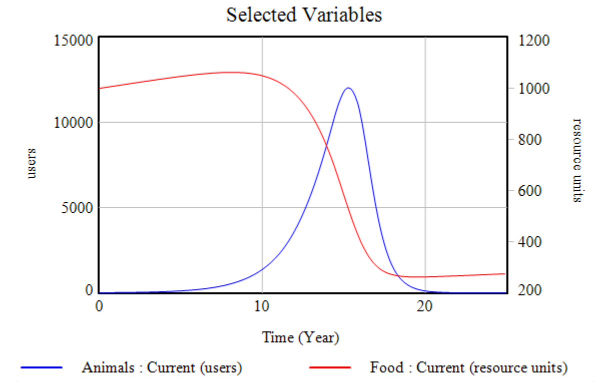


Sustained oscillation

(balancing feedback with delayed response)







Overshoot and collapse

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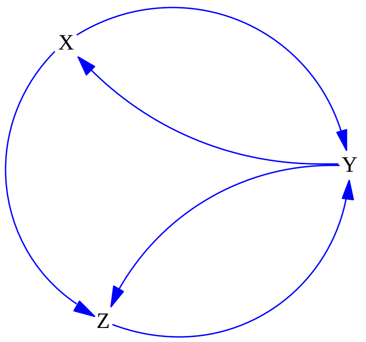

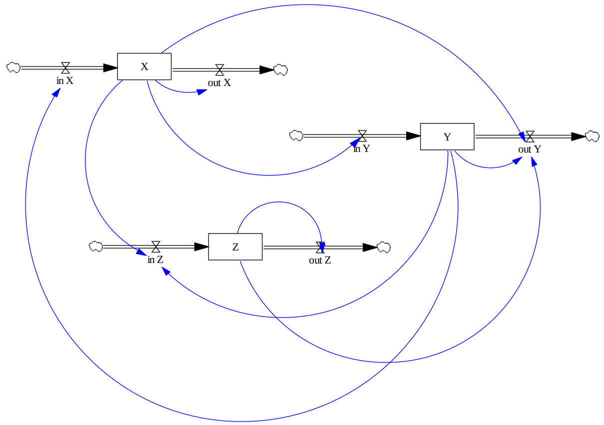

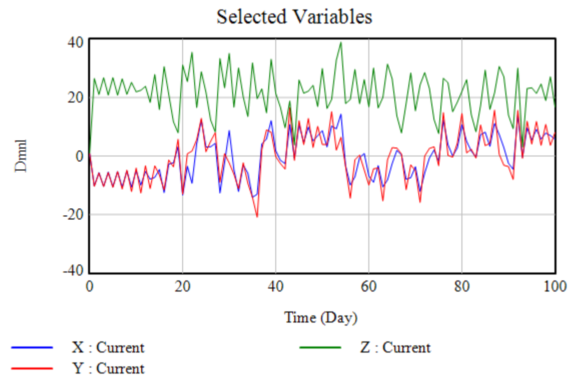

Chaotic behavior

Table 1 Different behavior modes of dynamic systems with feedback and examples of the causal loop diagrams and feedback structures generating a type of behavior. The seventh example shows chaotic behavior and is based on the famous Lorenz attractor model (Jørgensen and Bendoricchio, 2001).

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3 Problem scope and system feedback for the MALs

3.1 Multi-Actor Lab 1 - Belgian Coastal Zone (Belgium)

3.1.1 Problem scope

The Belgian coast (67 km length) and hinterland face environmental and economic stresses from intensive multifunctional use of space. Land- and sea-based activities such as agriculture, fisheries, agro-food industry, transport, energy production and recreation are closely interwoven and competing for space (Figure 6).

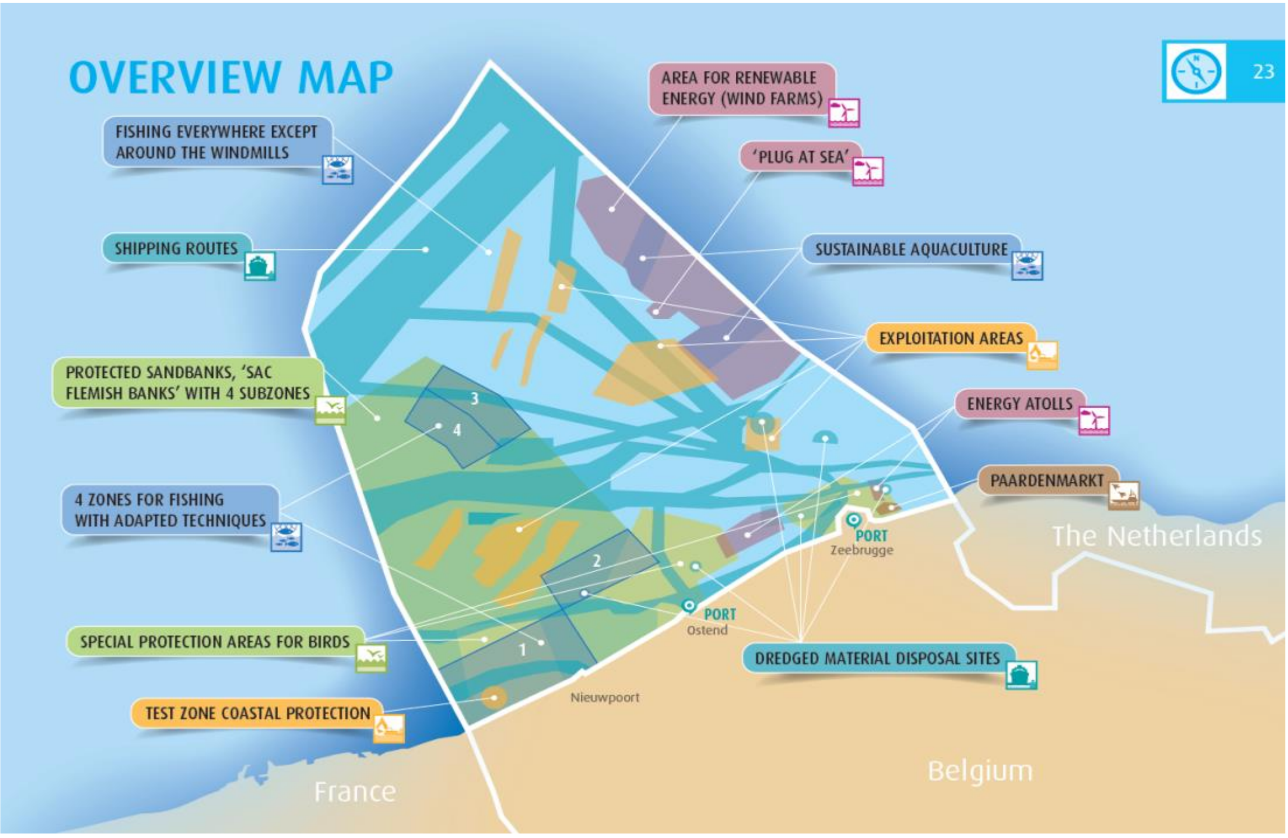

Figure 6 Overview Map for Marine Spatial Planning in the Belgian Coastal Zone (with permission Belgian Federal Public Service Health, Food Chain Service and Environment, 2015)

New development opportunities for this densely populated region are created by blue growth, and especially on- and offshore energy production which create opportunities for new jobs and strategic specialization of port activities. This includes innovative production methods using wave and tidal energy. Belgium is one of the leading countries in know-how related to offshore energy production and the first country to put in practice multi-purpose use of wind farms (i.e. combined with shellfish aquaculture). Meanwhile, the quality of fresh water resources is under pressure, and land-based emissions of nutrients still exceed the EU-WFD

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target levels and contribute to coastal eutrophication. The quantities of fresh water are under pressure during extended periods of drought, as a result of multiple demands from industry, tourism, population and agriculture. A major stressor is the increasing salinisation of inland waters, related to human waterworks, water management, and sea level rise. A main challenge for this case study is the fragmentation of policy and knowledge for coastal and rural development. A common administrative framework for coastal-rural integration is lacking and policy responsibilities are fragmented at the regional and national level.

3.1.2 Overview of land-sea interactions

An aggregated inventory of the main Land-Sea Interactions (LSI) was carried out by the project team to define the problem scope for this study region (Figure 7). The advantage of aggregating the land-sea interactions is to enable application by all Multi-Actor Labs, allowing for cross-comparison and identification of the main feedback mechanisms.

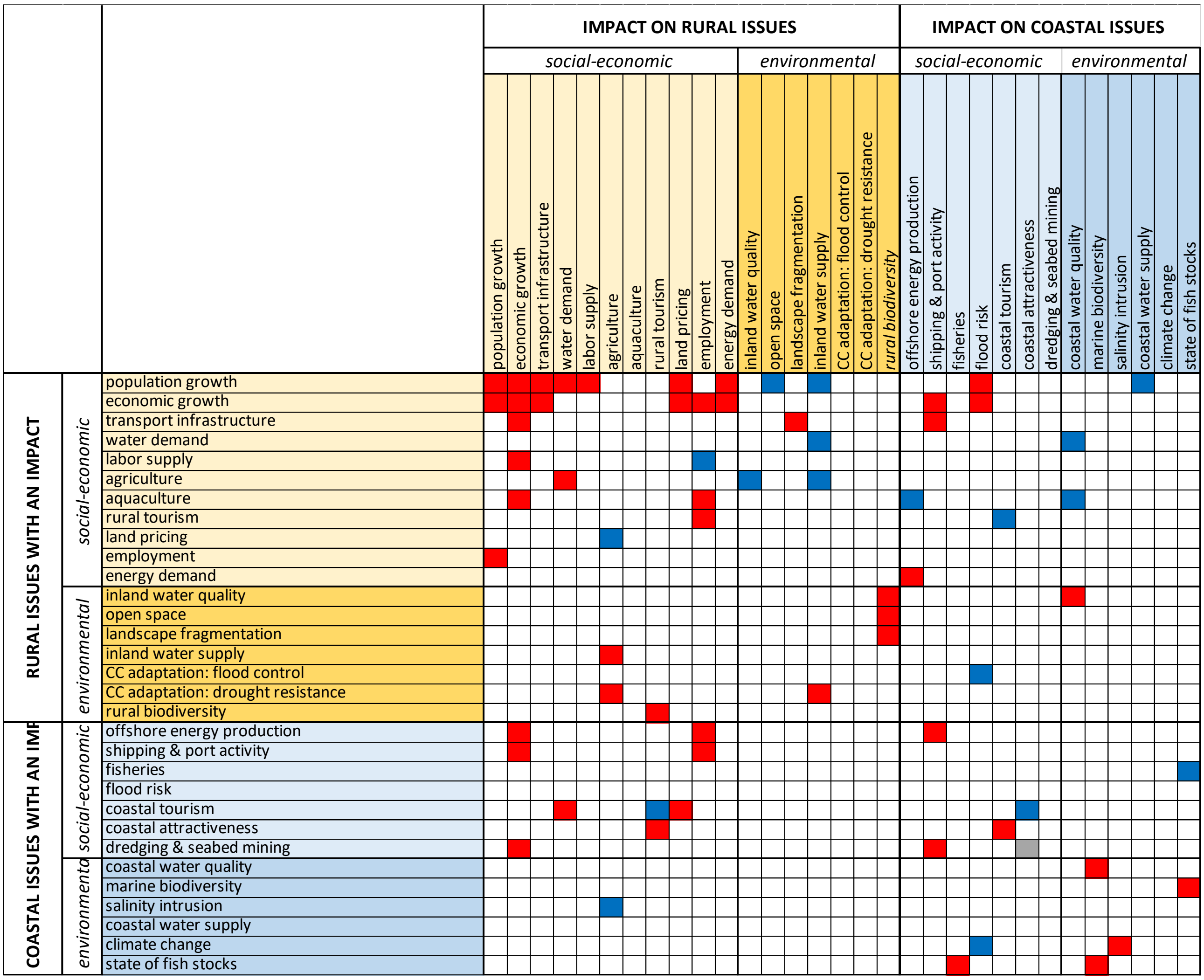

Figure 7 – Inventory of system interactions for the Belgian Coastal Zone (project team analysis).

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3.1.3 Overview of system feedback

Attempts to translate the contents of the LSI tables into a causal loop diagram in VenSim® turned out to be less useful for further analysis due to the larger number of interconnections between the variables (Figure 8).

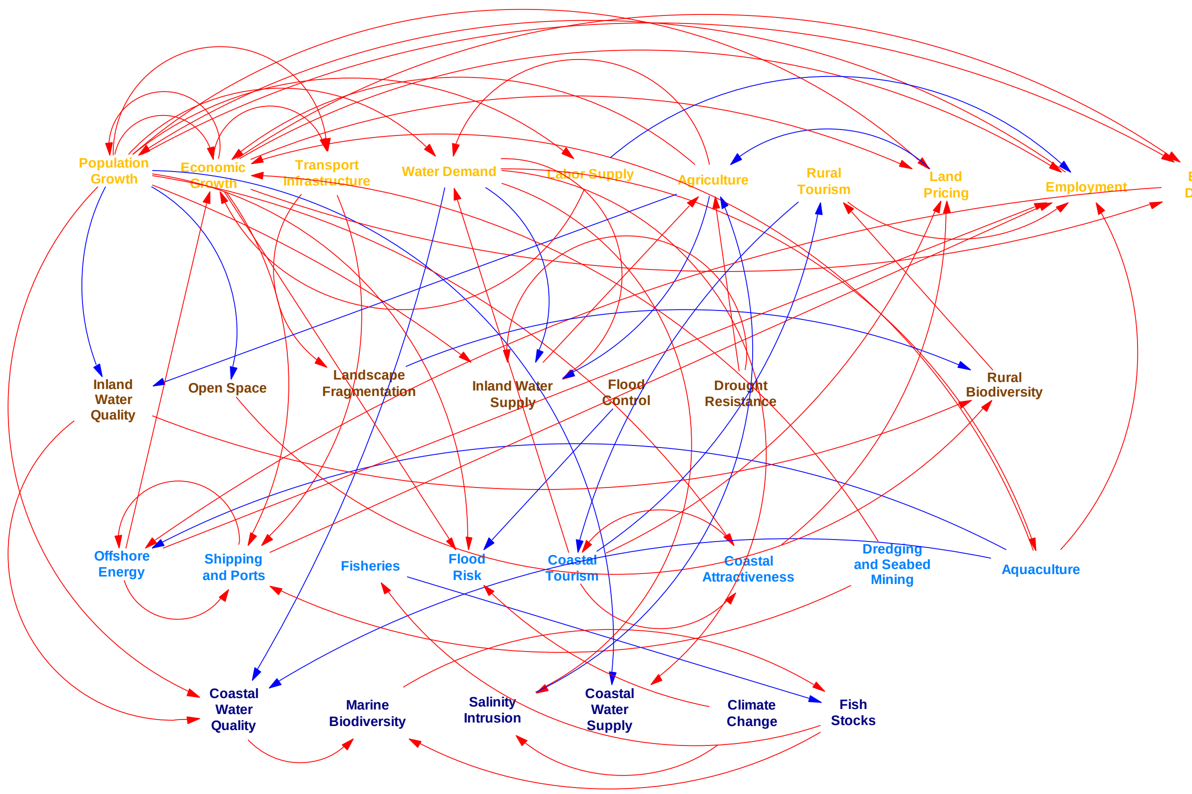

Figure 8 Graphical VenSim representation of the land-sea interactions of Figure 7.

Instead, an iterative loop-tracing algorithm (Kirk, 2007) was used to systematically trace and count the negative (balancing) and positive (reinforcing) feedback loops, based on the system interactions identified in the table. The algorithm used to trace the feedback loops was adapted to account for directed graphs and weights assigned to the connections. Without being exhaustive 46 reinforcing and 8 balancing feedback loops were identified after 1 million iteration steps, with a search depth of 8 steps (excluding unknown interactions marked as grey cells in Figure 7):

Reinforcing feedback loops found (sorted by length)

- *economic growth→economic growth*
- *population growth→population growth*
- *population growth→economic growth→population growth*
- *economic growth→transport infrastructure→economic growth*
- *economic growth→transport infrastructure→shipping & port activity→economic growth*
- *population growth→economic growth→employment→population growth*

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- *population growth→economic growth→land pricing→agriculture→inland water quality→rural biodiversity→rural tourism→employment→population growth*
- *population growth→economic growth→transport infrastructure→landscape fragmentation→rural biodiversity→rural tourism→employment→population growth*
- *population growth→labor supply→economic growth→shipping & port activity→employment→population growth*
- *population growth→transport infrastructure→economic growth→population growth*
- *rural tourism→coastal tourism→rural tourism*
- *population growth→economic growth→energy demand→offshore energy production→employment→population growth*
- *population growth→economic growth→energy demand→offshore energy production→shipping & port activity→employment→population growth*
- *population growth→energy demand→offshore energy production→economic growth→population growth*
- *population growth→energy demand→offshore energy production→employment→population growth*
- *population growth→labor supply→economic growth→land pricing→agriculture→inland water quality→rural biodiversity→rural tourism→employment→population growth*
- *population growth→transport infrastructure→economic growth→land pricing→agriculture→inland water quality→rural biodiversity→rural tourism→employment→population growth*
- *population growth→transport infrastructure→shipping & port activity→economic growth→energy demand→offshore energy production→employment→population growth*
- *population growth→transport infrastructure→shipping & port activity→economic growth→population growth*
- *economic growth→energy demand→offshore energy production→economic growth*
- *population growth→economic growth→shipping & port activity→employment→population growth*
- *population growth→energy demand→offshore energy production→economic growth→employment→population growth*
- *population growth→energy demand→offshore energy production→shipping & port activity→employment→population growth*
- *population growth→labor supply→economic growth→energy demand→offshore energy production→shipping & port activity→employment→population growth*
- *population growth→transport infrastructure→economic growth→energy demand→offshore energy production→shipping & port activity→employment→population growth*
- *population growth→transport infrastructure→shipping & port activity→economic growth→land pricing→agriculture→inland water quality→rural biodiversity→rural tourism→employment→population growth*
- *rural tourism→coastal tourism→coastal attractiveness→rural tourism*
- *economic growth→energy demand→offshore energy production→shipping & port activity→economic growth*

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- *marine biodiversity→state of fish stocks→marine biodiversity*
- *population growth→energy demand→offshore energy production→economic growth→shipping & port activity→employment→population growth*
- *population growth→energy demand→offshore energy production→shipping & port activity→economic growth→employment→population growth*
- *population growth→labor supply→economic growth→employment→population growth*
- *population growth→labor supply→economic growth→transport infrastructure→landscape fragmentation→rural biodiversity→rural tourism→employment→population growth*
- *population growth→transport infrastructure→economic growth→employment→population growth*
- *population growth→transport infrastructure→economic growth→shipping & port activity→employment→population growth*
- *economic growth→shipping & port activity→economic growth*
- *population growth→energy demand→offshore energy production→economic growth→transport infrastructure→shipping & port activity→employment→population growth*
- *population growth→inland water supply→agriculture→inland water quality→rural biodiversity→rural tourism→employment→population growth*
- *population growth→labor supply→economic growth→energy demand→offshore energy production→employment→population growth*
- *population growth→labor supply→economic growth→population growth*
- *population growth→land pricing→agriculture→inland water quality→rural biodiversity→rural tourism→employment→population growth*
- *population growth→transport infrastructure→economic growth→energy demand→offshore energy production→employment→population growth*
- *population growth→transport infrastructure→shipping & port activity→economic growth→employment→population growth*
- *population growth→economic growth→transport infrastructure→shipping & port activity→employment→population growth*
- *population growth→transport infrastructure→shipping & port activity→employment→population growth*
- *population growth→water demand→inland water supply→agriculture→inland water quality→rural biodiversity→rural tourism→employment→population growth*
- *population growth→energy demand→offshore energy production→economic growth→transport infrastructure→landscape fragmentation→rural biodiversity→rural tourism→employment→population growth*
- *population growth→energy demand→offshore energy production→shipping & port activity→economic growth→population growth*
- *population growth→labor supply→economic growth→transport infrastructure→shipping & port activity→employment→population growth*

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- *population growth→energy demand→offshore energy production→economic growth→land pricing→agriculture→inland water quality→rural biodiversity→rural tourism→employment→population growth*
- *population growth→energy demand→offshore energy production→shipping & port activity→economic growth→transport infrastructure→landscape fragmentation→rural biodiversity→rural tourism→employment→population growth*
- *population growth→transport infrastructure→landscape fragmentation→rural biodiversity→rural tourism→employment→population growt*

<u>Balancing feedback loops found:</u>

- *agriculture→inland water supply→agriculture*
- *fisheries→state of fish stocks→fisheries*
- *coastal tourism→coastal attractiveness→coastal tourism*
- *water demand→inland water supply→agriculture→water demand*
- *agriculture→inland water quality→rural biodiversity→rural tourism→coastal tourism→land pricing→agriculture*
- *water demand→inland water supply→agriculture→inland water quality→rural biodiversity→rural tourism→coastal tourism→water demand*
- *population growth→labor supply→employment→population growth*
- *population growth→open space→rural biodiversity→rural tourism→employment→population growth*

3.1.4 Sector workshop results

As could be expected, the six sector workshops (environment, spatial planning, fisheries and aquaculture, tourism, agriculture, and blue industry) provided a more detailed analysis of the problems and priorities of the study region. Some typical **land-sea interactions** for the region, identified during the sector workshops, are:

- The ‘coastal squeeze’ resulting from the dense use of space and real estate development, which leaves little room for other activities and reduces flood protection options
- Impact of sea level rise on salinity levels of low lying inland farming land
- Fragmentation of the natural landscape, a general problem in Flanders
- Impact of agriculture on coastal eutrophication, with emission levels still exceeding the EU-WFD targets
- Inland congestion during holidays and the peak season, resulting from coastal tourism

Figure 9 shows a mind map at a high level of analysis for these main land-sea interactions identified during the sector workshops.

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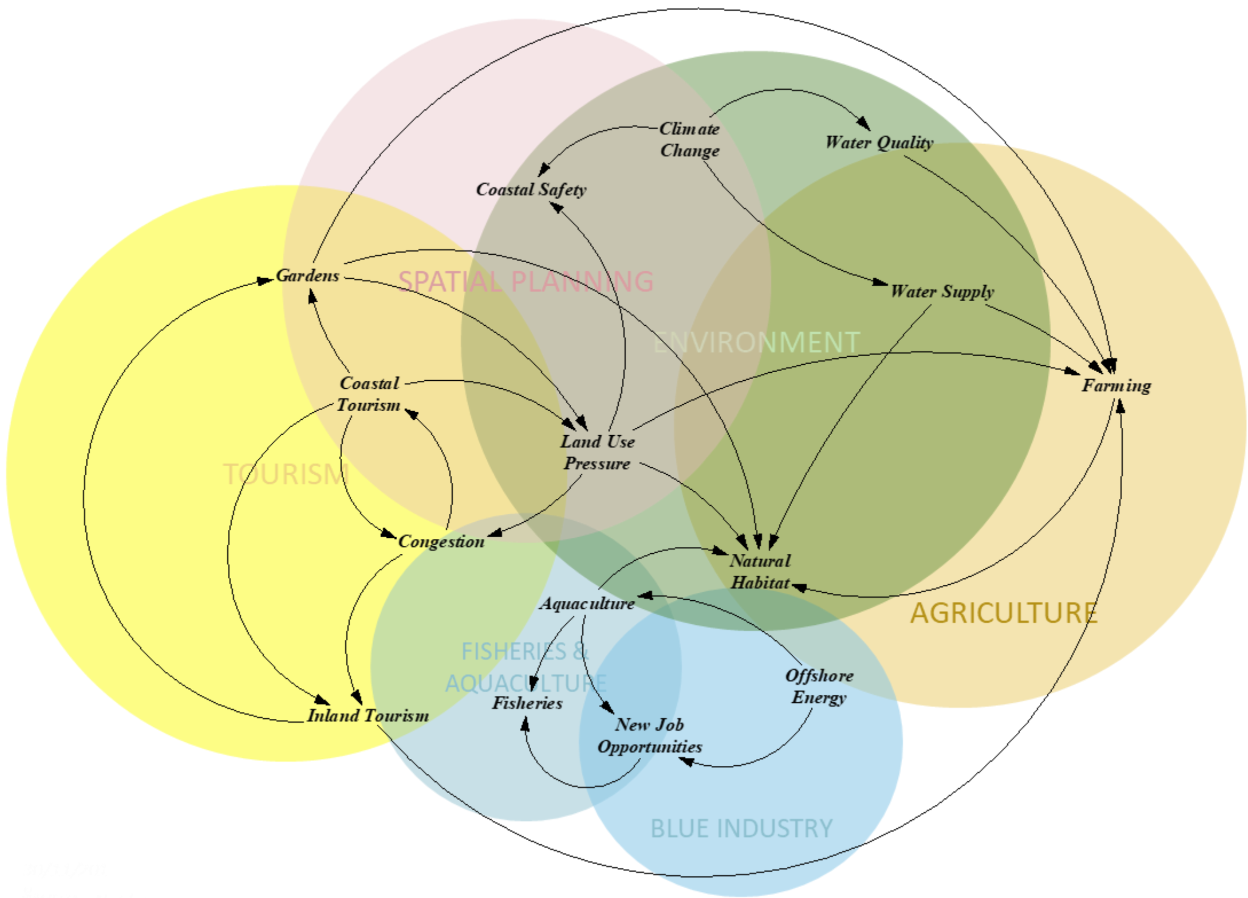

Figure 9 Overview mind map with the main issues and linkages for the Belgian Multi-Actor Lab (project team analysis), showing the themes for the six sector workshops and overlap in issues raised.

We compare the Land-Sea Interaction (LSI) table (Figure 7) with the mind maps developed in the sector workshops for the Belgian MAL (Tiller et al., 2019). An example for the tourism sector is shown in Figure 10.

We make two important observations:

- The mind maps are far more detailed, a large number of land-sea interactions and elements raised by the stakeholders are not found in the LSI matrix: the role of policy and regulation, impacts of flood risk and inland water supply on economic activities, impact of transport infrastructure on coastal and rural tourism, impact of labour supply on offshore energy, impact of economic growth on fragmentation of open land, interaction between agriculture and rural tourism, impact of climate change on water supply, … These examples are not exhaustive but demonstrate the added value of the multi-actor analysis, even from the sector-based perspective.

- The sector workshops focused on the priorities, opportunities, obstacles deemed important by the participants. As a result, the mind maps cannot be considered as causal loop diagrams and feedback mechanisms are not included or difficult to detect in case these exist. Instead, the mind maps include

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examples, hierarchical differences, open ends, etc. On the other hand, the LSI matrix is intrinsically designed for indicating system feedback, as the results of the loop analysis of Section 3.1.3 show. These feedback loops often include cross-sectoral interactions, which were given less attention by the workshop participants. The presence of system feedback can be identified with a high-level analysis of the land-sea interactions (Figure 9), but at the cost of the detail needed for proper analysis of the system. The challenge will be to identify the key linking variables, organise and combine the sector mind maps, and then identify the main causal loops governing the dynamics of the total land-sea system for the Belgian coastal zone and hinterland.

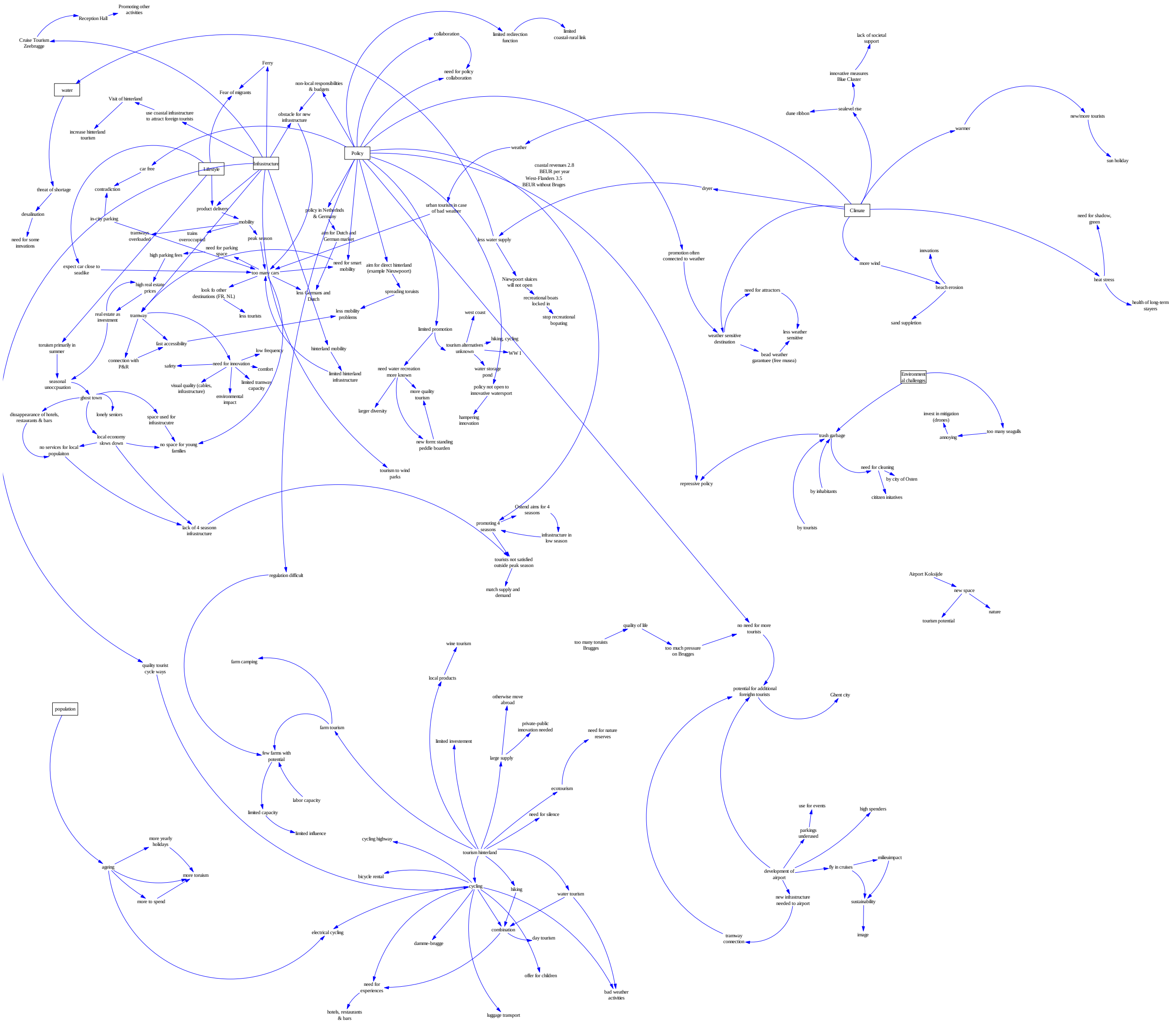

Figure 10 Stakeholder mind map for the tourism sector for the Belgian Coastal Zone (Tiller et al., 2019)

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3.2 Multi-Actor Lab 2 - South-West Messinia (Greece)

3.2.1 Problem scope

South West Messinia is a rural area with small towns and villages scattered in the landscape, which is mainly agricultural, where olive trees predominate. Agriculture and coastal tourism are the two major economic activities in the area. Tourism is expanding and goes hand in hand with infrastructure development (hotels, roads and airports) and can provide opportunities for diversified livelihoods, but also increases pressures on the agricultural land uses, the environment and cultural sites. These conflicts are also enhanced by the lack of a Regional and local Spatial Plans for the coastal and rural areas. Coastal areas are also affected by agrochemicals, soil erosion, solid waste landfills, and waste waters. In particular waste products from olive production form a threat to surface and coastal water quality. Climate change is expected to increase coastal erosion and decrease the availability of freshwater, with increased risk for saltwater intrusion into coastal wetlands and aquifers. There are also plans for offshore oil and gas exploration that will have implications for the area's rich coastal biodiversity. The study area comprises several important cultural sites and Mediterranean habitats included in the reference list of the Natura 2000 initiative. The MAL will develop a number of alternative strategies for local economic development. These will allow a diversification and strengthening of a sustainable local economy while minimizing the impact on the Natura 2000 sites. Long-

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term planning for sustainable tourism and agriculture will take into account resilience to future climatic changes, exploiting the expertise and experience of local stakeholders.

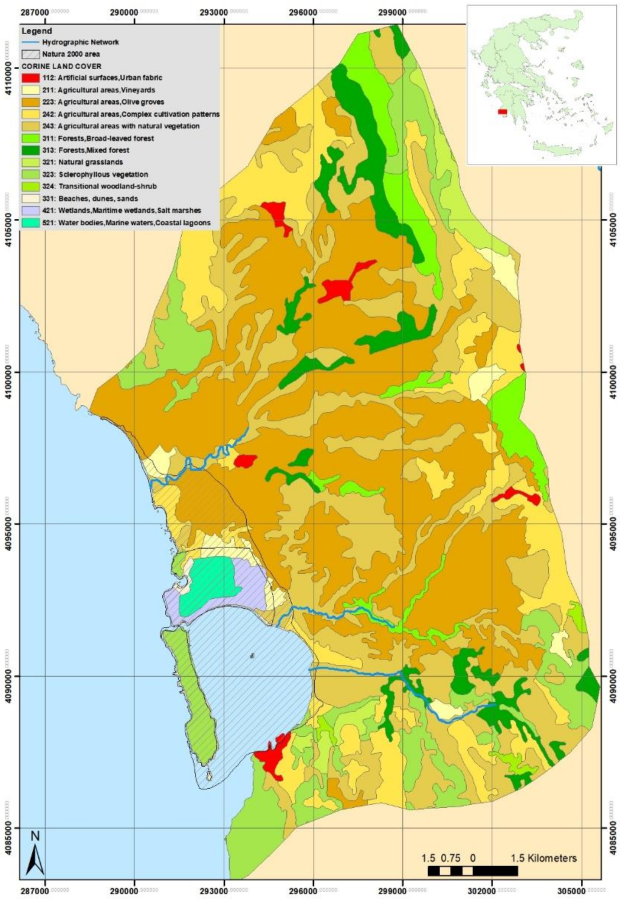

Figure 11 Overview Map of land cover characteristics in the West Messinia case study area

3.2.2 Overview of land-sea interactions

The LSI matrix for this MAL was more complex, due to the larger number of positive, negative and unknown interactions.

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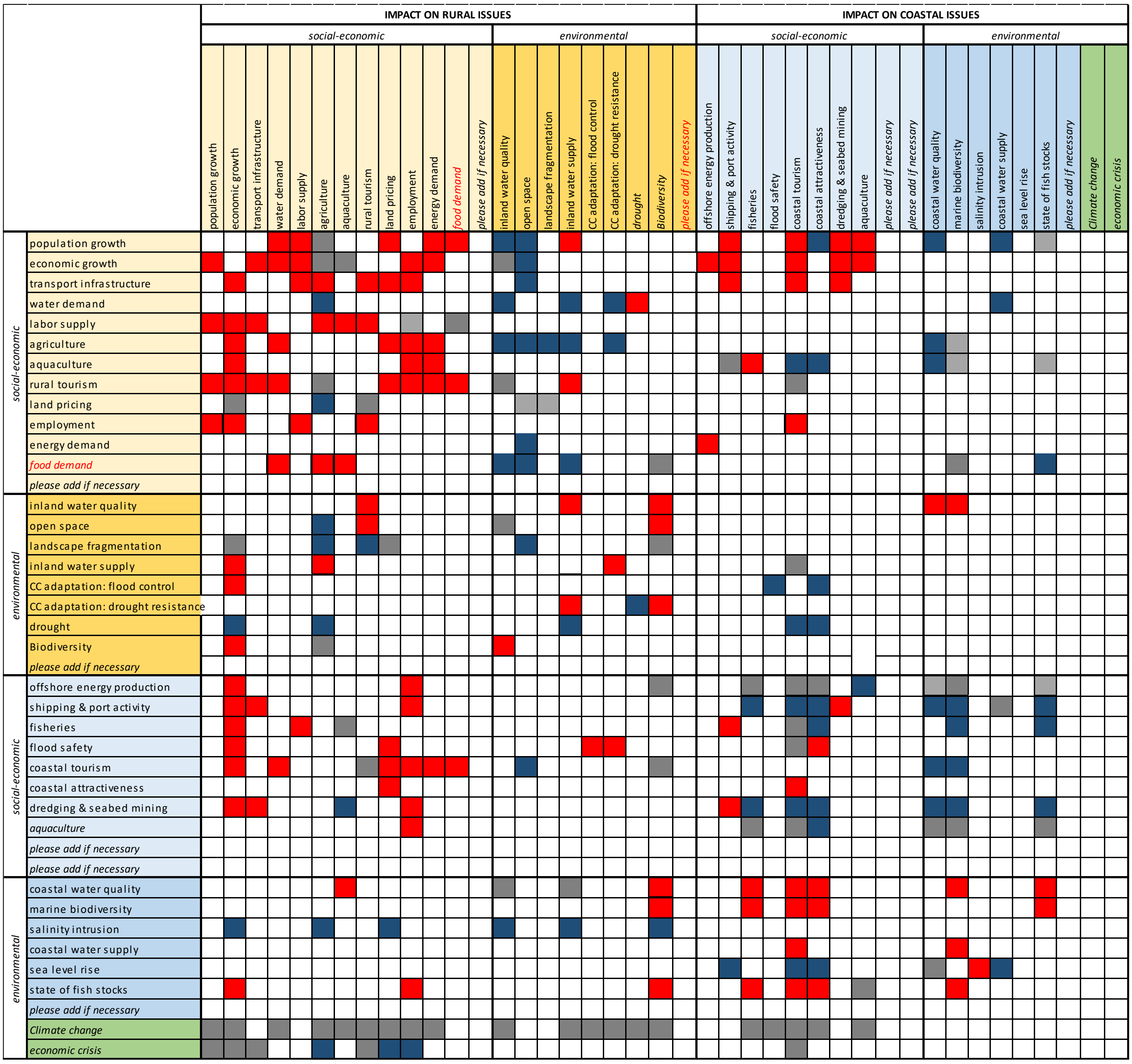

Figure 12 System interactions for the South-West Messinia Multi-Actor Lab (project team analysis).

3.2.3 Overview of system feedback

In total 1613 reinforcing and 2314 balancing feedback loops were identified after 1 million iterations. We list a small sample:

<u>Reinforcing feedback loops</u> (random sample, ordered by path length):

- *agriculture→open space→agriculture*
- *transport infrastructure→shipping & port activity→dredging & seabed mining→transport infrastructure*
- *aquaculture→coastal attractiveness→coastal tourism→coastal water quality→aquaculture*
- *agriculture→energy demand→open space→rural tourism→land pricing→agriculture*

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- *fisheries→state of fish stocks→coastal tourism→coastal water quality→marine biodiversity→fisheries*
- *agriculture→coastal water quality→aquaculture→employment→rural tourism→land pricing→agriculture*
- *transport infrastructure→rural tourism→energy demand→offshore energy production→employment→labor supply→transport infrastructure*
- *transport infrastructure→land pricing→agriculture→energy demand→open space→rural tourism→transport infrastructure*
- *transport infrastructure→land pricing→agriculture→coastal water quality→fisheries→labor supply→transport infrastructure*
- *agriculture→inland water quality→coastal water quality→state of fish stocks→coastal tourism→land pricing→agriculture*
- *agriculture→inland water quality→marine biodiversity→state of fish stocks→coastal attractiveness→land pricing→agriculture*
- *agriculture→landscape fragmentation→rural tourism→food demand→state of fish stocks→coastal attractiveness→land pricing→agriculture*
- *labor supply→agriculture→coastal water quality→fisheries→marine biodiversity→coastal tourism→employment→labor supply*
- *agriculture→energy demand→offshore energy production→aquaculture→employment→coastal tourism→land pricing→agriculture*
- *labor supply→agriculture→coastal water quality→fisheries→shipping & port activity→state of fish stocks→employment→labor supply*
- *transport infrastructure→agriculture→coastal water quality→aquaculture→energy demand→open space→rural tourism→transport infrastructure*
- *water demand→coastal water supply→coastal tourism→employment→rural tourism→land pricing→agriculture→water demand*
- *water demand→drought→coastal tourism→marine biodiversity→fisheries→labor supply→agriculture→water demand*
- *water demand→drought→coastal tourism→coastal water quality→state of fish stocks→fisheries→labor supply→agriculture→water demand*
- *transport infrastructure→agriculture→water demand→drought→coastal tourism→energy demand→open space→rural tourism→transport infrastructure*
- *transport infrastructure→land pricing→agriculture→water demand→inland water quality→coastal water quality→fisheries→labor supply→transport infrastructure*
- *water demand→inland water quality→coastal water quality→state of fish stocks→marine biodiversity→coastal tourism→land pricing→agriculture→water demand*
- *transport infrastructure→dredging & seabed mining→coastal attractiveness→coastal tourism→water demand→agriculture→employment→labor supply→transport infrastructure*

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- *population growth→water demand→agriculture→employment→labor supply→aquaculture→coastal water quality→state of fish stocks→economic growth→population growth*
- *population growth→water demand→agriculture→employment→labor supply→aquaculture→coastal water quality→coastal attractiveness→coastal tourism→economic growth→population growth*
- *population growth→water demand→agriculture→employment→labor supply→transport infrastructure→open space→rural tourism→inland water supply→economic growth→population growth*
- *population growth→water demand→agriculture→employment→labor supply→transport infrastructure→dredging & seabed mining→state of fish stocks→fisheries→economic growth→population growth*

Balancing feedback loops (random sample, ordered by path length)

- *agriculture→employment→coastal tourism→land pricing→agriculture*
- *labor supply→aquaculture→coastal water quality→marine biodiversity→fisheries→labor supply*
- *employment→coastal tourism→coastal water quality→marine biodiversity→state of fish stocks→employment*
- *transport infrastructure→agriculture→coastal water quality→state of fish stocks→employment→labor supply→transport infrastructure*
- *transport infrastructure→land pricing→agriculture→employment→labor supply→rural tourism→transport infrastructure*
- *transport infrastructure→dredging & seabed mining→marine biodiversity→Biodiversity→inland water quality→rural tourism→transport infrastructure*
- *agriculture→coastal water quality→aquaculture→coastal attractiveness→coastal tourism→land pricing→agriculture*
- *transport infrastructure→dredging & seabed mining→coastal water quality→marine biodiversity→fisheries→labor supply→transport infrastructure*
- *transport infrastructure→shipping & port activity→coastal water quality→aquaculture→fisheries→labor supply→transport infrastructure*
- *transport infrastructure→dredging & seabed mining→shipping & port activity→coastal tourism→employment→rural tourism→transport infrastructure*
- *transport infrastructure→agriculture→inland water quality→marine biodiversity→fisheries→shipping & port activity→transport infrastructure*
- *transport infrastructure→labor supply→agriculture→coastal water quality→state of fish stocks→fisheries→shipping & port activity→transport infrastructure*
- *labor supply→agriculture→coastal water quality→coastal tourism→food demand→aquaculture→fisheries→labor supply*

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- *agriculture→open space→rural tourism→food demand→state of fish stocks→coastal attractiveness→land pricing→agriculture*
- *agriculture→inland water quality→marine biodiversity→coastal tourism→coastal water quality→coastal attractiveness→land pricing→agriculture*
- *transport infrastructure→agriculture→employment→coastal tourism→food demand→inland water quality→rural tourism→transport infrastructure*
- *transport infrastructure→agriculture→energy demand→open space→rural tourism→employment→labor supply→transport infrastructure*
- *agriculture→coastal water quality→state of fish stocks→coastal tourism→marine biodiversity→coastal attractiveness→land pricing→agriculture*
- *water demand→coastal water supply→coastal tourism→food demand→inland water quality→rural tourism→land pricing→agriculture→water demand*
- *transport infrastructure→agriculture→water demand→coastal water supply→marine biodiversity→coastal tourism→employment→labor supply→transport infrastructure*
- *water demand→drought→coastal tourism→food demand→open space→rural tourism→land pricing→agriculture→water demand*
- *water demand→inland water quality→rural tourism→food demand→aquaculture→coastal tourism→land pricing→agriculture→water demand*
- *water demand→drought→coastal tourism→food demand→aquaculture→coastal attractiveness→land pricing→agriculture→water demand*
- *water demand→inland water quality→coastal water quality→fisheries→shipping & port activity→employment→labor supply→agriculture→water demand*
- *population growth→water demand→agriculture→employment→labor supply→aquaculture→coastal tourism→coastal water quality→fisheries→economic growth→population growth*

3.2.4 Sector workshop results

As could be expected, the six sector workshops (agriculture, olive-oil industry, tourism, fisheries, administration, environment -i.e. NGOs and institutions) provided a more detailed analysis of the problems and priorities of the study region. All the different sectors were aware of the links among the different economic activities, and were able to discuss opportunities, obstacles as well as identify interactions with other sectors and the natural environment.

In summary the following coastal, rural, and land-sea interactions were identified by the stakeholders:

- Agrochemicals and by-products from the olive-oil sector were highlighted as threats for both transitional and coastal waters.
- Impact of agriculture on coastal eutrophication, with emission levels still exceeding the EU-WFD targets

- Lack of adequate irrigation infrastructure has led to illegal irrigation activities which has caused salinisation of in some of the coastal aquifers
- Inland congestion during holidays and the peak season, resulting from coastal tourism
- Seasonal water demand during the dry summer months both by agriculture and high tourism influx
- The lack of a strategic spatial planning approach causes land use conflicts due to an increased demand for tourism facilities in an area characterised as high quality agricultural land
- Lack of adequate communication between local authorities causes management gaps, which coupled with non-compliance with legislation is related to several illegal activities (unauthorised irrigation, excessive olive – mill waste, fishing, coastal canteens in the lagoon)
- Fragmentation of agricultural land is seen as a constraint for business development as small farmers cannot meet the needs of global markets
- Ageing of farming population coupled with lack of education and environmental awareness is seen as a general problem of the local population
- Agro-, thematic- and eco-tourism remains of a great potential in the area and offers opportunities to increase land-sea synergies, coastal-rural stakeholders' collaborations and creation of more jobs. It can also create a new market for local products.
- Smart agriculture, re-use of different types of by-products from the olive-oil farming and innovative tourism solutions were brought up by the participants and could be major drivers for the sustainable development of Messinia region.
- The local secondary sector, and especially pomace-mills, could provide innovative solutions in the fields of energy production and management/ re-use of waste and by-products in the farm, thus feeding a circular-economy model with benefits to the rural and coastal environment.

As indicated above, the main conclusions drawn from the six sectoral workshops in Messinia can be briefly summarized as follows:

- Agriculture impacts on inland water quality, coastal eutrophication, and possibly fisheries.
- Local population growth is strongly linked to the creation of new job opportunities in the tourism sector. Actually, young people prefer the tourism sector.
- Agro-, thematic- and eco-tourism remains of a great potential in the area and offers opportunities to increase land-sea synergies, coastal-rural stakeholders' collaborations and creation of more jobs and a new market for local products.
- The local secondary sector, and especially pomace-mills, could provide innovative solutions in the fields of energy production and management/ re-use of waste and by-products in the farm, thus feeding a circular-economy model with benefits to the rural and coastal environment.

Compared to the conclusions above, in our LSI matrix we see both similarities and differences. We had indicated that agriculture has clear impacts on both inland and coastal water quality but not so much on fisheries and aquaculture. We had also highlighted a few conflicts between agricultural and coastal (mainly tourism) activities, which were confirmed from the sectoral workshops, although the participants seemed

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even more optimistic than us that the two sectors can co-exist within a healthy environment, increasing the economic status of the area. Regarding the disturbance of specific coastal activities (e.g. fisheries, aquaculture, coastal tourism) and the potential threats of land-sea relationships such as sea water intrusion, coastal water supply etc. that we addressed in the LSI matrix based on theoretical knowledge, there were no significant concerns from the participants in the workshops. This is also the case for the impacts of economic crisis on all activities in the region, in contrast to climate change for which, participants agreed that there are already signs of negative impacts.

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3.3 Multi-Actor Lab 3 - Norrström and Baltic Sea (Sweden)

3.3.1 Problem scope

The Baltic Sea is one of the world's largest brackish water bodies, with a land catchment area about four times larger than the sea surface area (Figure 13). In the Swedish part of the Baltic catchment, the Norrström drainage basin and its adjacent and surrounding coastal zones (MAL3 in COASTAL, also shown in Figure 13) is a key area with a large human population. It includes the Swedish capital of Stockholm as well as agricultural and industrial activities and contributes considerable nutrient loading to the Baltic Sea. As a consequence of such loading, the MAL3 archipelago and coastal waters, as many other parts of the Baltic Sea, suffer from eutrophication and harmful algae blooms. International agreements and environmental regulations put in place since decades still have not managed to decrease the nutrient loads from land sufficiently for combating the severe eutrophication, hypoxia and algae bloom problems in the coastal and marine waters of the Baltic Sea.

How to achieve sufficient management and mitigation of the nutrient loads in the short and long term, under changing human pressures and hydro-climatic conditions, is a key problem to address in MAL3 for the sustainable development of this coastal zone and its rural and urban hinterland areas, as for the entire catchment and coastal region of the whole Baltic Sea. Furthermore, also other environmental and social challenges need to be addressed and met for achieving sustainable development in this coastal region, such as maintaining ecosystem services and enhancing human wellbeing under multiple regional changes and change drivers.

Figure 13 The Baltic Sea and its catchment area with the Norrström drainage basin outlined in yellow.

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3.3.2 Overview of land-sea interactions

Figure 14 shows the aggregated LSI inventory carried out by the project team to define the problem scope for MAL3, resulting in a complex LSI matrix with a large number of positive, negative and unknown interactions.

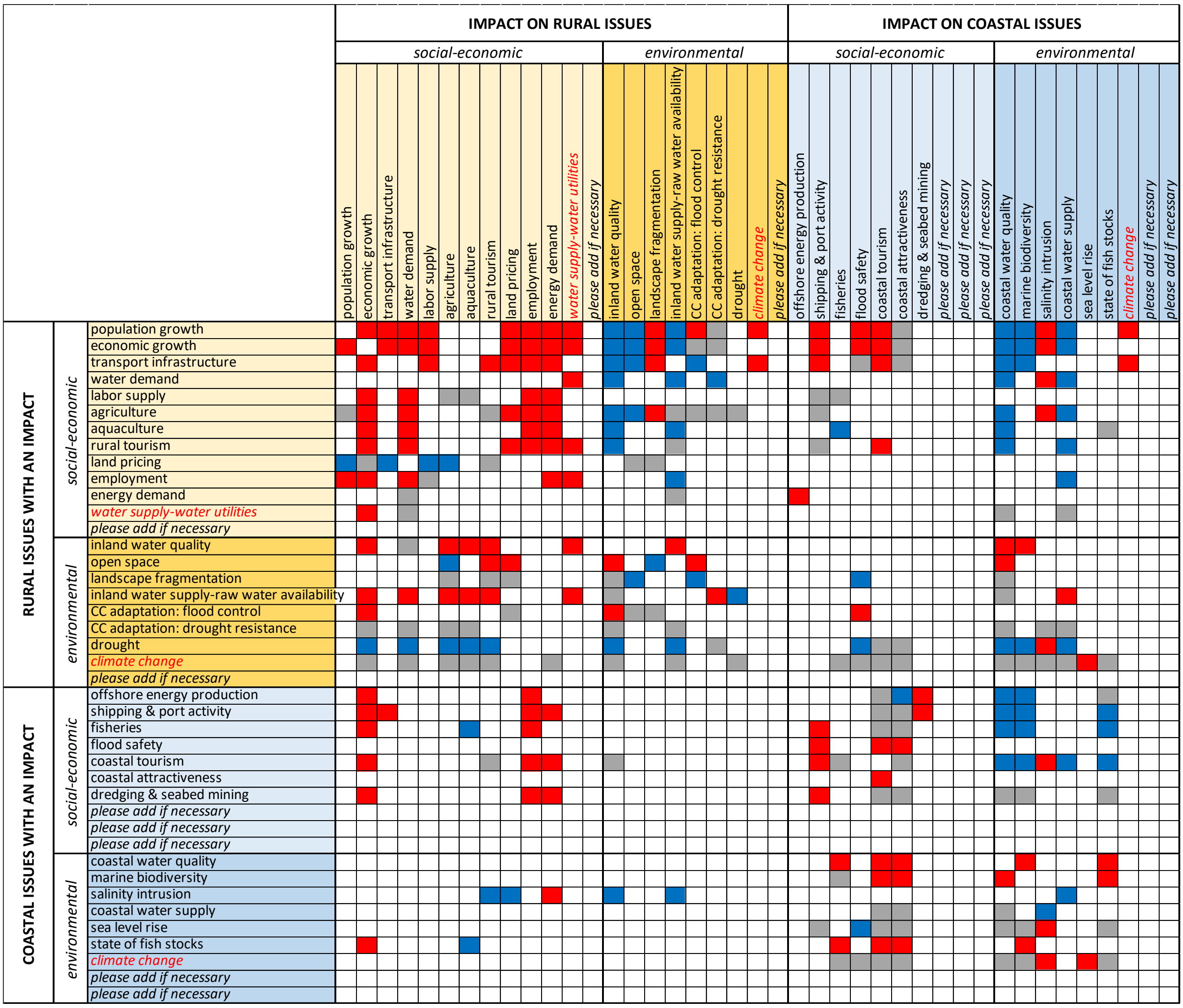

Figure 14 System interactions for the Norrström / Baltic Sea (project team analysis).

3.3.3 Overview of system feedback

In total 1408 reinforcing and 1995 balancing feedback loops were identified after 1 million iterations. We list a small sample:

Reinforcing feedback loops (sample, ordered by path length):

- *population growth→economic growth→population growth*
- *population growth→employment→population growth*

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- *economic growth→transport infrastructure→economic growth*
- *economic growth→labor supply→economic growth*
- *economic growth→employment→economic growth*
- *economic growth→water supply-water utilities→economic growth*
- *economic growth→shipping & port activity→economic growth*
- *economic growth→coastal tourism→economic growth*
- *transport infrastructure→shipping & port activity→transport infrastructure*
- *agriculture→open space→agriculture*
- *aquaculture→fisheries→aquaculture*
- *open space→landscape fragmentation→open space*
- *inland water supply-raw water availability→drought→inland water supply-raw water availability*
- *shipping & port activity→dredging & seabed mining→shipping & port activity*
- *coastal water quality→marine biodiversity→coastal water quality*
- *marine biodiversity→state of fish stocks→marine biodiversity*
- *salinity intrusion→coastal water supply→salinity intrusion*
- *population growth→transport infrastructure→economic growth→population growth*
- *agriculture→open space→land pricing→agriculture*
- *agriculture→salinity intrusion→land pricing→agriculture*
- *inland water supply-raw water availability→drought→salinity intrusion→inland water supply-raw water availability*
- *inland water supply-raw water availability→coastal water supply→salinity intrusion→inland water supply-raw water availability*
- *aquaculture→coastal water quality→fisheries→aquaculture*
- *aquaculture→coastal water quality→state of fish stocks→aquaculture*
- *employment→energy demand→offshore energy production→employment*
- *population growth→transport infrastructure→labor supply→economic growth→population growth*
- *agriculture→inland water quality→rural tourism→land pricing→agriculture*
- *agriculture→open space→rural tourism→land pricing→agriculture*
- *agriculture→salinity intrusion→rural tourism→land pricing→agriculture*
- *agriculture→landscape fragmentation→open space→land pricing→agriculture*
- *water demand→salinity intrusion→land pricing→agriculture→water demand*
- *agriculture→coastal water supply→salinity intrusion→land pricing→agriculture*
- *water demand→inland water quality→rural tourism→land pricing→agriculture→water demand*
- *agriculture→open space→inland water quality→rural tourism→land pricing→agriculture*
- *agriculture→salinity intrusion→inland water quality→rural tourism→land pricing→agriculture*
- *agriculture→landscape fragmentation→open space→rural tourism→land pricing→agriculture*
- *water demand→inland water supply-raw water availability→rural tourism→land pricing→agriculture→water demand*

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- *agriculture→employment→inland water supply-raw water availability→rural tourism→land pricing→agriculture*
- *agriculture→inland water quality→inland water supply-raw water availability→rural tourism→land pricing→agriculture*
- *agriculture→salinity intrusion→inland water supply-raw water availability→rural tourism→land pricing→agriculture*
- *water demand→salinity intrusion→rural tourism→land pricing→agriculture→water demand*
- *agriculture→coastal water supply→salinity intrusion→rural tourism→land pricing→agriculture*
- *water demand→coastal water supply→salinity intrusion→land pricing→agriculture→water demand*
- *agriculture→employment→coastal water supply→salinity intrusion→land pricing→agriculture*
- *water demand→salinity intrusion→inland water quality→rural tourism→land pricing→agriculture→water demand*
- *water demand→inland water quality→inland water supply-raw water availability→rural tourism→land pricing→agriculture→water demand*
- *water demand→salinity intrusion→inland water supply-raw water availability→rural tourism→land pricing→agriculture→water demand*
- *water demand→inland water supply-raw water availability→drought→rural tourism→land pricing→agriculture→water demand*
- *water demand→coastal water supply→salinity intrusion→rural tourism→land pricing→agriculture→water demand*
- *water demand→inland water supply-raw water availability→drought→salinity intrusion→land pricing→agriculture→water demand*
- *water demand→inland water supply-raw water availability→coastal water supply→salinity intrusion→land pricing→agriculture→water demand*

Balancing feedback loops:

- *population growth→land pricing→population growth*
- *economic growth→inland water quality→economic growth*
- *economic growth→inland water supply-raw water availability→economic growth*
- *transport infrastructure→land pricing→transport infrastructure*
- *water demand→inland water supply-raw water availability→water demand*
- *agriculture→land pricing→agriculture*
- *agriculture→inland water quality→agriculture*
- *aquaculture→inland water quality→aquaculture*
- *aquaculture→inland water supply-raw water availability→aquaculture*
- *rural tourism→inland water quality→rural tourism*

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- *fisheries→coastal water quality→fisheries*
- *fisheries→state of fish stocks→fisheries*
- *coastal tourism→coastal water quality→coastal tourism*
- *coastal tourism→marine biodiversity→coastal tourism*
- *coastal tourism→state of fish stocks→coastal tourism*
- *rural tourism→employment→inland water supply-raw water availability→rural tourism*
- *rural tourism→inland water quality→inland water supply-raw water availability→rural tourism*
- *rural tourism→coastal tourism→salinity intrusion→rural tourism*
- *rural tourism→coastal water supply→salinity intrusion→rural tourism*
- *aquaculture→inland water quality→inland water supply-raw water availability→aquaculture*
- *aquaculture→employment→inland water supply-raw water availability→aquaculture*
- *aquaculture→inland water supply-raw water availability→drought→aquaculture*
- *aquaculture→fisheries→state of fish stocks→aquaculture*
- *agriculture→employment→inland water supply-raw water availability→agriculture*
- *shipping & port activity→coastal water quality→fisheries→shipping & port activity*
- *shipping & port activity→state of fish stocks→fisheries→shipping & port activity*
- *shipping & port activity→coastal water quality→coastal tourism→shipping & port activity*
- *shipping & port activity→marine biodiversity→coastal tourism→shipping & port activity*
- *shipping & port activity→state of fish stocks→coastal tourism→shipping & port activity*
- *fisheries→marine biodiversity→coastal water quality→fisheries*
- *fisheries→coastal water quality→state of fish stocks→fisheries*
- *fisheries→marine biodiversity→state of fish stocks→fisheries*
- *coastal tourism→coastal water quality→coastal attractiveness→coastal tourism*
- *coastal tourism→marine biodiversity→coastal attractiveness→coastal tourism*
- *coastal tourism→state of fish stocks→coastal attractiveness→coastal tourism*
- *coastal tourism→coastal water quality→marine biodiversity→coastal tourism*
- *coastal tourism→coastal water quality→state of fish stocks→coastal tourism*
- *coastal tourism→marine biodiversity→state of fish stocks→coastal tourism*
- *aquaculture→employment→inland water supply-raw water availability→drought→aquaculture*
- *rural tourism→employment→inland water supply-raw water availability→drought→rural tourism*
- *rural tourism→employment→coastal water supply→salinity intrusion→rural tourism*
- *rural tourism→coastal tourism→employment→inland water supply-raw water availability→rural tourism*
- *agriculture→employment→inland water supply-raw water availability→drought→agriculture*
- *energy demand→offshore energy production→coastal attractiveness→coastal tourism→energy demand*
- *agriculture→coastal water quality→coastal tourism→salinity intrusion→land pricing→agriculture*
- *agriculture→employment→inland water supply-raw water availability→drought→inland water quality→agriculture*

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- *agriculture→employment→coastal water supply→salinity intrusion→inland water quality→agriculture*
- *agriculture→employment→coastal water supply→salinity intrusion→inland water supply-raw water availability→agriculture*
- *agriculture→energy demand→offshore energy production→employment→inland water supply-raw water availability→agriculture*
- *water demand→coastal water quality→coastal tourism→salinity intrusion→land pricing→agriculture→water demand*

3.3.4 Sector workshop results

As could be expected, the six sector workshops provided an even more extensive view of problem issues and system aspects than the LSI matrix for the MAL3 study region. *Figure 15* shows resulting causal loop diagrams from the workshops and, for direct comparison, Figure 16 illustrates the LSI matrix in a corresponding causal loop diagram context, considering also and linking to the same main drivers as in the sector workshops: *Water, Environmental challenges, Life style, Climate, Population, Policy, Infrastructure, and Regional economy*.

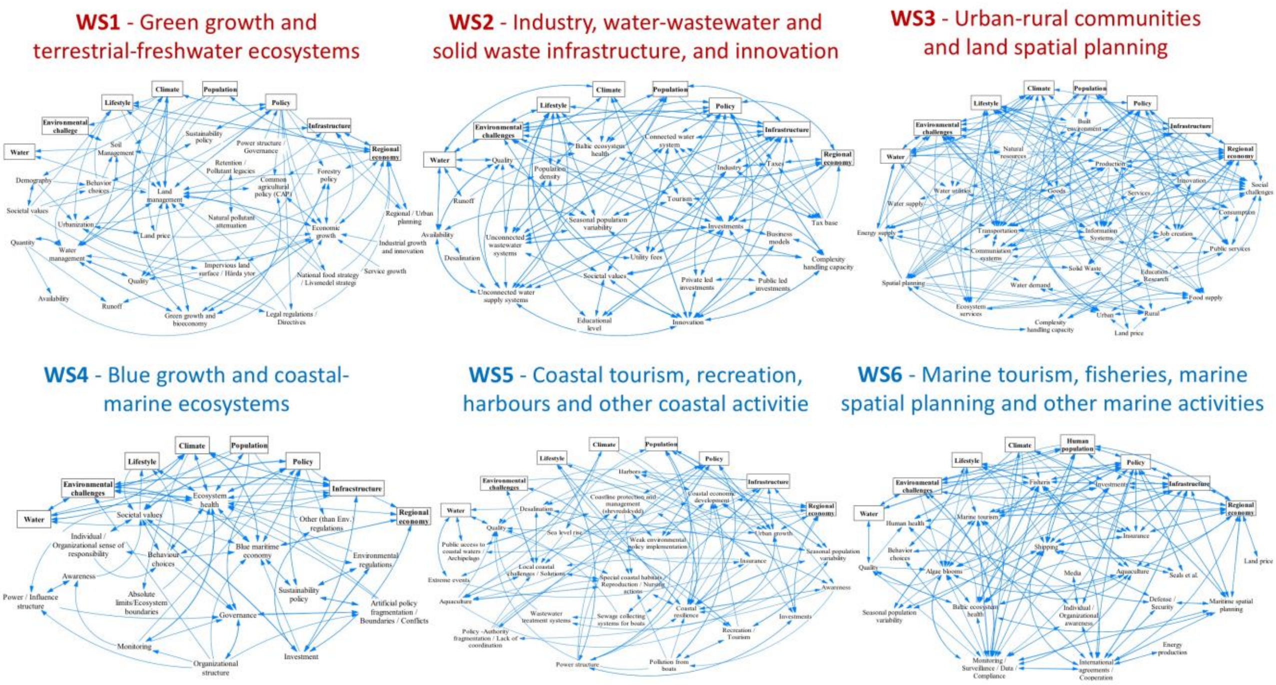

Figure 15 Causal loop diagrams from the six sector workshops (WS, with 3 top from land perspective, and three bottom from sea perspective) for the Norrström / Baltic Sea.

In summary, the comparison of causal loop diagrams shows a much larger variety of word elements, associated with different problem/system issues/aspects, across the sector workshops (*Figure 15*) than in the LSI matrix (Figure 16). The words (problem/system issues/aspects) that came up most frequently among

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(at least 3 of) the workshops were: *Water quality, Baltic ecosystem health, Investments, Land price, Recreation/Tourism, Behaviour choices, Societal values, Seasonal population variability, Power/influence structure*. These aspects are thus indicated as main concerns for various MAL3 sectors and stakeholders, with only some of them included in the LSI matrix (*Water quality, Land price, Tourism*, and to some degree also *Baltic ecosystem health* in terms of *Marine biodiversity* and *State of fish stocks*). Missing from the LSI matrix were: *Investments*, *Behaviour choices*, *Societal values*, and *Power/influence structure*, which all represent socio-economic issues and challenges; as well as *Seasonal population variability*, which represents a major socio-economic and environmental pressure/opportunity issue for development planning in coastal areas.

Furthermore, across the six workshops, the highest number of different words that, semantically, related most closely to one main driver came up for *Policy*. These *Policy*-related words highlighted a wide range of different types of policy seen by stakeholders as relevant for sustainable development in the MAL3 region. In contrast, the LSI matrix included only few *Policy*-related word elements/aspects of limited scope (*Flood safety* and *Climate change adaptation* policies for *flood control* and *drought resistance*). Finally, many words brought up by stakeholders across the sector workshops were semantically closest to concepts of *Biogeophysical system behaviour* and *Social challenges*, indicating these as two additional types of main drivers, with associated problem/system issues/aspects that were largely missing from the LSI matrix.

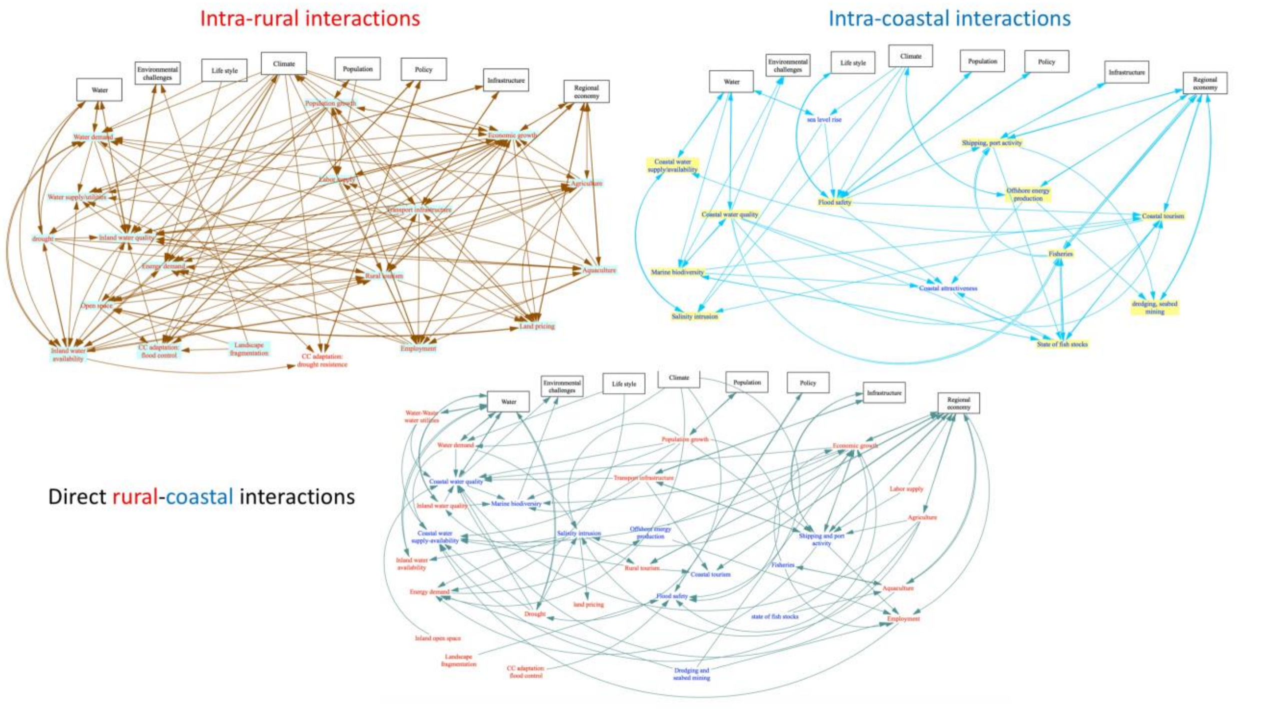

Figure 16 Causal loop diagrams created from the LSI matrix for the Norrström / Baltic Sea (Figure 14). For illustrative and comparative purposes, word elements in the LSI matrix are linked to the same main drivers as in the sector workshops (Figure 15), and only interactions marked as known in the LSI matrix (red and blue) are included; marked unknown (gray) interactions are excluded. The resulting causal loops are structured and illustrated separately for: (top left) intra-rural interactions (with light blue shading for elements with direct coastal links); (top right) intra-coastal interactions (with light yellow shading for elements with direct rural links); and (bottom) direct interactions among rural (red) and coastal (blue) elements.

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3.4 Multi-Actor Lab 4 - Charente River Basin (France)

3.4.1 Problem scope

The Charente River watershed (10000 km²) upstream, downstream and beyond the coastal zone is under significant environmental pressure from different economic activities such as summer tourism, agriculture, and shellfish farming. Environmental issues are even more important as the urban coastal population is steadily increasing, resulting in continued pressure on rural areas, protected areas and the many salty or freshwater wetlands. Drinking water, irrigated agriculture and the quality of aquatic environments require large volumes of water. Water resources are limited, and this limitation is even enhanced by the effect of climate change. This situation although quite frequent in France and Europe is exacerbated in the Charente catchment area. Pressure on water resources affects both quality (i.e. pollution by nitrate and pesticides) and quantity (impact on natural environments and availability of drinking water). In this area, activities carried out inland (irrigation of crops, use of nitrate (cereal crops) and pesticides (particularly on vines used for Cognac production) and domestic use have a significant impact on water resources. Changes in farming practices are the only opportunity to improve the quality of fresh water resources. This impact is felt downstream, in coastal areas, in significant sectors for the local economy such as shellfish farming and tourism.

Coastal water quality (salinity, planktonic and benthic production) is of utmost importance for selfish farming and professional inshore fishing. In addition, the flatness of the coast, the presence of important wetlands increases the effects of climate change (sea level rise) and the possible rise of salt in agricultural or coastal farming areas. At the same time, the two major ports in the area rely on local agricultural produce for a sizeable portion of their business. Any significant change in activities and land use in one part of the area will impact employment in several sectors in other location of the rural-coastal zone.
What is added to that situation is the continuous increase of residential elderly population and of tourists on coastal zones causing important effect on land prices and changes of demand for products and services.

New development opportunities in this bring up questions that are controversial or sensitive: The development of reservoirs could be a means for farmers to access a reliable source of water to irrigate their crops and ensure production of their main export crops (cereals, corn), on which the activity of La Rochelle port largely depends. Another new opportunity likely to cause disruption is a shift from present farming systems towards organic farming, with less water-hungry crops. The development of diversified crops could be a real opportunity for the second merchant port along the Charente River, (Tonnay-Charente), which, due to its more upstream location, can only be reached by smaller vessels.

3.4.2 Overview of land-sea interactions

The LSI matrix for this MAL was more complex, due to the larger number of positive, negative and unknown interactions.

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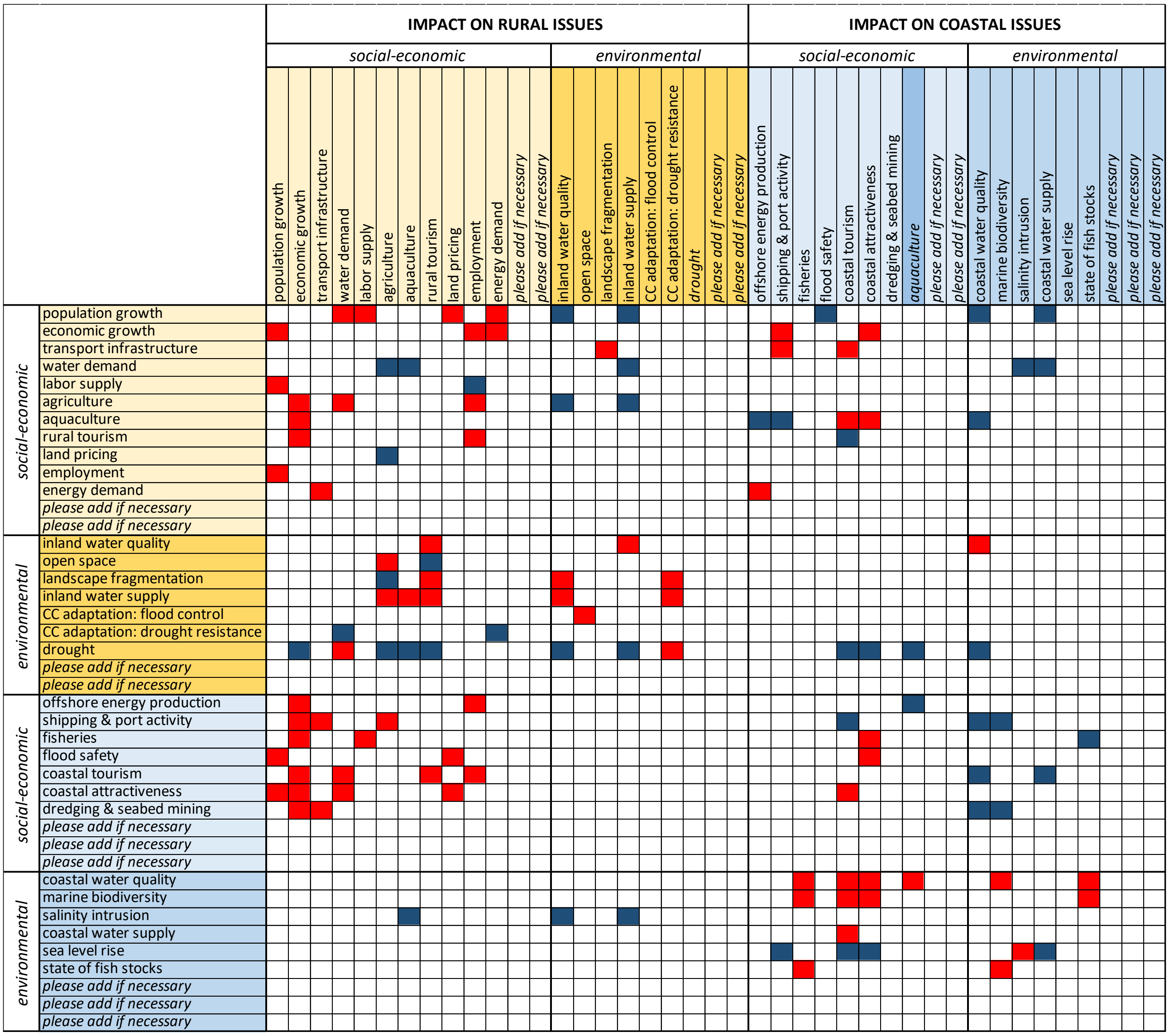

Figure 17 System interactions for the Charente (project team analysis).

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3.4.3 Overview of system feedback

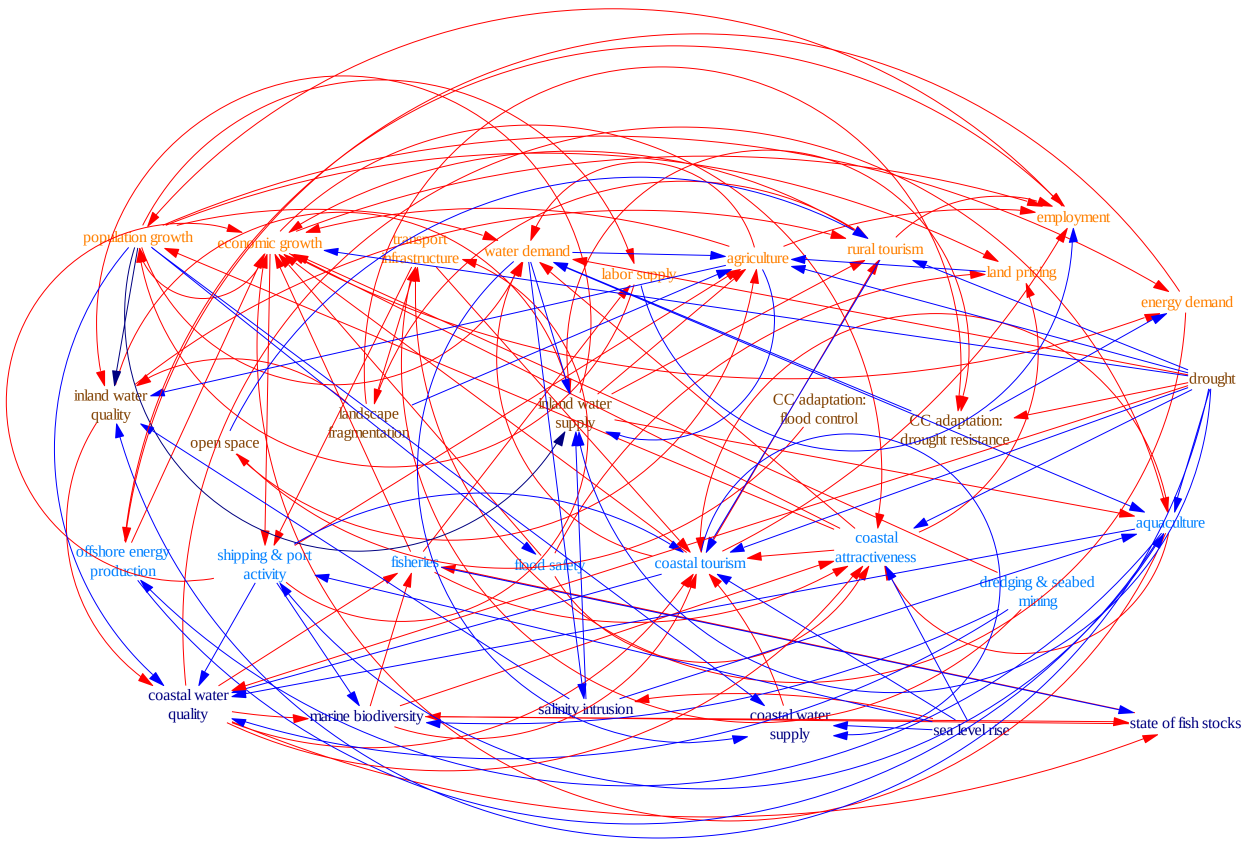

Figure 18 Causal-loop diagram in VenSim for the Charente MAL, based on the land-sea interactions of Figure 17.

In total 1362 reinforcing and 1230 balancing feedback loops were identified after 1 million iterations. We list a small sample:

Reinforcing feedback loops (sample, ordered by path length):

- *population growth→labor supply→population growth*
- *economic growth→shipping & port activity→economic growth*
- *economic growth→coastal attractiveness→economic growth*
- *transport infrastructure→shipping & port activity→transport infrastructure*
- *inland water quality→inland water supply→inland water quality*
- *marine biodiversity→state of fish stocks→marine biodiversity*
- *water demand→aquaculture→shipping & port activity→agriculture→water demand*
- *water demand→aquaculture→coastal water quality→coastal tourism→water demand*
- *water demand→aquaculture→coastal water quality→coastal attractiveness→water demand*
- *water demand→aquaculture→offshore energy production→rural tourism→coastal tourism→water demand*

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- *transport infrastructure→coastal tourism→water demand→aquaculture→shipping & port activity →transport infrastructure*
- *fisheries→state of fish stocks→marine biodiversity→coastal tourism→coastal water quality→fisheries*
- *water demand→aquaculture→coastal tourism→coastal water quality→coastal attractiveness→water demand*
- *water demand→aquaculture→coastal attractiveness→land pricing→agriculture→water demand*
- *water demand→aquaculture→coastal water quality→fisheries→coastal attractiveness→water demand*
- *water demand→aquaculture→coastal water quality→coastal attractiveness→coastal tourism→water demand*
- *water demand→aquaculture→coastal water quality→marine biodiversity→coastal tourism→water demand*
- *water demand→aquaculture→coastal water quality→marine biodiversity→coastal attractiveness→water demand*
- *water demand→inland water supply→aquaculture→shipping & port activity→agriculture→water demand*
- *water demand→aquaculture→shipping & port activity→coastal tourism→coastal water quality→coastal attractiveness→water demand*
- *water demand→aquaculture→coastal tourism→coastal water quality→fisheries→coastal attractiveness→water demand*
- *water demand→aquaculture→coastal tourism→coastal water quality→marine biodiversity→coastal attractiveness→water demand*
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- *water demand→aquaculture→coastal water quality→state of fish stocks→fisheries→coastal attractiveness→water demand*
- *water demand→aquaculture→coastal water quality→state of fish stocks→marine biodiversity→coastal tourism→water demand*
- *water demand→aquaculture→coastal water quality→state of fish stocks→marine biodiversity→coastal attractiveness→water demand*
- *water demand→inland water supply→aquaculture→offshore energy production→rural tourism→coastal tourism→water demand*
- *transport infrastructure→coastal tourism→water demand→inland water supply→aquaculture→shipping & port activity→transport infrastructure*

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- *water demand→aquaculture→shipping & port activity→coastal tourism→coastal water quality→fisheries→coastal attractiveness→water demand*
- *water demand→aquaculture→shipping & port activity→coastal tourism→coastal water quality→marine biodiversity→coastal attractiveness→water demand*
- *water demand→aquaculture→shipping & port activity→coastal water quality→coastal attractiveness→land pricing→agriculture→water demand*
- *water demand→aquaculture→shipping & port activity→marine biodiversity→coastal tourism→coastal water quality→coastal attractiveness→water demand*
- *water demand→aquaculture→shipping & port activity→marine biodiversity→coastal attractiveness→land pricing→agriculture→water demand*
- *water demand→aquaculture→coastal tourism→coastal water quality→marine biodiversity→fisheries→coastal attractiveness→water demand*
- *water demand→aquaculture→coastal tourism→coastal water quality→state of fish stocks→fisheries→coastal attractiveness→water demand*
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- *water demand→aquaculture→coastal water quality→state of fish stocks→fisheries→coastal attractiveness→coastal tourism→water demand*
- *water demand→aquaculture→coastal water quality→state of fish stocks→marine biodiversity→fisheries→coastal attractiveness→water demand*
- *water demand→aquaculture→coastal water quality→state of fish stocks→marine biodiversity→coastal attractiveness→coastal tourism→water demand*
- *water demand→inland water supply→aquaculture→shipping & port activity→coastal tourism→coastal water quality→coastal attractiveness→water demand*
- *water demand→inland water supply→aquaculture→coastal tourism→coastal water quality→fisheries→coastal attractiveness→water demand*
- *transport infrastructure→landscape fragmentation→inland water quality→inland water supply→agriculture→water demand→aquaculture→shipping & port activity→transport infrastructure*
- *water demand→aquaculture→shipping & port activity→coastal water quality→fisheries→coastal attractiveness→land pricing→agriculture→water demand*
- *water demand→aquaculture→shipping & port activity→coastal water quality→marine biodiversity→coastal attractiveness→land pricing→agriculture→water demand*
- *water demand→aquaculture→shipping & port activity→marine biodiversity→fisheries→coastal attractiveness→land pricing→agriculture→water demand*

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- *water demand→inland water supply→aquaculture→shipping & port activity→coastal water quality→coastal attractiveness→land pricing→agriculture→water demand*
- *water demand→inland water supply→aquaculture→shipping & port activity→marine biodiversity→coastal attractiveness→land pricing→agriculture→water demand*

Balancing feedback loops (sample, ordered by path length):

- *population growth→flood safety→population growth*
- *water demand→agriculture→water demand*
- *agriculture→inland water supply→agriculture*
- *rural tourism→coastal tourism→rural tourism*
- *fisheries→state of fish stocks→fisheries*
- *coastal tourism→coastal water quality→coastal tourism*
- *coastal tourism→coastal water supply→coastal tourism*
- *coastal tourism→coastal water quality→coastal attractiveness→coastal tourism*
- *coastal tourism→coastal water quality→marine biodiversity→coastal tourism*
- *fisheries→state of fish stocks→marine biodiversity→fisheries*
- *water demand→aquaculture→coastal tourism→water demand*
- *water demand→aquaculture→coastal attractiveness→water demand*
- *population growth→water demand→agriculture→economic growth→population growth*
- *transport infrastructure→landscape fragmentation→CC adaptation: drought resistance→energy demand→transport infrastructure*
- *water demand→aquaculture→shipping & port activity→coastal tourism→water demand*
- *fisheries→coastal attractiveness→coastal tourism→coastal water quality→fisheries*
- *coastal tourism→coastal water quality→marine biodiversity→coastal attractiveness→coastal tourism*
- *coastal tourism→coastal water quality→state of fish stocks→marine biodiversity→coastal tourism*
- *water demand→aquaculture→coastal attractiveness→coastal tourism→water demand*
- *water demand→aquaculture→shipping & port activity→coastal water quality→coastal tourism→water demand*
- *water demand→aquaculture→shipping & port activity→coastal water quality→coastal attractiveness→water demand*
- *water demand→aquaculture→shipping & port activity→marine biodiversity→coastal tourism→water demand*
- *water demand→aquaculture→shipping & port activity→marine biodiversity→coastal attractiveness→water demand*
- *fisheries→coastal attractiveness→coastal tourism→coastal water quality→marine biodiversity→fisheries*

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- *fisheries→coastal attractiveness→coastal tourism→coastal water quality→state of fish stocks→fisheries*
- *coastal tourism→coastal water quality→state of fish stocks→marine biodiversity→coastal attractiveness→coastal tourism*
- *transport infrastructure→landscape fragmentation→inland water quality→inland water supply→aquaculture→shipping & port activity→transport infrastructure*
- *transport infrastructure→landscape fragmentation→CC adaptation: drought resistance→water demand→aquaculture→shipping & port activity→transport infrastructure*
- *water demand→aquaculture→shipping & port activity→coastal water quality→fisheries→coastal attractiveness→water demand*
- *water demand→aquaculture→shipping & port activity→coastal water quality→coastal attractiveness→coastal tourism→water demand*
- *water demand→aquaculture→shipping & port activity→coastal water quality→marine biodiversity→coastal tourism→water demand*
- *water demand→aquaculture→shipping & port activity→coastal water quality→marine biodiversity→coastal attractiveness→water demand*
- *water demand→aquaculture→shipping & port activity→marine biodiversity→fisheries→coastal attractiveness→water demand*
- *water demand→aquaculture→shipping & port activity→marine biodiversity→coastal attractiveness→coastal tourism→water demand*
- *water demand→aquaculture→offshore energy production→rural tourism→coastal tourism→coastal water quality→coastal attractiveness→water demand*
- *transport infrastructure→landscape fragmentation→rural tourism→coastal tourism→water demand→aquaculture→shipping & port activity→transport infrastructure*
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- *water demand→aquaculture→shipping & port activity→coastal water quality→fisheries→coastal attractiveness→coastal tourism→water demand*
- *water demand→aquaculture→shipping & port activity→coastal water quality→marine biodiversity→fisheries→coastal attractiveness→water demand*
- *water demand→aquaculture→shipping & port activity→coastal water quality→marine biodiversity→coastal attractiveness→coastal tourism→water demand*
- *water demand→aquaculture→shipping & port activity→coastal water quality→state of fish stocks→fisheries→coastal attractiveness→water demand*
- *water demand→aquaculture→shipping & port activity→coastal water quality→state of fish stocks→marine biodiversity→coastal tourism→water demand*
- *water demand→aquaculture→shipping & port activity→coastal water quality→state of fish stocks→marine biodiversity→coastal attractiveness→water demand*

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- *water demand→aquaculture→shipping & port activity→marine biodiversity→fisheries→coastal attractiveness→coastal tourism→water demand*
- *water demand→aquaculture→shipping & port activity→marine biodiversity→state of fish stocks→fisheries→coastal attractiveness→water demand*
- *water demand→aquaculture→coastal tourism→coastal water quality→coastal attractiveness→land pricing→agriculture→water demand*
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- *water demand→aquaculture→coastal water quality→fisheries→state of fish stocks→marine biodiversity→coastal tourism→water demand*
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3.4.4 Sector workshop results

As could be expected, the six sector workshops (Agriculture and Agro-industry; Water sector; Environmental and territorial development policies; Port activities, infrastructures, energy; Shellfish farming, aquaculture and fishing; Rural and coastal tourism) provided a detailed analysis and a wider overview of the issues and concerns of rural and coastal areas with links and connections between sectors.

The key topics discussed in the workshops were the following: impacts of climate change, population changes and concentration of activities, development of organic farming and adaptation of current farming systems, inland water storage, development of sustainable energies, and adaptation of coastal activities to sea level rises.

Analysis of problems and priorities reveals that all sectors of activities are going to face constraints on water resources, and climate change consequences such as water shortages and intrusion of saline water.

Adapting to address these concerns presents opportunities to change production systems (particularly farming systems) and practices to make current activities more future-proof.

The main coastal, rural, and land-sea interactions identified during the workshop are listed below:

- High dependence of downstream activities on upstream activities in terms of water quantity and quality. Coastal water quality is essential for shellfish farming and tourism and depends on water uptake and pollution.
- The attractiveness of coastal areas amplifies the increase and changes of population because both summer tourists and retirees favour coastal zones. This phenomenon causes an upsurge in land prices, a change in consumption behaviour, and demands for new services.
- Summer tourism causes coastal congestion and leads to a growing demand for drinking water and needs for larger capacities for water treatment plants.
- The development of ports relies on inland agricultural production and any change in farming systems may have large impact on port activities. When crops are diversified, ports should adapt their activities. The Tonnay-Charente port is better suited to such changes than the La Rochelle port, which tends to develop greater capacity for receiving huge container ships.
- Climate change will impact coastal zones, coastal farmland, and the need to develop adapted agriculture and tourism in these areas.

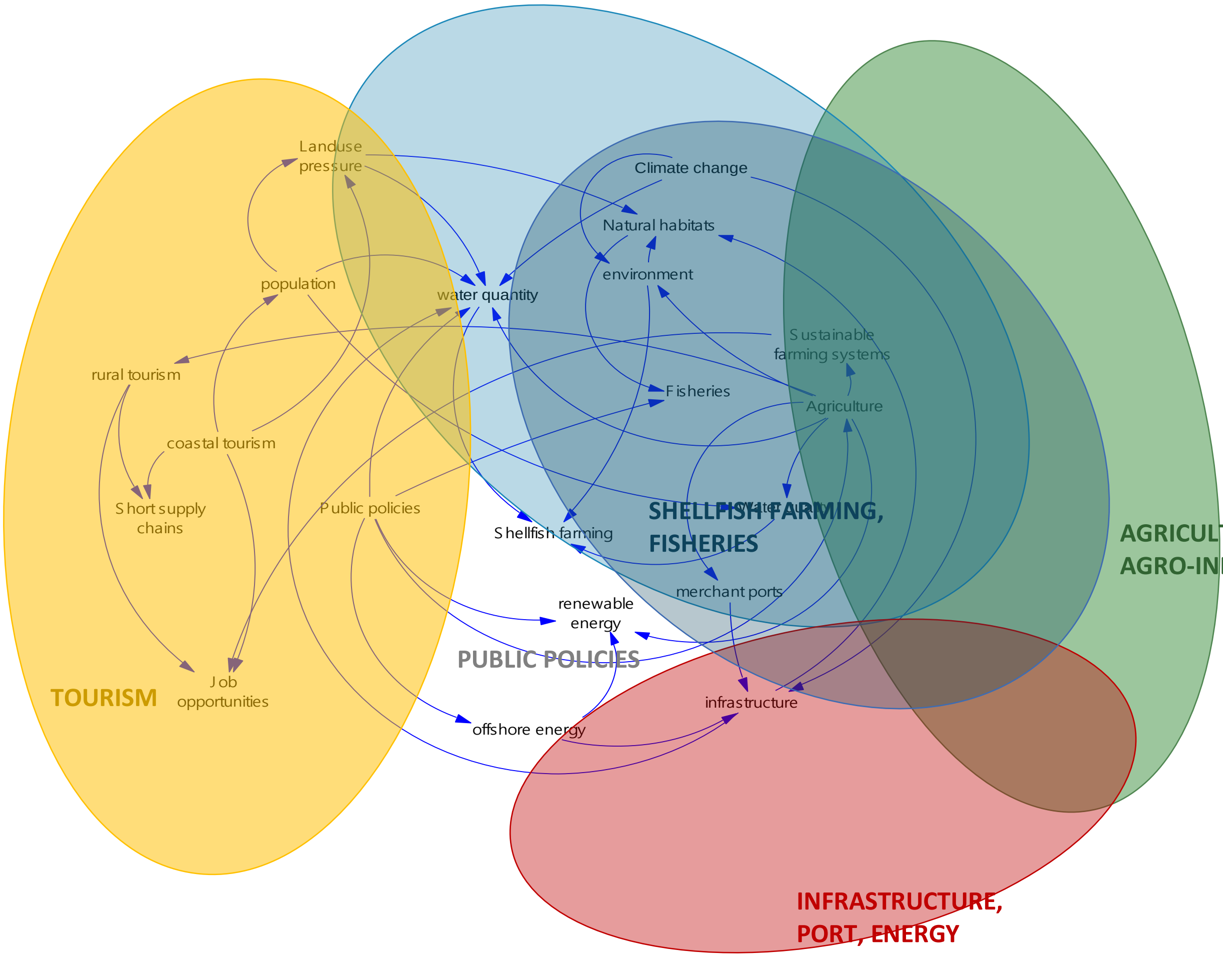

Figure 19 gives an overview mind map for the main land-sea interactions identified during the sector workshops.

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3.5 Multi-Actor Lab 5 -Danube's Mouths and Black Sea (Romania)

3.5.1 Problem scope

The Black Sea has special natural features due to its semi-enclosed location and catchment area five times higher than its surface. Therefore, it is vulnerable to anthropogenic pressures and pollution sources (BSC, 2008). Until the '60s, the Western part of the Black Sea (Danube's mouths) was known as an example of natural eutrophic ecosystem due to the permanent Danube's nutrients input (Gomoiu, 1981). Further, with anthropogenic activities enhancement, increased use of fertilizers, wastewater discharges, detergents, etc., the nutrients regime has undergone significant changes. These changes were related to the Danube's nutrients input that increased significantly (Mee & Topping, 1999; Cociaşu et al., 2008) and led to alterations in the Black Sea ecosystem. Mismanagement of nutrients in the Danube Basin has led to severe ecological problems: the deterioration of groundwater resources and the eutrophication of rivers, lakes and especially the Black Sea. These problems were directly related to social and economic issues (e.g. drinking water supply, tourism and fishery as affected sectors; agriculture, nutrition, industry and waste water management as drivers) (danubs). The Black Sea eutrophication effects appeared soon: the transparency decreasing, higher quantities of organic matter decomposition and oxygen depletion (Gomoiu, 1992) and bottom waters became seasonally hypoxic or even anoxic (ICPDR – ICBS, 1999) transforming the North Western part of the Black Sea into a highly eutrophic one (Zaitsev in Mee, 1999). In the early 90s, have found decreasing nutrients input resulted in the first recovery signs (decreasing of phytoplankton blooms, improvement of bottom oxygen regime, increasing of benthic macro fauna (Gomoiu, 1992).

The second largest wetland of Europe — after the Volga Delta — is the Danube Delta and the adjacent Razim-Sinoe complex of lagoons, located in Romania and Ukraine. The Danube River splits into three channels: the Chilia, the Sulina and the Sfântu Gheorghe, carrying 63 %, 16 % and 21 % of the total runoff respectively. Navigation is possible only through the Sulina Channel, which has been straightened and dredged along its 60 km length. The nutrient regime of the Danube has undergone significant changes due to increased economic activity, use of fertilizers, waste water discharges, and use of detergents, leading to changes in the Black Sea ecosystem. Eutrophication results in decreased transparency, higher quantities of organic matter decomposition and oxygen depletion with bottom waters becoming seasonally hypoxic or even anoxic. Since the early 90s decreasing nutrient inputs resulted in signs of recovery. Today the Black Sea catchment is still under pressure from excess nutrients and contaminants due to emissions from agriculture, tourism, industry and urbanization in the Danube basin. This prevents achieving the Good Environmental Status by 2020, as required by the EU-Marine Strategy Framework Directive. The increased rates of eutrophication, pollution and bioaccumulation affect both the biodiversity (including Natura 2000 sites) and fishing sectors. Mass tourism is an important growth sector for the Black Sea and eco-tourism is becoming more important in the region. Approximately 65% of the Romanian coastline is in the Danube Delta Biosphere Reserve and subject to tourism regulations, resulting in conflicts between nature conservation and economic development. Failing to resolve these conflicts has economic and political impacts.

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3.5.2 Overview of land-sea interactions

The LSI matrix for this MAL was more complex, due to the larger number of positive, negative and unknown interactions.

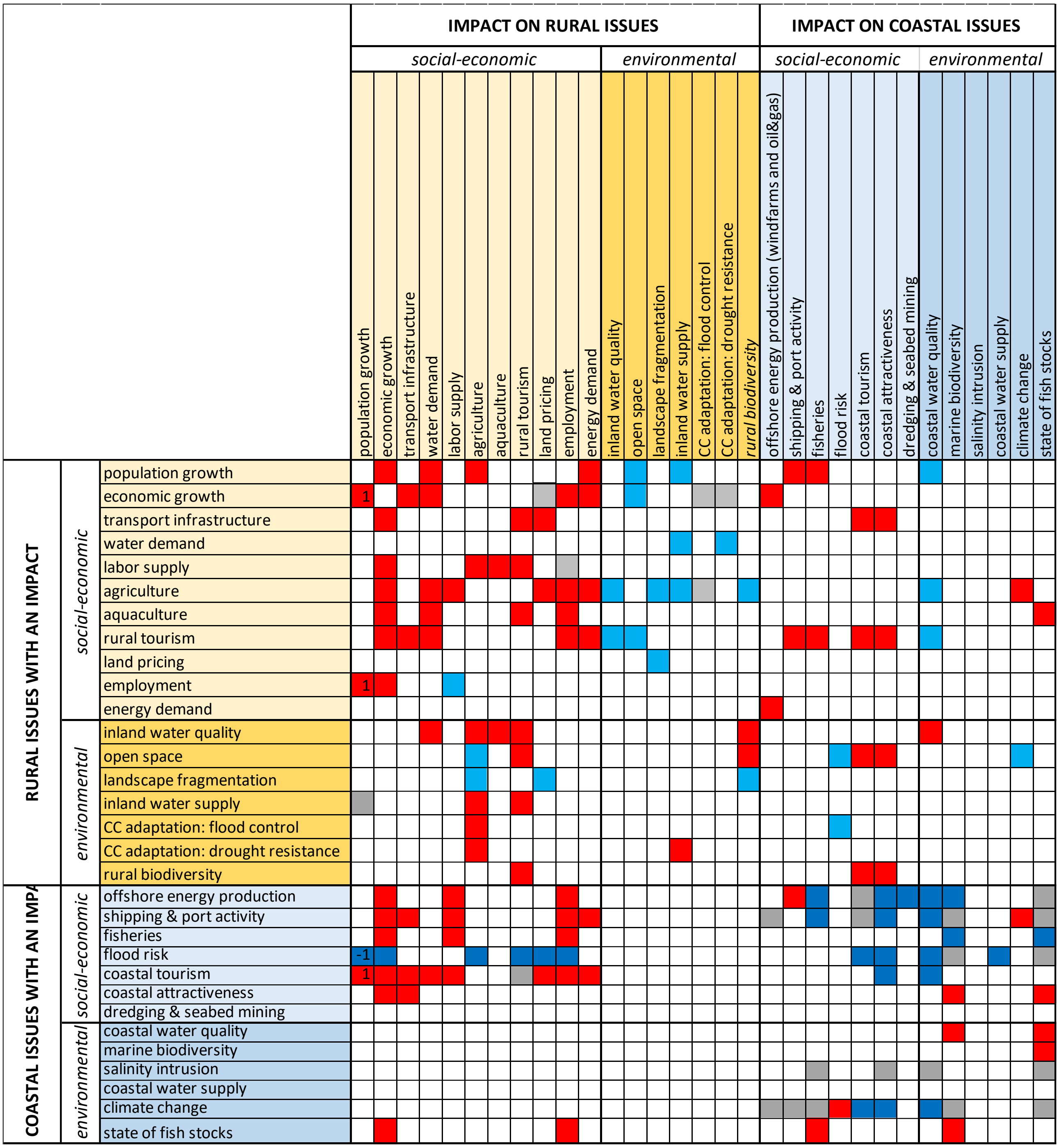

Figure 20 System interactions for the Danube Mouth and Black Sea (project team analysis).

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3.5.3 Overview of system feedback

In total 1062 reinforcing and 1159 balancing feedback loops were identified after 1 million iterations. We list a small sample:

Balancing feedback loops (sample, ordered by path length):

- *agriculture→inland water quality→agriculture*
- *agriculture→inland water supply→agriculture*
- *rural tourism→inland water quality→rural tourism*
- *rural tourism→open space→rural tourism*
- *fisheries→state of fish stocks→fisheries*
- *transport infrastructure→coastal tourism→coastal attractiveness→transport infrastructure*
- *aquaculture→rural tourism→inland water quality→aquaculture*
- *rural tourism→inland water quality→rural biodiversity→rural tourism*
- *rural tourism→open space→rural biodiversity→rural tourism*
- *rural tourism→open space→flood risk→rural tourism*
- *fisheries→marine biodiversity→state of fish stocks→fisheries*
- *labor supply→aquaculture→employment→labor supply*
- *labor supply→rural tourism→employment→labor supply*
- *labor supply→agriculture→employment→labor supply*
- *transport infrastructure→rural tourism→open space→coastal tourism→transport infrastructure*
- *transport infrastructure→rural tourism→open space→coastal attractiveness→transport infrastructure*
- *transport infrastructure→rural tourism→shipping & port activity→coastal attractiveness→transport infrastructure*
- *transport infrastructure→rural tourism→coastal tourism→coastal attractiveness→transport infrastructure*
- *labor supply→aquaculture→rural tourism→employment→labor supply*
- *rural tourism→open space→climate change→flood risk→rural tourism*
- *rural tourism→shipping & port activity→climate change→flood risk→rural tourism*
- *labor supply→aquaculture→state of fish stocks→employment→labor supply*
- *labor supply→rural tourism→inland water quality→agriculture→labor supply*
- *labor supply→rural tourism→open space→coastal tourism→labor supply*
- *labor supply→rural tourism→shipping & port activity→employment→labor supply*

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Reinforcing feedback loops (sample, ordered by path length):

- *population growth→economic growth→population growth*
- *economic growth→transport infrastructure→economic growth*
- *economic growth→employment→economic growth*
- *economic growth→offshore energy production (windfarms and oil&gas)→economic growth*
- *transport infrastructure→rural tourism→transport infrastructure*
- *transport infrastructure→coastal tourism→transport infrastructure*
- *transport infrastructure→coastal attractiveness→transport infrastructure*
- *labor supply→agriculture→labor supply*
- *agriculture→landscape fragmentation→agriculture*
- *land pricing→landscape fragmentation→land pricing*
- *marine biodiversity→state of fish stocks→marine biodiversity*
- *transport infrastructure→rural tourism→shipping & port activity→transport infrastructure*
- *transport infrastructure→rural tourism→coastal tourism→transport infrastructure*
- *transport infrastructure→rural tourism→coastal attractiveness→transport infrastructure*
- *energy demand→offshore energy production (windfarms and oil&gas)→shipping & port activity→energy demand*
- *labor supply→rural tourism→shipping & port activity→labor supply*
- *labor supply→rural tourism→fisheries→labor supply*
- *labor supply→rural tourism→coastal tourism→labor supply*
- *agriculture→land pricing→landscape fragmentation→agriculture*
- *labor supply→aquaculture→rural tourism→shipping & port activity→labor supply*
- *labor supply→aquaculture→rural tourism→fisheries→labor supply*
- *labor supply→aquaculture→rural tourism→coastal tourism→labor supply*
- *labor supply→aquaculture→state of fish stocks→fisheries→labor supply*
- *transport infrastructure→coastal tourism→labor supply→rural tourism→transport infrastructure*
- *labor supply→rural tourism→energy demand→offshore energy production (windfarms and oil&gas)→labor supply*
- *labor supply→rural tourism→open space→agriculture→labor supply*

3.5.4 Sector workshop results

As could be expected, the six sector workshops (*Coastal* - Blue Growth, Tourism, Fisheries, *Rural* – Farming, Rural Tourism, Policy Making) provided a more detailed analysis of the problems and priorities of the study region. All the different sectors were aware of the links among the different economic activities, and were able to discuss opportunities, obstacles as well as identify interactions with other sectors and the Black Sea.

In summary the following coastal, rural, and land-sea interactions were identified by the stakeholders:

- Danube's Delta clogged canals and invasive species (jackal) are disturbing the transport, fisheries and tourism in the area.

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- It was highlighted the lack of local authority and decisions for development usually governed by national/regional authorities.
- The under-development drove to the depopulation of the areas. Thus, many houses are now the property of the people from developed area (big cities) who have no time and so much interest to participate in the area development.

A general conclusion outlined that governance and excessive bureaucracy are disturbing the business (planning, facilities for investors (lack of), lack of compensatory measures, tourism, infrastructure) and social areas (health, incomes, protection, jobs), moving away from real problems like the conflict between Marine Protected Areas (and restrictive measures) and the exploitation of resources or the Danube Delta's clogged canals and invasive species (jackal). Compared to the conclusions above, in our LSI matrix we see both similarities and differences. We had indicated that agriculture has clear impacts on both inland and coastal water quality and found that the locals are not aware of causes, effects and impacts of the pollution on the Black Sea and even on the limited areas. The agriculture is a subsistence one and the area is very poor developed. On the contrary, due to the Danube Delta protected area there is a pressure downward the coastal zone for the seasonal tourism (only three - four months/year). Thus, there is a population artificial "growth" which is not sustained by the "real" economic development reflecting some partial similarities with the LSI matrix.

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3.6 Multi-Actor Lab 6 - Mar Menor Coastal Lagoon (Spain)

3.6.1 Problem scope

The Mar Menor coastal lagoon (135 km2) is located in the Region of Murcia (SE Spain). The area is characterized by multiple environmental, social-cultural and economic interests, often competing for scarce resources, water being the most important. There is a high potential for complementarity, win-win scenarios and development of sustainable business cases based on public-private collaboration, efficient use of water, and innovative farming practices and a transition to sustainable models of tourism and agriculture. The Campo de Cartagena catchment draining into the Mar Menor covers an area of 1.255 km2 and is mainly covered by intensive irrigated agricultural and tree crops. The intensive and highly profitable irrigated agriculture depends on scarce low-quality groundwater and water from inland inter-basin water transfers. Agriculture provides labour and income to the region but forms a source of excessive nutrients and contamination into the Mar Menor coastal lagoon. The resulting poor water quality affects the ecology of the lagoon with severe implications for its potential function for tourism and fisheries. The coastal lagoon forms part of a Specially Protected Area of Mediterranean Importance (SPAMI). The Mar Menor is one of the hotspots for tourism in the Region of Murcia, with a total number of 346,000 tourists and 1.4 million over-night stays in 2016. Beside international visitors, the Mar Menor has an important touristic function for the regional population (1.5 million inhabitants). The availability of water for irrigation and drinking water for tourism will be further reduced under future climate conditions. As such, the Mar Menor is strongly influenced by interactions between inland agriculture on the one side, and coastal tourism and fisheries affecting natural ecological values and socioeconomic sustainability on the other side. The need to move towards sustainable modes of agriculture, fishery and tourism is increasingly recognized and recently revived strongly due to sudden increase in contamination levels resulting in a strong drop in tourism. The main driver that has caused a hydrological and nutrients imbalance in the study area is intensive agriculture. The opening of the Tajo-Segura water transfer in the 80's promoted an uncontrolled flourishing of irrigated croplands in an area that had been traditionally dominated by rainfed agriculture. Pubic administrations are not controlling that best agricultural practices are being implemented and there is a general lack of support of touristic activities by the local and regional governments, favouring the development of agriculture, which is the main cause of the ecological crash of the Mar Menor lagoon. This crash is, on the other hand, negatively affecting the attractiveness and touristic potential of the area, impoverishing local communities.

3.6.2 Overview of land-sea interactions

The LSI matrix for this MAL was less complex, due to the limited number of positive, negative and unknown interactions.

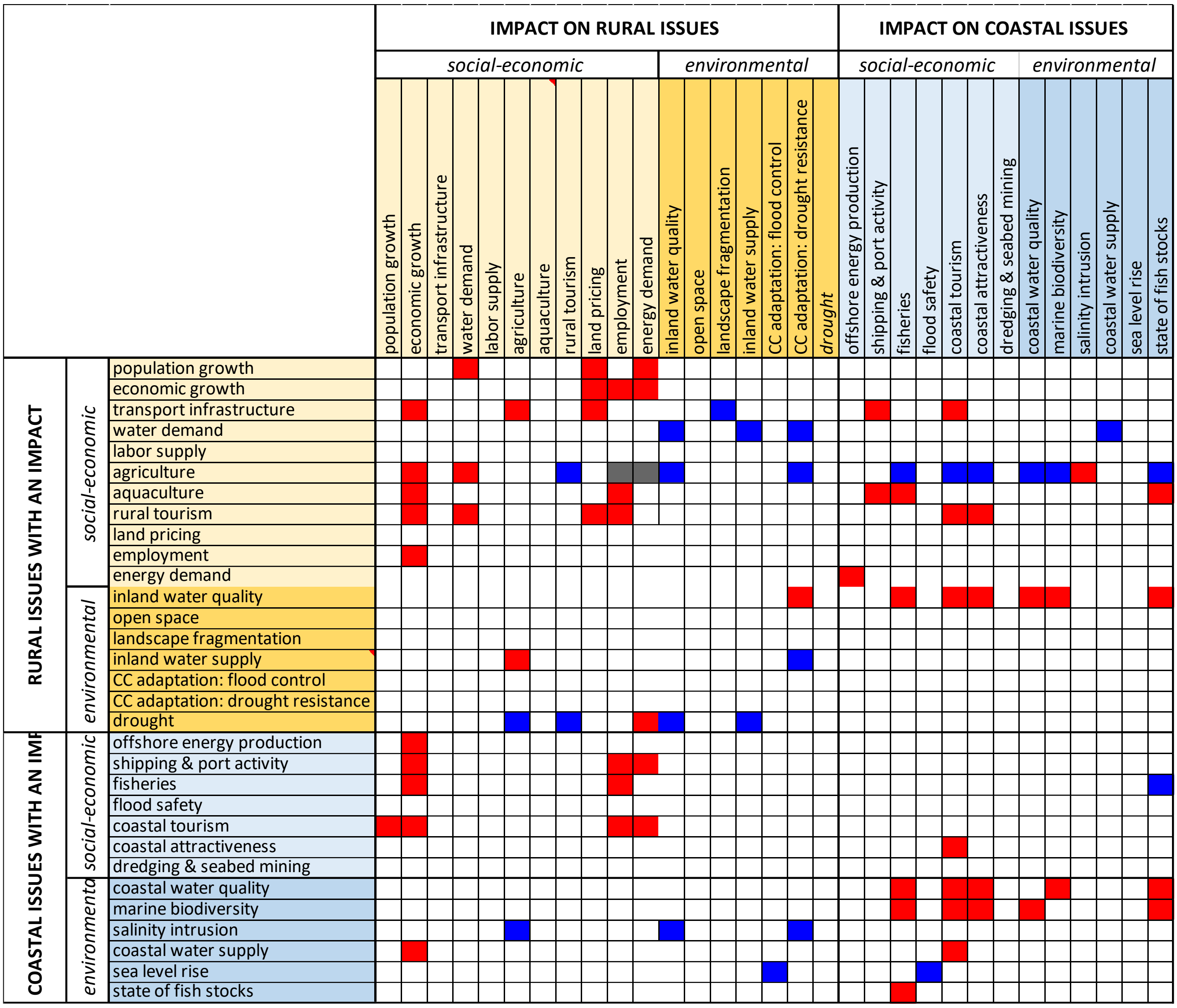

Figure 21 System interactions for the Mar Menor Lagoon (project team analysis).

3.6.3 Overview of system feedback

In total 34 reinforcing and 14 balancing feedback loops were identified after 1 million iterations. We list a small sample:

<u>Balancing feedback loops</u> (sample, ordered by path length):

- *agriculture→salinity intrusion→agriculture*
- *fisheries→state of fish stocks→fisheries*
- *water demand→inland water supply→agriculture→water demand*
- *population growth→water demand→inland water quality→coastal tourism→population growth*
- *population growth→water demand→coastal water supply→coastal tourism→population growth*
- *population growth→water demand→inland water quality→coastal attractiveness→coastal tourism→population growth*
- *population growth→water demand→inland water quality→coastal water quality→coastal tourism→population growth*

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- *population growth→water demand→inland water quality→marine biodiversity→coastal tourism→population growth*
- *population growth→water demand→inland water quality→coastal water quality→coastal attractiveness→coastal tourism→population growth*
- *population growth→water demand→inland water quality→marine biodiversity→coastal attractiveness→coastal tourism→population growth*
- *population growth→water demand→inland water quality→marine biodiversity→coastal water quality→coastal tourism→population growth*
- *population growth→water demand→inland water quality→coastal water quality→marine biodiversity→coastal tourism→population growth*
- *population growth→water demand→inland water quality→marine biodiversity→coastal water quality→coastal attractiveness→coastal tourism→population growth*
- *population growth→water demand→inland water quality→coastal water quality→marine biodiversity→coastal attractiveness→coastal tourism→population growth*

Reinforcing feedback loops (sample, ordered by path length):

- *economic growth→employment→economic growth*
- *coastal water quality→marine biodiversity→coastal water quality*
- *economic growth→energy demand→offshore energy production→economic growth*
- *water demand→inland water supply→agriculture→rural tourism→water demand*
- *population growth→water demand→inland water supply→agriculture→rural tourism→coastal tourism→population growth*
- *population growth→water demand→inland water supply→agriculture→rural tourism→coastal attractiveness→coastal tourism→population growth*

3.6.4 Sector workshop results

As could be expected, the six sector workshops (environment, public administrations, fisheries and saltpans, tourism, agriculture and local population) provided a more detailed analysis of the problems and priorities of the study region. Some typical **land-sea interactions** for the region, identified during the sector workshops, were:

- Habitat degradation and biodiversity loss in the lagoon and associated wetlands around the Mar Menor lagoon due to eutrophication (nutrients and sediments from agriculture, urban areas and cattle manure, heavy metals from the old mining areas and wastewater inputs)
- Decrease in the depth of the lagoon due to sediment inputs

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- Decrease in recreation opportunities for local populations living around the Mar Menor lagoon and tourists due to poor water quality
- Inland congestion during holidays and the peak season, resulting from coastal tourism
- Decrease in the number of fisheries target species due to lagoon water pollution
- Devaluation of house prices in coastal areas due to the bad ecological status of the Mar Menor lagoon
- Devastating floods in urban coastal areas of the Campo de Cartagena, exacerbated by high sediment transport rates

The main conclusions of all sector workshops support the LSI matrix, detailing specific links among the variables and producing also a comprehensive list of issues and solutions. Energy issues, however, have not been mentioned during the workshops but appear in the MSI matrix.

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3.7 System Feedback for the Multi-Actor Labs

It is useful use the results of the land-sea interaction tables to compare the six Multi-Actor Labs and identify any similarities and differences in terms of the system complexity - and feedback. Several graph-theoretical system indicators are available for this purpose, and were automatically derived for the land-sea interactions tables:

- the number of transmitters: a transmitter is a variable influencing other variables without being affected itself. Usually these are exogeneous drivers of the system, beyond control of the regional planners (sea level rise, oil price trend, etc.). In case system feedback exists, a well-designed model should derive its dynamics from the *internal* feedback structure – corresponding with a limited number of transmitters.
- the number of receivers: a receiver is a variable being influenced by other variables without influencing variables itself. Usually these are policy indicators for different scenarios derived with the system model. A well-designed system model should derive its dynamics from the *internal* feedback structure – corresponding with a limited number of receivers.
- the number of ordinary variables: all variables which are not a transmitter or receiver
- system complexity: the ratio of the number of transmitters to receivers. If the system is endogenously driven the complexity will be high, contrary a low system complexity points to a system which is largely exogenously driven.
- the number of connections: the total sum of all in- and outgoing connections between the transmitters, receivers and ordinary variables
- system density: the ratio of the number of connections to the maximum possible number of connections (i.e. if all variables were interconnected) – a measure of the complexity of the system
- the number of feedback loops: obviously important for the dynamic behavior of the system, feedback loops involving a single variable only (‘self-loops’) should be included. As explained exhaustive tracing of all feedback cycles is difficult for larger systems. Nevertheless, the presence of feedback for different systems can be compared for a limited number of iterations.
- the fraction of balancing loops: the fraction of balancing loops (see Introduction), stabilizing the system, is important for the dynamics of the system. Systems without balancing loops can show exponential, unlimited growth.
- variable indegree: the sum of the absolute values of all ingoing connections to a variable, treating positive and negative impacts equally. Receivers can have a large indegree, whereas transmitters always have a zero indegree.
- variable outdegree: the sum of the absolute values of all outgoing connections from a variable, treating positive and negative impacts equally. Transmitters can have a large outdegree, whereas receivers always have a zero outdegree.
- variable centrality: the sum of all indegrees and outdegrees – a measure of the importance of a variable. For the complete system it can be useful to determine the mean sand maximum centrality, as well as it’s variance.

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System Indicator	BE-01	GR-02	SE-03	FR-04	RO-05	ES-06
Number of transmitters	5	2	0	4	1	4
Number of receivers	2	1	1	0	3	8
Number of ordinary variables	24	33	33	27	27	19
System complexity	0.40	0,50	-	0	3.0	2.0
Number of system connections	68	201	217	119	144	85
System density	0,07	0,16	0,19	0,12	0,15	0,09
Number of feedback loops[1]	54	3927	3403	2592	2221	48
Fraction of balancing loops	15	59	59	47	48	29
Average centrality	2,2	5,6	6,4	3,8	4,6	2,7
Maximum centrality	11	15	22	11	12	12
Centrality variance	4.9	23	26	5.4	13	7.5
Percentage land-sea interactions	32	36	21	36	36	44

Table 2 System comparison for the MALs

[1] Identified after 1 million iterations using the modified ICLA algorithm (Kirk, 2007) with a maximum path search depth of eight steps.

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			IMPACT ON RURAL ISSUES																	IMPACT ON COASTAL ISSUES												
			social-economic											*environmental*						*social-economic*							*environmental*					
			population growth	economic growth	transport infrastructure	water demand	labor supply	agriculture	aquaculture	rural tourism	land pricing	employment	energy demand	inland water quality	open space	landscape fragmentation	inland water supply	CC adaptation: flood control	CC adaptation: drought resistance	offshore energy production	shipping & port activity	fisheries	flood risk	coastal tourism	coastal attractiveness	dredging & seabed mining	coastal water quality	marine biodiversity	salinity intrusion	coastal water supply	climate change	state of fish stocks
RURAL ISSUES WITH AN IMPACT	*social-economic*	population growth	0,63	0,53	0,53	1,00	0,53	0,63		0,63	0,63	0,63	1,00	0,50	0,53	0,63	0,24	0,63	0,63		0,50	0,63	0,31	0,53	0,63	0,63	0,53	0,63	0,63	0,53	0,63	0,63
		economic growth	0,63	0,63	0,53	0,50	0,53			0,63	0,53	1,00	1,00	0,63	0,50	0,63	0,53		0,63	0,53	0,53		0,31	0,53	0,63	0,63	0,53	0,53	0,42	0,53		
		transport infrastructure	0,63	0,63			0,53	0,53		0,50	0,53	0,53	0,63	0,63	0,53	0,10		0,63			0,63			0,63	0,42	0,63	0,53	0,53			0,63	
		water demand						0,53	0,63					0,50			1,00		0,53								0,50		0,31	0,53		
		labor supply	0,53	0,53	0,63	0,63		0,53	0,53	0,53		0,31	0,63								0,63											
		agriculture		0,63		1,00	0,53			0,42	0,50	0,53	0,50	1,00	0,53	0,31	0,53	0,63	0,53			0,63		0,63	0,63		0,53	0,63	0,53	0,63	0,63	0,63
		aquaculture		1,00		0,53				0,63		0,63	0,53	0,63			0,63			0,53	0,42	0,31		0,42	0,42		0,53					0,53
		rural tourism	0,63	0,63	0,53	0,53					0,50	1,00	0,50	0,53	0,63		0,63				0,63	0,63		0,10	0,53		0,53			0,63		
		land pricing	0,53		0,63		0,63	0,53								0,63																
		employment	0,63	0,53		0,63	0,42			0,63			0,63				0,63							0,63						0,63		
		energy demand			0,63										0,63					1,00												
	environmental	inland water quality		0,53		0,63		0,50	0,53	0,53	0,63						0,50		0,63			0,63		0,63	0,63		1,00	0,50				0,63
		open space				0,63		0,25		0,50	0,53		0,63	0,63		0,53		0,63					0,63	0,63	0,63		0,63				0,63	
		landscape fragmentation						0,53		0,42	0,63			0,63	0,53			0,63	0,63				0,63									
		inland water supply		0,53		0,63		1,00	0,53	0,53				0,63					0,25										0,63	0,63		
		CC adaptation: flood control		0,53		0,63		0,53			0,63			0,63	0,63		0,63		0,63				0,18		0,63				0,63			
		CC adaptation: drought resistance				0,53		0,50					0,63				0,50	0,63					0,63	0,63	0,63				0,63			
COASTAL ISSUES WITH AN IMPACT	*social-economic*	offshore energy production		1,00	0,63		0,53			0,63		0,63									0,53	0,63			0,53	0,42	0,53	0,53				
		shipping & port activity		1,00	0,53	0,63	0,63	0,63				0,63	0,50									0,53		0,53	0,53	0,53	0,53	0,50			0,63	0,53
		fisheries		0,63			0,50		0,63			0,50									0,53				0,42		0,63	0,50				1,00
		flood risk	0,42	0,42				0,42		0,63	0,31	0,63		0,63				0,63	0,63		0,63			0,42	0,25		0,63		0,63	0,63		
		coastal tourism	0,50	0,63	0,53	0,53	0,63			0,42	0,50	0,63	0,53		0,63						0,53				0,50		0,53	0,53	0,63	0,53		0,63
		coastal attractiveness	0,53	0,50	0,63	0,53				0,63	0,53		0,63											0,63				0,63				0,63
		dredging & seabed mining		0,53	0,53				0,63			0,53	0,63								0,50	0,63		0,63	0,63		0,53	0,53				0,63
	environmental	coastal water quality							0,63													0,53		0,53	0,53			1,00				0,63
		marine biodiversity																				0,50		0,53	0,53		0,53					1,00
		salinity intrusion		0,63				0,50	0,63	0,53	0,53	0,63	0,53	0,53			0,50		0,63								0,63			0,53		
		coastal water supply		0,63																				0,50				0,63	0,53			
		climate change						0,63			0,63		0,63					0,63			0,53		0,25	0,50	0,50		0,63		0,53	0,53		
		state of fish stocks		0,50					0,63			0,53										1,00		0,53	0,53			0,63				

Figure 22 Agreement index based on normalized standard deviation for identified system interactions for the Multi-Actor Labs (matrix based on selection of common issues). Empty cells refer to system interactions left open for all MALs.

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We conclude the following from a general examination and comparison with the stakeholder mind maps (Tiller et al., 2019) with the LSI tables, Figure 21 and Figure 22:

- as to be expected the stakeholder mind maps are far more complex and detailed than the LSI tables, but show limited system feedback. If system feedback is present, it is difficult to detect. This could be expected as the mind maps address the land-sea interactions from a sector-based perspective
- the number of transmitter and receiver variables is low compared to the total number of variables for all LSI tables, but the tables differ in terms of the connectivity and complexity; primarily due to the number of system interactions identified (Table 2) the total number of connections being the lowest for the Belgian MAL and highest for the Greek and Swedish MALs
- a clear dependency can be observed between the system density and number of feedback loops identified
- a larger maximum centrality is observed the Greek and Swedish (respectively the largest value for the economic growth and population growth)
- the number of balancing feedback loops is relatively low for the Belgian MAL which could point to ignoring of negative impacts – something to take into consideration when designing the causal loop diagrams with the WP1 coordinator partner
- the MAL project teams (i.e. researchers) agree on the presence and type of land-sea interactions (Figure 22) with an average agreement index of 58 % with 8.5 % disagreement or 30 of the identified system interactions being identified as positive impact by some MALs and a negative impact by other MALs. This call for further analysis of these interactions.
- only 5 % of the land-sea interactions are identified as being present and of the same nature (positive or negative) for all MALs;
- disagreement can be observed for a few interactions (interaction between coastal and rural tourism and impact of transport infrastructure and landscape fragmentation). This disagreement should can be interpreted in two ways: either the interactions in the MALs are different, or the project teams differ in their opinion on the significance
- the differences in complexity in the LSI tables (Table 2) are possibly due to the inclusion of indirect dependencies in the LSI tables for some of the MALs – it could be useful to reconsider the land-sea interactions in this respect because the algorithms used to analyze the tables automatically traces indirect system interactions (i.e. avoiding double counting)
- both the stakeholder mind maps and LSI tables are based on human judgement and personal interpretation – i.e. subjective. Reconsideration of all interactions and restructuring will be essential when designing the Causal Loops Diagrams and integrating the sector mind maps

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4 Data inventory guidelines and alignment with WP2

System Dynamics (Sterman, 2001) and in particular Stock-Flow (SF) Modelling was chosen as analytical framework for policy analysis in the COASTAL project for a number of reasons: (1) the graphical character of SF models allows for a natural alignment with the mental models developed by and with the stakeholders and interactive feedback on the model structure, (2) the focus on system feedback provides a structure for integrating land- and sea-based processes in a domain-independent way while serving as common modelling approach for the project consortium, (3) SF models are inherently dynamic and therefore useful for examining transition pathways quantitatively, and (4) the complexity of SF models is in a correct representation of this feedback structure rather than the numerical description of individuals interactions. In particular the latter aspect has consequences for identifying the data needs for the models and collecting supportive data collected from field samples, study reports and supportive models. Although SD models are excellent tools for integrating thematic models and expertise (Figure 23) a common misunderstanding is to confuse the type of modelling for the thematic 'silo models' and corresponding data needs with those of the SD model layer integrating in the 'silo models'. Ideally the collection of data should be driven by the model design rather than the other way around. As COASTAL demonstrates modelling and data development can take place in parallel, and iterative approach is sometimes preferably. This could start from historic data for an observed problem, which is to be explained from the system feedback structure. The collection of supportive data and model results to derive the initial model conditions, parameter settings, equations and non-linear proxy functions is the responsibility of Workpackage 2 (Knowledge Transition) and can be a challenge in terms of the purpose, quality and level of detail of the data to be collected.

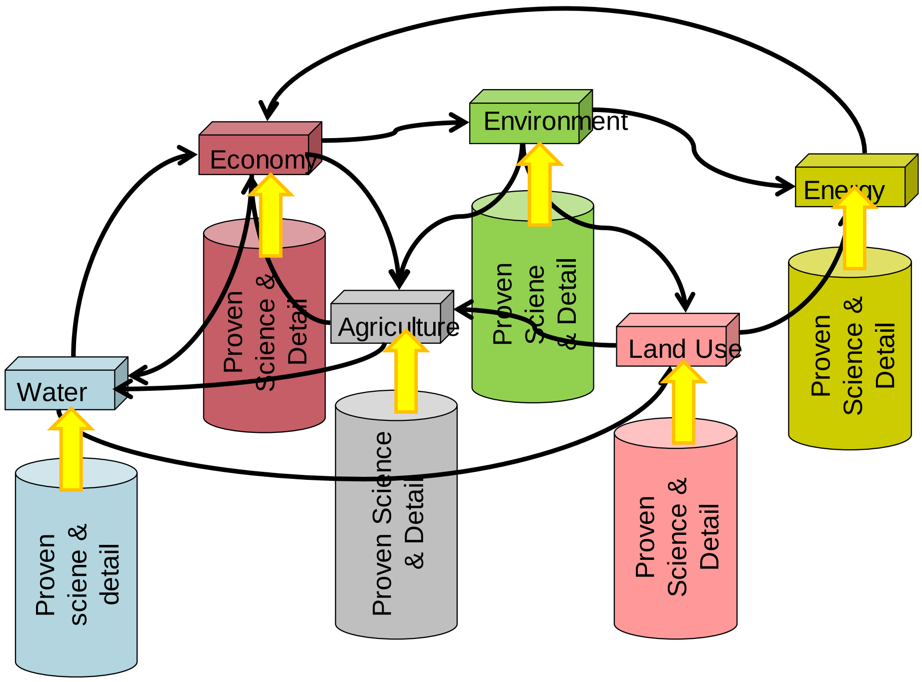

Figure 23 Thematic integration using a system dynamics framework (De Kok et al., 2015).

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By nature, model structuring (as part of WP4) and data collection for model quantification (as part of WP2) are two interactive and parallel activities. However, in order to avoid investment in data which are not used or modelling without sufficient data support, the following practical guidelines are proposed to ensure adequate alignment of the efforts of WP2 and WP4 and avoid investment in data which are not used or modelling without sufficient data support.

Reflecting on the problem and dependency between the scope of the SF models and the data collection we propose to structure the data collection around the following principles:

a) Characteristic elements of SF models are very useful for identifying the data needs: the initial value and range of stock variables, systemic limitations, time delays, rate of change, (non)linear interactions;
b) Modelling teams should define the appropriate units of measurement as soon as a basic model structure has been fixed;
c) Depending on the problem scope a time horizon and time resolution can be defined for the SF model which is also guiding for the data collection process;
d) An iterative approach for the modelling is acceptable and has been anticipated in the general project workflow – adjusting models based on stakeholder feedback. For data collection this would be less inefficient. This can be addressed in a step-wise process of identifying data needs and collecting data following the gradual development of the models and fixation of the model design. In an early stage, model developers can focus more on the architecture of their models and equations and work with proxy data to feed the models;
e) Data collection is not limited to statistics, field data, scientifically validated and peer-reviewed data but should also consider data generated by supportive models as depicted in Figure 23;
f) Preferably, the data collection and modelling are carried out by the same teams and experiences exchanged between the MALs. MAL-specific available data and supportive models (with relevant repositories) for SD model quantification are included in deliverable D06 (WP2) and shared among all MALs to support data sharing at an early stage in the project. Actual data and model results that are used for SD model quantification will also be included in deliverable D07 (WP2) to be shared between the MALs.
g) The recently upgraded COASTAL sharepoint is already in use for sharing SF model structures among MALs. Currently, this data sharing is managed by the lead partners for WP2 and the COASTAL sharepoint. In a later phase of the project the COASTAL data repository (Kastanidi et al., 2019) will be made public following the FAIR principles[2] for sharing open data;
h) Responding to the concern of the project reviewers concerning data availability a new Data Task Force or DTF has been created for the COASTAL project, which is responsible for the practical implementation of the COASTAL Data Management Plan as set out in Deliverable D26 (De Kok et al., 2018). This DTF will take the responsibility for refining, clarifying or adjusting the guidelines when needed.

[2] https://www.openaire.eu/how-to-make-your-data-fair

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5 Synthesis

The purpose of system modelling is to support the design, testing and demonstration of **evidence-based** solutions for improving land-sea synergy by means of quantified analyses, indicators, and tools. It is difficult for the human brain to capture the full implications of even a few interacting feedback mechanisms, let alone for the complex land-sea systems in COASTAL. Quantitative stock-flow modelling allows us to examine the significance of the different reinforcing and balancing feedback loops and their interactions by making adaptations to the models (Table 1). The ultimate goal is **policy and business analysis**, i.e. to design new strategies to eliminate or reduce problems and create new opportunities for development of the coastal regions and hinterland based on scientific evidence and data. At the general level the agreement of the land-sea interactions and economic activities is considerable for the Multi-Actor Labs (Figure 22). Coastal eutrophication, flood risk and water shortages, pressure on land, peak season tourism, loss of biodiversity etc. are challenges faced by all the regions. The **mind mapping** exercises gives us a more detailed, complex and differentiated view on the problems, opportunities, obstacles, and causal interactions. These were deemed important by the stakeholders at the level of the rural and coastal sectors. By itself, however, this local knowledge is not sufficient. System feedback and transitions should be taken into consideration to ensure the business and policy strategies are robust and effective at the mid- and long-term time scale. The need for a holistic view on problems was clearly explained to the participants of the workshops and well appreciated. The sectoral focus of the mind maps did not yet allow the teams to identify the feedback structures underlying the problems raised. At the point of completion of the sector workshops (December, 2018) the challenge is to polish, refine and translate the combined mind maps into **Causal Loop Diagrams (CLDs)**, contributing to the qualitative architecture for the system modelling. **Dynamic hypotheses** can be formulated to explain historic behaviour of the system and existing problems, prior to the design of these CLDs.

The examples of Table 1 illustrate the impact system feedback structures on the transition behaviour of systems. The effectiveness and correctness of policy and business decisions cannot be judged without proper understanding of this aspect of the dynamics of the systems concerned. The mind mapping exercises are a first step in the modelling process which should be **problem-driven.** This means the systems modelling should be a process of **co-creation** aimed at understanding the problems rather than attempting to model the system as a whole (Sterman, 2000). This co-creation also includes feedback on and validation of simulated scenarios, business road maps and policy guidelines (Figure 1). The application of results in the process of **policy analysis** is much more than adapting selected model parameters (Sterman, 2000) and should also take into consideration the need to adapt, remove or add system feedback, change time delays etc. Another common misunderstanding is that data are always quantitative. Qualitative data, mental models and other forms of non-quantitative knowledge are equally useful for designing a stock-flow model. The challenges faced by the Systems Modelling Work package are to:

- ensure the qualitative and quantitative activities do not develop as two separate trajectories
- help the MALs understand and apply SD modelling for policy and business analyses

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- develop a generic toolbox for land-sea synergy, and support the exchange of knowledge

The following steps outline the **general modelling strategy** to achieve these three goals:

a) identify the main stock variables for each sector mind map
b) identify or if necessary add the causal interactions between these stock variables
c) design and combine the causal loop diagrams for the sectors, supported with dynamic hypotheses
d) collection of data (initial conditions, parameter settings, time delays, ...) and models (equations and non-linear table functions) to quantify the CLD
e) design, implementation and testing of generic model archetypes and inspiring tutorial examples
f) implementation of stock-flow models
g) calibration, testing, and validation
h) policy design (identifying policy levers) and policy analyses

Some of these steps are run in parallel and allow for iterations, based on close interaction of the different work packages. The interchangeable and connectable example models will concern relevant problems and activities (start up and growth of SMEs, consumer product adoptation, coastal eutrophication, bioaccumulation, age cohort model, wind/solar energy decommissioning etc.). Ultimately, the exchange of knowledge, data and models between the MALs is of key importance for the success of COASTAL. Generic tutorial models will become part of an SD modelling toolbox, to be maintained and further developed through the COASTAL knowledge exchange platform (Figure 24).

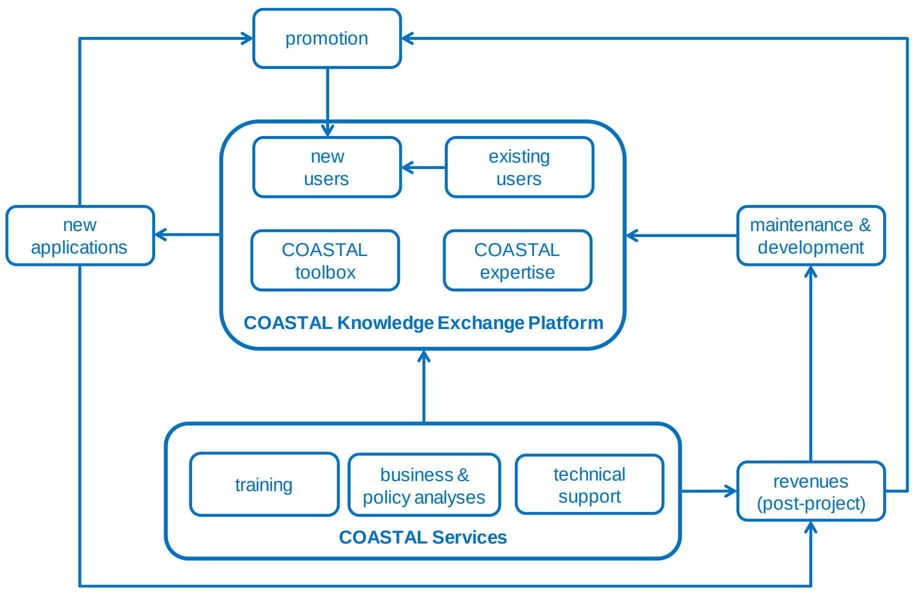

Figure 24 Service-oriented business model proposed for the COASTAL Knowledge Exchange Platform (h2020-coastal.eu/platform).

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